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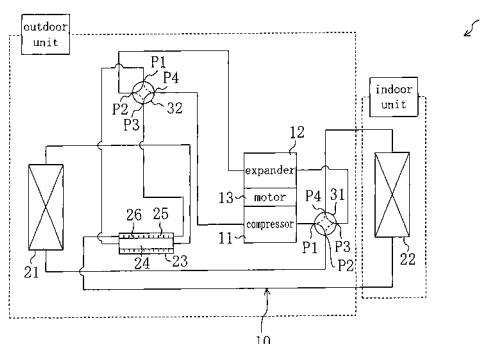
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(54) **REFRIGERATING DEVICE**

(57) A refrigeration system includes an internal heat exchanger (23) capable of controlling the temperature of refrigerant flowing towards an expander (12). Upon change of the operating conditions, the internal heat exchanger (23) controls the temperature of the refrigerant to control the specific volume or the flow rate of the refrigerant, thereby eliminating imbalance between the flow rate through a compressor (11) and the flow rate through

the expander (12). In a cooling operation in which the refrigerant circulation amount is larger than in a heating operation, the cooling capacity of the internal heat exchanger (23) is enhanced as compared to that in the heating operation, thereby increasing the flow rate of refrigerant into the expander (12) without part of the refrigerant bypassing the expander (12). This prevents the COP of the refrigeration system from being deteriorated.

FIG. 1



Description

Technical Field

[0001] This invention relates to refrigeration systems including a refrigerant circuit for operating in a vapor compression refrigeration cycle and particularly relates to refrigeration systems in which an expander constituting an expansion mechanism in the refrigerant circuit is mechanically connected to a compressor.

Background Art

[0002] Refrigeration systems have been conventionally known which operate in a refrigeration cycle by circulating refrigerant through a refrigerant circuit that is a closed circuit and are widely used as for air conditioners. As disclosed, for example, in Patent Document 1, there is known a refrigeration system of such kind in which the high-side pressure of a refrigeration cycle is set higher than the critical pressure of the refrigerant. The refrigeration system includes as an expansion mechanism for refrigerant an expander constituted by a scroll fluid machine. The expander is mechanically connected to a compressor by a shaft. Power extracted from the expander is used to drive the compressor, thereby improving the COP (coefficient of performance).

[0003] In the refrigeration system of Patent Document 1, the mass flow rate of refrigerant passing through the expander is always equal to that of refrigerant passing through the compressor. This is because the refrigerant circuit is a closed circuit. Meanwhile, the refrigerant densities at the entrances of the expander and compressor vary depending upon the operating conditions of the refrigeration system. Despite this, the refrigeration system of Patent Document 1 cannot change the displacement volume ratio between the expander and compressor since they are connected to each other. This invites a problem that upon change of the operating conditions the refrigeration system cannot continue to operate with stability.

[0004] For example, if a refrigeration system of this kind is configured to be capable of both cooling and heating operations, the refrigerant circulation amount during the cooling operation varies from that during the heating operation, which breaks the balance between the flow rate through the compressor and the flow rate through the expander. To be specific, if the refrigeration cycle is designed to keep the balance between the flow rate through the expander and the flow rate through the compressor during the heating operation, the refrigerant circulation amount increases during the cooling operation in which the suction gas of the compressor reaches high temperature and, therefore, the expander falls short of the flow rate (displacement) with respect to the increased refrigerant circulation amount.

[0005] The foregoing is described below in other words.

[0006] In the refrigeration system of Patent Document 1, because the refrigerant circuit is a closed circuit and the expander and compressor have the same number of rotations, the power recovery efficiency of the compressor is low, which makes it difficult to achieve a high-COP refrigeration cycle.

[0007] In the refrigerant circuit that is a closed circuit, the mass flow rate M_e of refrigerant passing through the expander is equal to the mass flow rate M_c of refrigerant passing through the compressor. In this case, the relational expressions $M_e = V_e \times d_e$ and $M_c = V_c \times d_c$ hold (where V_e is the circulation volume of refrigerant passing through the expander, d_e is the density of refrigerant flowing into the expander, V_c is the circulation volume of refrigerant passing through the compressor and d_c is the density of refrigerant sucked into the compressor). Furthermore, the circulation volumes (V_c , V_e) are determined by multiplying the cylinder volume of each fluid machine by the number of rotations thereof.

[0008] Since the mass flow rate M_e through the expander is equal to the mass flow rate M_c through the compressor, the relation $V_e/V_c = d_e/d_c$ holds from the above expressions. Furthermore, since the expander and the compressor have the same number of rotations, the value V_e/V_c is a fixed value determined by the designed volume of the cylinders. Therefore, in the refrigeration system, the refrigerant mass flow rates M_e and M_c through the expander and the compressor can be balanced by making the density ratio (d_e/d_c) constant.

[0009] However, if a refrigeration system of this kind is used as for an air conditioner, it may be difficult to keep the density ratio (d_e/d_c) constant depending upon the service conditions. To be specific, for example, in an air conditioner in which a cooling operation and a heating operation are selectively performed, the refrigerant evaporation pressure in its utilization side heat exchanger (evaporator) is increased during the cooling operation as compared with that during the heating operation and, therefore, the density d_c of refrigerant sucked in the compressor is also increased during the cooling operation. As a result, the mass flow rate M_e of refrigerant passing through the expander becomes smaller than the mass flow rate M_c of refrigerant passing through the compressor, which breaks the balance between the refrigerant mass flow rates M_e and M_c through the expander and the compressor.

[0010] To cope with this problem, as disclosed in Patent Document 2, a countermeasure has been proposed that the refrigerant circuit is provided with a bypass pipe allowing the refrigerant to bypass the expander. To be specific, when the expander falls short of its displacement, part of the refrigerant after releasing heat is caused to flow into the bypass pipe to restrict the amount of refrigerant flowing into the expander, thereby continuing the refrigeration cycle with stability. In other words, when the mass flow rate M_e of refrigerant passing through the expander is smaller than the mass flow rate M_c of refrigerant passing through the compressor, part of the refrigerant

erant after releasing heat is introduced into the bypass pipe to bypass the expander, thereby providing a well-balanced mass flow rate as the entire refrigerant circuit.

Patent Document 1: Published Japanese Patent Application No. 2001-107881

Patent Document 2: Published Japanese Patent Application No. 2001-116371

Disclosure of the Invention

Problem to Be Solved by the Invention

[0011] However, if in the refrigeration system of Patent Document 2 part of refrigerant is caused to flow into the bypass pipe upon change of the operating conditions, power extracted from the expander is reduced, thereby deteriorating the coefficient of performance (COP) of the refrigeration system.

[0012] The present invention has been made in view of the above problem and, therefore, its object is to eliminate the imbalance between the flow rate through the compressor and the flow rate through the expander when the operating conditions change (i.e., to balance the mass flow rate of refrigerant passing through the compressor and the mass flow rate of refrigerant passing through the expander) and concurrently prevent the COP of the refrigeration system from being deteriorated.

Means to Solve the Problem

[0013] First to eight aspects of the present invention are concerned with, upon change of the operating conditions, controlling the temperature of refrigerant flowing towards the expander to control the specific volume of the refrigerant, thereby eliminating imbalance between the flow rate through the compressor and the flow rate through the expander and preventing the COP of the refrigeration system from being deteriorated.

[0014] Specifically, the first aspect of the invention is directed to a refrigeration system including a refrigerant circuit (10) in which a compressor (11), a heat-source side heat exchanger (21), an expansion mechanism (12) and a utilization side heat exchanger (22) are connected to provide a vapor compression refrigeration cycle, the expansion mechanism (12) being constituted by an expander (12) for generating power by the expansion of refrigerant, the expander (12) being mechanically connected to the compressor (11).

[0015] Furthermore, the refrigeration system further comprises a temperature controller (23) capable of controlling the temperature of refrigerant flowing towards the expander (12).

[0016] According to the first aspect, the temperature of refrigerant flowing towards the expander (12) is controlled by the temperature controller, thereby providing control over the specific volume of the refrigerant. To be specific, as the refrigerant reaches a lower temperature,

its specific volume is reduced and the refrigerant flow rate into the expander is increased. As the refrigerant reaches a higher temperature, its specific volume is increased and the refrigerant flow rate into the expander is reduced. Therefore, if the temperature of refrigerant flowing towards the expander (12) is controlled, the flow rate through the compressor (11) and the flow rate through the expander (12) can be balanced even if the operating conditions change. Furthermore, since according to this aspect there is no need for the refrigerant flowing towards the expander (12) to bypass the expander (12), the power extracted from the expander (12) is not reduced.

[0017] The second aspect of the invention is the refrigeration system of the first aspect, wherein the refrigerant circuit (10) is configured to be capable of a heating operation in which refrigerant flowing through the utilization side heat exchanger (22) releases heat and a cooling operation in which refrigerant flowing through the utilization side heat exchanger (22) takes heat and wherein the temperature controller (23) is configured to have a higher capacity to cool refrigerant flowing towards the expander (12) during the cooling operation than during the heating operation.

[0018] According to the second aspect, the cooling capacity of the temperature controller (23) is higher during the cooling operation than during the heating operation. Therefore, even if the refrigerant circulation amount increases during the cooling operation under the condition that the refrigeration cycle is designed to balance, in the heating operation, the flow rate through the compressor (11) and the flow rate through the expander (12), the flow rate of refrigerant flowing into the expander (12) can be increased. This prevents shortage of the refrigerant flow rate through the expander (12) during the cooling operation. Hence, the flow rate through the compressor (11) and the flow rate through the expander (12) can be balanced during both the cooling operation and the heating operation and the recovery power from the expander (12) is not reduced because of no need for the refrigerant to bypass the expander (12).

[0019] The third aspect of the invention is the refrigeration system according to the second aspect, wherein the temperature controller (23) is constituted by an internal heat exchanger (23) in which, during the cooling operation, refrigerant after passing through the heat-source side heat exchanger (21) serving as a gas cooler is cooled by heat exchange with refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator.

[0020] According to the third aspect, during the cooling operation, the refrigerant after passing through the heat-source side heat exchanger (21) serving as a gas cooler is cooled by heat exchange at the internal heat exchanger (23) with the refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator. Thus, the specific volume or the flow rate of refrigerant flowing into the expander (12) is controlled,

thereby balancing the flow rate through the compressor (11) and the flow rate through the expander (12) during both the cooling operation and the heating operation.

[0021] The fourth aspect of the invention is the refrigeration system according to the third aspect, wherein the internal heat exchanger (23) is configured so that, during the cooling operation, a refrigerant channel (25) thereof through which refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator flows has a higher heat transfer capacity than a refrigerant channel (24) thereof through which refrigerant after passing through the heat-source side heat exchanger (21) serving as a gas cooler flows and that, during the heating operation, the refrigerant channel (24) through which refrigerant before or after passing through the heat-source side heat exchanger (21) serving as an evaporator flows has a lower heat transfer capacity than the refrigerant channel (25) through which refrigerant after passing through the utilization side heat exchanger (22) serving as a gas cooler flows.

[0022] In the refrigerant circuit, refrigerant after passing through a gas cooler has a higher heat transfer coefficient than refrigerant of low pressure before or after passing through an evaporator. According to the fourth aspect, the internal heat exchanger (23) is configured so that, during the cooling operation, the refrigerant channel (25) through which refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator flows has a higher heat transfer capacity than the refrigerant channel (24) through which refrigerant after passing through the heat-source side heat exchanger (21) serving as a gas cooler flows and that, during the heating operation, the refrigerant channel (24) through which refrigerant before or after passing through the heat-source side heat exchanger (21) serving as an evaporator flows has a lower heat transfer capacity than the refrigerant channel (25) through which refrigerant after passing through the utilization side heat exchanger (22) serving as a gas cooler flows. Thus, the amount of heat exchange during the cooling operation becomes larger than that during the heating operation. Therefore, during the cooling operation, the refrigerant flowing towards the expander (12) is cooled more than during the heating operation. Hence, the flow rate of refrigerant flowing into the expander (12) during the cooling operation is increased, whereby the flow rate through the compressor (11) and the flow rate through the expander (12) can be balanced during both the cooling operation and the heating operation.

[0023] The fifth aspect of the invention is the refrigeration system according to the fourth aspect, wherein the internal heat exchanger (23) includes a heat transfer fin (26) provided on the refrigerant channel (25) through which, during the cooling operation, refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator flows and, during the heating operation, refrigerant after passing through the utilization side heat exchanger (22) serving as a gas cooler

flows.

[0024] According to the fifth aspect, since the particular refrigerant channel (25) in the internal heat exchanger (23) is provided with a heat transfer fin (26), the amount of heat exchange in the internal heat exchanger (23) during the cooling operation is larger than that during the heating operation. Thus, the specific volume or the flow rate of refrigerant flowing into the expander (12) can be controlled. Therefore, the flow rate through the compressor (11) and the flow rate through the expander (12) can be balanced during both the cooling operation and the heating operation.

[0025] The sixth aspect of the invention is the refrigeration system according to the third aspect, wherein the internal heat exchanger (23) is configured so that, during the cooling operation, refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator and refrigerant after passing through the heat-source side heat exchanger (21) serving as a gas cooler flow therethrough in opposite directions to each other and that, during the heating operation, refrigerant before or after passing through the heat-source side heat exchanger (21) serving as an evaporator and refrigerant after passing through the utilization side heat exchanger (22) serving as a gas cooler flow therethrough in the same direction.

[0026] According to the sixth aspect, the internal heat exchanger (23) has a higher heat exchanger efficiency during the cooling operation than during the heating operation. Thus, the internal heat exchanger (23) has a higher capacity to cool the refrigerant after passing through the expander (12) during the cooling operation than during the heating operation. Therefore, the flow rate through the compressor (11) and the flow rate through the expander (12) can be balanced during both the cooling operation and the heating operation.

[0027] The seventh aspect of the invention is the refrigeration system according to the third aspect, wherein the internal heat exchanger (23) is constituted by a double-pipe heat exchanger including an inner channel (24) and an outer channel (25) disposed adjacent each other.

[0028] According to the seventh aspect, during the cooling operation, the double-pipe heat exchanger is used to exchange heat between the refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator and the refrigerant after passing through the heat-source side heat exchanger (21) serving as a gas cooler, thereby controlling the specific volume or the flow rate of refrigerant flowing into the expander (12). Therefore, the flow rate through the compressor (11) and the flow rate through the expander (12) can be balanced during both the cooling operation and the heating operation.

[0029] The eighth aspect of the invention is the refrigeration system according to the third aspect, wherein the internal heat exchanger (23) is constituted by a three-layered plate heat exchanger including an inner channel (24), a first outer channel (25A) disposed adjacent an

outside of the inner channel (24) and a second outer channel (25B) disposed adjacent another outside of the inner channel (24).

[0030] According to the eighth aspect, during the cooling operation, the three-layered plate heat exchanger is used to exchange heat between the refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator and the refrigerant after passing through the heat-source side heat exchanger (21) serving as a gas cooler, thereby controlling the specific volume or the flow rate of refrigerant flowing into the expander (12). Therefore, the flow rate through the compressor (11) and the flow rate through the expander (12) can be balanced during both the cooling operation and the heating operation.

[0031] Ninth to seventeenth aspects of the invention are characterized by providing a temperature controller (23) for cooling refrigerant flowing towards the expander (12) only during the cooling operation and stopping the above cooling function during the heating operation.

[0032] Specifically, the ninth aspect of the invention is directed to a refrigeration system including a refrigerant circuit (10) in which a compressor (11), a heat-source side heat exchanger (21), an expansion mechanism (12) and a utilization side heat exchanger (22) are connected to provide a vapor compression refrigeration cycle, the refrigerant circuit (10) being configured to be capable of a heating operation in which refrigerant flowing through the utilization side heat exchanger (22) releases heat and a cooling operation in which refrigerant flowing through the utilization side heat exchanger (22) takes heat, the expansion mechanism (12) being constituted by an expander (12) for generating power by the expansion of refrigerant, the expander (12) being mechanically connected to the compressor (11).

[0033] Furthermore, the refrigeration system further comprises a temperature controller (23) capable of controlling the temperature of high-pressure refrigerant flowing towards the expander (12) and the temperature controller (23) is configured to cool the high-pressure refrigerant only during the cooling operation but stop the cooling of the high-pressure refrigerant during the heating operation.

[0034] According to the ninth aspect, since the high-pressure refrigerant flowing towards the expander (12) is cooled only during the cooling operation but is not cooled during the heating operation, the density ρ of refrigerant flowing into the expander (12) during the cooling operation can be increased. Therefore, even if the mass flow rate M_c of refrigerant passing through the compressor (11) becomes larger during the cooling operation than during the heating operation, the refrigerant to be introduced into the expander (12) is accordingly cooled to increase the mass flow rate M_e of refrigerant passing through the expander (12). This balances both the refrigerant mass flow rates M_c and M_e . Furthermore, according to this aspect, since there is not need for the refrigerant flowing towards the expander (12) to bypass the

expander (12), the power extracted from the expander (12) is not reduced.

[0035] The tenth aspect of the invention is the refrigeration system according to the ninth aspect, wherein the temperature controller (23) is constituted by an internal heat exchanger (23) in which during the cooling operation the high-pressure refrigerant is cooled by heat exchange with low-pressure refrigerant.

[0036] According to the tenth aspect, during the cooling operation, the high-pressure refrigerant is cooled in the internal heat exchanger (23) by heat exchange with the low-pressure refrigerant. Thus, the suction temperature of the compressor (11) increases and the refrigerant density in the compressor (11) thereby reduces. Concurrently, the inlet temperature of the expander (12) reduces and the refrigerant density in the expander (12) thereby increases. Therefore, during the cooling operation, the mass flow rate M_e of refrigerant passing through the expander (12) can be increased to balance it with the mass flow rate M_c of refrigerant passing through the compressor (11).

[0037] The eleventh aspect of the invention is the refrigeration system according to the tenth aspect, wherein the internal heat exchanger (23) includes a first channel (27) and a second channel (28) and is configured to be capable of heat exchange between refrigerant flowing through the first channel (27) and refrigerant flowing through the second channel (28) and wherein the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure refrigerant flows through the first channel (27) and low-pressure refrigerant flows through the second channel (28) and that, during the heating operation, high-pressure refrigerant flows through both the channels (27, 28).

[0038] According to the eleventh aspect, during the heating operation, since high-pressure refrigerant flows through both the channels (27, 28) in the internal heat exchanger (23), it flows into the expander (12) without changing its temperature. On the other hand, during the cooling operation, high-pressure refrigerant flowing through the first channel (27) in the internal heat exchanger (23) is cooled by heat exchange with low-pressure refrigerant flowing through the second channel (28). Thus, during the cooling operation, the mass flow rate M_e of refrigerant passing through the expander (12) can be increased to balance it with the mass flow rate M_c of refrigerant passing through the compressor (11).

[0039] The twelfth aspect of the invention is the refrigeration system according to the tenth aspect, wherein the internal heat exchanger (23) includes a first channel (27) and a second channel (28) and is configured to be capable of heat exchange between refrigerant flowing through the first channel (27) and refrigerant flowing through the second channel (28), wherein the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure refrigerant flows through the first channel (27) and low-pressure refrigerant flows through the second channel (28) and wherein the refriger-

eration system further comprises a bypass passage (45) that, during the heating operation, allows high-pressure refrigerant to bypass the internal heat exchanger (23).

[0040] According to the twelfth aspect, during the heating operation, since the high-pressure refrigerant bypasses the internal heat exchanger (23), it flows into the expander (12) without changing its temperature. On the other hand, during the cooling operation, the high-pressure refrigerant flowing through the first channel (27) is cooled in the internal heat exchanger (23) by heat exchange with the low-pressure refrigerant flowing through the second channel (28). Thus, during the cooling operation, the mass flow rate M_e of refrigerant passing through the expander (12) can be increased to balance it with the mass flow rate M_c of refrigerant passing through the compressor (11).

[0041] The thirteenth aspect of the invention is the refrigeration system according to the tenth aspect, wherein the internal heat exchanger (23) includes a first channel (27) and a second channel (28) and is configured to be capable of heat exchange between refrigerant flowing through the first channel (27) and refrigerant flowing through the second channel (28), wherein the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure refrigerant flows through the first channel (27) and low-pressure refrigerant flows through the second channel (28) and wherein the refrigeration system further comprises a bypass passage (46) that, during the heating operation, allows low-pressure refrigerant to bypass the internal heat exchanger (23).

[0042] According to the thirteenth aspect, during the heating operation, since the low-pressure refrigerant bypasses the internal heat exchanger (23), the high-pressure refrigerant flows into the expander (12) without changing its temperature. On the other hand, during the cooling operation, the high-pressure refrigerant flowing through the first channel (27) is cooled in the internal heat exchanger (23) by heat exchange with the low-pressure refrigerant flowing through the second channel (28). Thus, during the cooling operation, the mass flow rate M_e of refrigerant passing through the expander (12) can be increased to balance it with the mass flow rate M_c of refrigerant passing through the compressor (11).

[0043] The fourteenth aspect of the invention is the refrigeration system according to the tenth aspect, wherein the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure refrigerant after passing through the heat-source side heat exchanger (21) is cooled therein by heat exchange with low-pressure refrigerant before passing through the utilization side heat exchanger (22).

[0044] According to the fourteenth aspect, during the cooling operation, since the high-pressure refrigerant after passing through the heat-source side heat exchanger (21) is cooled by heat exchange with the low-pressure refrigerant before passing through the utilization side heat exchanger (22), it flows into the expander (12) with its temperature reduced and its density increased. Thus,

during the cooling operation, the mass flow rate M_e of refrigerant passing through the expander (12) can be increased to balance it with the mass flow rate M_c of refrigerant passing through the compressor (11).

5 [0045] The fifteenth aspect of the invention is the refrigeration system according to the tenth aspect, wherein the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure refrigerant after passing through the heat-source side heat exchanger (21) is cooled therein by heat exchange with low-pressure refrigerant after passing through the utilization side heat exchanger (22).

10 [0046] According to the fifteenth aspect, during the cooling operation, since the high-pressure refrigerant after passing through the heat-source side heat exchanger (21) is cooled by heat exchange with the low-pressure refrigerant after passing through the utilization side heat exchanger (22), it flows into the expander (12) with its temperature reduced and its density increased. Thus, during the cooling operation, the mass flow rate M_e of refrigerant passing through the expander (12) can be increased to balance it with the mass flow rate M_c of refrigerant passing through the compressor (11).

15 [0047] The sixteenth aspect of the invention is the refrigeration system according to the tenth aspect, wherein the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure refrigerant and low-pressure refrigerant flow therethrough in opposite directions to each other.

20 [0048] According to the sixteenth aspect, during the cooling operation, since the high-pressure refrigerant and low-pressure refrigerant flow through the internal heat exchanger (23) in opposite directions to each other, the high-pressure refrigerant is effectively cooled. Therefore, as according to the above aspect, during the cooling operation, the mass flow rate M_e of refrigerant passing through the expander (12) can be increased to balance it with the mass flow rate M_c of refrigerant passing through the compressor (11).

25 [0049] The seventeenth aspect of the invention is the refrigeration system according to the ninth aspect, wherein refrigerant in the refrigerant circuit (10) is carbon dioxide.

30 [0050] According to the seventeenth aspect, since carbon dioxide is used as the refrigerant, the differential pressure between the high-side pressure and low-side pressure in the refrigeration cycle can be increased as compared with other kinds of refrigerants. Therefore, the expansion power of the refrigerant obtained by the expander (12) can be increased.

35 [0051] Eighteenth to twenty-ninth aspects of the invention are characterized by using a gas-liquid separator including an internal heat exchanger allowing heat exchange between refrigerant expanded by the expander and refrigerant to be introduced into the expander.

40 [0052] Specifically, the eighteenth aspect is directed to a refrigeration system including a refrigerant circuit (10) in which a compressor (11), a heat-source side heat

exchanger (21), an expander (12) and a utilization side heat exchanger (22) are connected to provide a refrigeration cycle, the compressor (11) being mechanically connected to the expander (12) to recover expansion power from the expander (12). Furthermore, the refrigeration system further comprises a gas-liquid separator (51) for separating refrigerant expanded by the expander (12) into a liquid refrigerant and a gas refrigerant and temporarily storing the liquid and gas refrigerants, and the gas-liquid separator (51) comprises an internal heat exchange part (50) for exchanging heat between the liquid refrigerant separated in the gas-liquid separator (51) and refrigerant to be introduced into the expander (12).

[0053] According to the eighteenth aspect, the refrigerant circuit (10) is provided with a gas-liquid separator (51). The gas-liquid separator (51) separates the refrigerant in gas-liquid two-phase form after expanded by the expander (12) into a gas refrigerant and a liquid refrigerant. Furthermore, the gas-liquid separator (51) is provided with an internal heat exchange part (50). The internal heat exchange part (50) allows heat exchange between the refrigerant to be introduced into the expander (12) and the liquid refrigerant stored in the gas-liquid separator (51).

[0054] In this case, since the refrigerant to be introduced into the expander (12) has a higher temperature than the liquid refrigerant after expanded by the expander (12), the refrigerant to be introduced into the expander (12) is cooled in the internal heat exchange part (50). Thus, the density ρ_e of refrigerant flowing into the expander (12) can be increased. Therefore, even if the mass flow rate $\dot{m}_c$ of refrigerant passing through the compressor (11) is increased, for example, during the cooling operation, the refrigerant to be introduced into the expander (12) is accordingly cooled to increase the mass flow rate $\dot{m}_e$ of refrigerant passing through the expander (12). This balances both the refrigerant mass flow rates $\dot{m}_c$ and $\dot{m}_e$.

[0055] The nineteenth aspect of the invention is the refrigeration system according to the eighteenth aspect which further comprises a heat exchange control mechanism (60) for changing the amount of heat exchange of refrigerant in the internal heat exchange part (50) according to the operating conditions. The term "heat exchange control mechanism" means a mechanism which can not only finely control the amount of heat exchange according to the operating conditions but also control the amount of heat exchange in two stages (ON/OFF), i.e., to either substantially zero or a predetermined value.

[0056] According to the nineteenth aspect, the amount of heat exchange between the refrigerant to be introduced into the expander (12) and the liquid refrigerant separated by the liquid-gas separator (51) is changed according to the operating conditions by the heat exchange control mechanism (60). Therefore, when the mass flow rate $\dot{m}_e$ of refrigerant through the expander (12) becomes larger than the mass flow rate $\dot{m}_c$ of refrigerant through the compressor (11) owing to a change

in the operating conditions, the mass flow rate $\dot{m}_e$ of refrigerant through the expander (12) can be equal to the mass flow rate $\dot{m}_c$ of refrigerant through the compressor (11) by controlling the amount of heat exchange in the internal heat exchange part (50).

[0057] The twentieth aspect of the invention is the refrigeration system according to the nineteenth aspect, wherein the gas-liquid separator (51) further comprises a liquid storage section (52) for storing the separated liquid refrigerant and a heat transfer tube (50) which is disposed adjacent the liquid storage section (52) and through which the refrigerant to be introduced into the expander (12) flows and wherein the heat transfer tube (50) constitutes an internal heat exchange part for exchanging heat between the liquid refrigerant in the liquid storage section (52) and the refrigerant in the heat transfer tube (50).

[0058] According to the twentieth aspect, the gas-liquid separator (51) is provided with a heat transfer tube (50) serving as the internal heat exchange part. The heat transfer tube (50) is disposed adjacent the liquid storage section (52). Thus, the refrigerant to be introduced into the expander (12) is cooled during the passage through the heat transfer tube (50) by the liquid refrigerant stored adjacent the outer surface of the heat transfer tube (50). Therefore, the density ρ_e of refrigerant flowing into the expander (12) can be surely increased.

[0059] The twenty-first aspect of the invention is the refrigeration system according to the twentieth aspect which further comprises a refrigerant switching mechanism (31, 33) for switching the circulation direction of refrigerant in the refrigerant circuit (10) to selectively provide either the cooling operation or the heating operation, wherein the heat exchange control mechanism (60) allows heat exchange of refrigerant in the internal heat exchange part (50) only during the cooling operation.

[0060] According to the twenty-first aspect, the refrigerant circuit (10) is provided with a refrigerant switching mechanism (31, 33). The refrigerant switching mechanism (31, 33) switches the circulation direction of the refrigerant, thereby providing switching between the cooling operation in which the utilization side heat exchanger (22) serves as an evaporator and the heating operation in which the utilization side heat exchanger (22) serves as a gas cooler.

[0061] In this case, the heat exchange control mechanism (60) allows, only during the cooling operation, heat exchange of refrigerant in the internal heat exchange part (50). Therefore, in the cooling operation in which the refrigerant mass flow rate $\dot{m}_e$ through the expander (12) is likely to be smaller than the refrigerant mass flow rate $\dot{m}_c$ through the compressor (11), the density ρ_e of refrigerant flowing into the expander (12) can be increased to make the refrigerant mass flow rate $\dot{m}_e$ through the expander (12) equal to the refrigerant mass flow rate $\dot{m}_c$ through the compressor (11).

[0062] On the other hand, if the cylinder volume ratio between the expander (12) and the compressor (11) is

designed according to the density ratio between the density d_e of refrigerant flowing into the expander (12) and the density d_c of refrigerant flowing into the compressor (11), the refrigerant mass flow rate M_e through the expander (12), also in the heating operation, can be made equal to the refrigerant mass flow rate M_c through the compressor (11). Therefore, there is no need to use the heat exchange control mechanism (60) to provide heat exchange in the internal heat exchange part (50).

[0063] The twenty-second aspect of the invention is the refrigeration system according to the twenty-first aspect, wherein the heat exchange control mechanism (60) is constituted by a bypass pipe (57) allowing refrigerant to bypass the heat transfer tube (50) and then flow into the expander (12), a first motor-operated valve (36) for controlling the flow rate of refrigerant flowing through the heat transfer tube (50), and a second motor-operated valve (37) for controlling the flow rate of refrigerant through the bypass pipe (57).

[0064] According to the twenty-second aspect, the amount of heat exchange in the heat transfer tube (50) is controlled by controlling the openings of the first and second motor-operated valves (36, 37). To be specific, for example, when the first motor-operated valve (36) is fully opened and the second motor-operated valve (37) is fully closed, the flow rate of refrigerant flowing through the heat transfer tube (50) is maximized and the amount of heat exchange of refrigerant in the heat transfer tube (50) is thereby controlled to its maximum value. On the other hand, for example, when the first motor-operated valve (36) is fully closed and the second motor-operated valve (37) is fully opened, the flow rate of refrigerant flowing through the heat transfer tube (50) becomes substantially zero and the amount of heat exchange of refrigerant in the heat transfer tube (50) thereby also becomes zero. Thus, the amount of heat exchange in the heat transfer tube (50) can be controlled within the range from zero to maximum by controlling the openings of the first and second motor-operated valves (36, 37) to appropriate values. Therefore, heat exchange of refrigerant can be provided according to the operating conditions to make the refrigerant mass flow rate M_e through the expander (12) equal to the refrigerant mass flow rate M_c through the compressor (11).

[0065] The twenty-third aspect of the invention is the refrigeration system according to the twenty-first aspect, wherein the heat exchange control mechanism (60) is constituted by a four-way selector valve (32).

[0066] According to the twenty-third aspect, the flow of refrigerant can be changed by position change of the four-way selector valve (32) serving as the heat exchange control mechanism (60). Therefore, for example, if the position of the four-way selector valve (32) is changed in the cooling operation to allow the refrigerant to flow through the heat transfer tube (50) and changed in the heating operation so as not to allow the refrigerant to flow through the heat transfer tube (50), the refrigerant mass flow rate M_e through the expander (12) can be

equal to the refrigerant mass flow rate M_c through the compressor (11) during both the operations.

[0067] The twenty-fourth aspect of the invention is the refrigeration system according to the twenty-first aspect, wherein the heat exchange control mechanism (60) is constituted by a bypass pipe (57) allowing refrigerant to bypass the heat transfer tube (50) and then flow into the expander (12), a first solenoid shut-off valve (34) selectively allowing or inhibiting the flow of refrigerant through the heat transfer tube (50), and a second solenoid shut-off valve (35) selectively allowing or inhibiting the flow of refrigerant through the bypass pipe (57).

[0068] According to the twenty-fourth aspect, the flow of refrigerant through the heat transfer tube (50) is changed by opening one of the first and second solenoid shut-off valves (34, 35) and closing the other. To be specific, for example, when in the cooling operation the first solenoid shut-off valve (34) is turned open and the second solenoid shut-off valve (35) is turned closed, this provides the flow of refrigerant through the heat transfer tube (50) and thereby provides heat exchange of refrigerant in the heat transfer tube (50). On the other hand, for example, when in the heating operation the first solenoid shut-off valve (34) is turned closed and the second solenoid shut-off valve (35) is turned open, this provides the flow of refrigerant through the bypass pipe (57) and inhibits the flow of refrigerant through the heat transfer tube (50). In other words, in this state, the refrigerant cannot be allowed to exchange heat in the heat transfer tube (50). Therefore, the refrigerant mass flow rate M_e through the expander (12) can be equal to the refrigerant mass flow rate M_c through the compressor (11) during both the operations.

[0069] The twenty-fifth aspect of the invention is the refrigeration system according to the twenty-first aspect, wherein the heat exchange control mechanism (60) is constituted by a combination of pipes and check valves (81, 82, 83, 84).

[0070] According to the twenty-fifth aspect, the particular pipe lines and the check valves (81, 82, 83, 84) are provided as the heat exchange control mechanism (60). Therefore, for example, if the check valves (81, 82, 83, 84) and the pipe lines are provided to allow the flow of refrigerant through the heat transfer tube (50) during the cooling operation and inhibit it during the heating operation, the refrigerant mass flow rate M_e through the expander (12) can be equal to the refrigerant mass flow rate M_c through the compressor (11) during both the operations.

[0071] The twenty-sixth aspect of the invention is the refrigeration system according to the eighteenth aspect, wherein the refrigerant circuit (10) further includes a first injection pipe (55) for sending the gas refrigerant in the gas-liquid separator (51) to the suction side of the compressor (11) and a gas control valve (38) for controlling the flow rate of refrigerant through the first injection pipe (55).

[0072] According to the twenty-sixth aspect, the gas

refrigerant separated in the gas-liquid separator (51) can be sent via the first injection pipe (55) to the suction side of the compressor (11). Therefore, so-called gas injection can be made as necessary and the amount of gas injection can be controlled by changing the opening of the gas control valve (38).

[0073] The twenty-seventh aspect of the invention is the refrigeration system according to the eighteenth aspect, wherein the refrigerant circuit (10) further includes a second injection pipe (59) for sending the liquid refrigerant in the gas-liquid separator (51) to the suction side of the compressor (11) and a liquid control valve (39) for controlling the flow rate of refrigerant through the second injection pipe (59).

[0074] According to the twenty-seventh aspect, the liquid refrigerant separated in the gas-liquid separator (51) can be sent via the second injection pipe (59) to the suction side of the compressor (11). Therefore, so-called liquid injection can be made as necessary and the amount of liquid injection can be controlled by changing the opening of the liquid control valve (39).

[0075] The twenty-eighth aspect of the invention is the refrigeration system according to the eighteenth aspect, wherein a plurality of said utilization side heat exchangers (22a, 22b, 22c) are connected in parallel with each other in the refrigerant circuit (10) and wherein the refrigeration system further comprises a plurality of flow control valves (61a, 61b, 61c) each for controlling the flow rate of refrigerant flowing into an associated one of the plurality of utilization side heat exchangers (22a, 22b, 22c).

[0076] According to the twenty-eighth aspect, the refrigerant circuit (10) is provided with a plurality of utilization side heat exchangers (22a, 22b, 22c). Thus, in the refrigeration system, cooling or heating can be made concurrently at plural locations through the plurality of utilization side heat exchangers (22a, 22b, 22c). Furthermore, when the plurality of flow control valves (61a, 61b, 61c) associated with respective ones of the plurality of utilization side heat exchangers (22a, 22b, 22c) are individually controlled in opening, the respective flow rates of refrigerant flowing through the utilization side heat exchangers (22a, 22b, 22c) can be individually controlled.

[0077] The twenty-ninth aspect of the invention is the refrigeration system according to the eighteenth aspect, wherein carbon dioxide is used as the refrigerant in the refrigerant circuit (10).

[0078] According to the twenty-ninth aspect, the refrigerant circuit (10) is charged with carbon dioxide as the refrigerant. Since carbon dioxide can increase the differential pressure between the high-side pressure and low-side pressure in the refrigeration cycle as compared with other kinds of refrigerants, the expansion power of the refrigerant obtained by the expander (12) can be increased.

Effects of the Invention

[0079] According to the first aspect, the provision of

the temperature controller (23) capable of controlling the temperature of refrigerant flowing towards the expander (12) enables the control over the specific volume or the flow rate of the refrigerant. Therefore, the flow rate through the compressor (11) and the flow rate through the expander (12) can be balanced even if the operating conditions change. Furthermore, since according to this aspect there is no need for part of the refrigerant to bypass the expander (12) even if the expander (12) falls short of the refrigerant flow rate therethrough, the power extracted from the expander (12) is not reduced. This prevents the COP from being deteriorated.

[0080] According to the second aspect, the temperature controller (23) is configured to have a higher capacity to cool refrigerant flowing towards the expander (12) during the cooling operation than during the heating operation. Therefore, if the refrigeration cycle is designed to balance, in the heating operation, the flow rate through the compressor (11) and the flow rate through the expander (12), the shortage of the refrigerant flow rate through the expander (12) during the cooling operation can be prevented without the refrigerant bypassing the expander (12). Thus, the flow rate through the compressor (11) and the flow rate through the expander (12) can be balanced during both the cooling operation and the heating operation. Hence, the deterioration in COP can be prevented.

[0081] According to the third aspect, since the refrigerant circuit (10) is provided with an internal heat exchanger (23) in which, during the cooling operation, the refrigerant after passing through the heat-source side heat exchanger (21) serving as a gas cooler is cooled by heat exchange with the refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator, the specific volume or the flow rate of refrigerant flowing into the expander (12) can be controlled to balance the flow rate through the compressor (11) and the flow rate through the expander (12). Therefore, the deterioration in COP can be prevented.

[0082] According to the fourth aspect, the internal heat exchanger (23) is configured so that, during the cooling operation, the refrigerant channel (25) through which refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator flows has a higher heat transfer capacity than the refrigerant channel (24) through which refrigerant after passing through the heat-source side heat exchanger (21) serving as a gas cooler flows and that, during the heating operation, the refrigerant channel (24) through which refrigerant before or after passing through the heat-source side heat exchanger (21) serving as an evaporator flows has a lower heat transfer capacity than the refrigerant channel (25) through which refrigerant after passing through the utilization side heat exchanger (22) serving as a gas cooler flows. Therefore, like according to the third aspect, the specific volume or the flow rate of refrigerant flowing into the expander (12) can be controlled to balance the flow rate through the compressor (11) and

the flow rate through the expander (12). Therefore, the deterioration in COP can be prevented.

[0083] According to the fifth aspect, since the particular refrigerant channel (25) in the internal heat exchanger (23) is provided with a heat transfer fin (26) so that the amount of heat exchange in the internal heat exchanger (23) during the cooling operation becomes larger than that during the heating operation, the specific volume or the flow rate of refrigerant flowing into the expander (12) can be controlled. Therefore, the flow rate through the compressor (11) and the flow rate through the expander (12) can be balanced during both the cooling operation and the heating operation, thereby preventing the deterioration in COP.

[0084] According to the sixth aspect, since the cooling capacity of the internal heat exchanger (23) during the cooling operation can be higher than that during the heating operation by reversing the circulation direction of refrigerant flowing through the internal heat exchanger (23) at the change from the cooling operation to the heating operation and vice versa, the specific volume or the flow rate of refrigerant flowing into the expander (12) can be controlled. Therefore, the flow rate through the compressor (11) and the flow rate through the expander (12) can be balanced during both the cooling operation and the heating operation, thereby preventing the deterioration in COP.

[0085] According to the seventh aspect, the specific volume or the flow rate of refrigerant flowing into the expander (12) can be controlled during the cooling operation by using the double-pipe heat exchanger to exchange heat between the refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator and the refrigerant after passing through the heat-source side heat exchanger (21) serving as a gas cooler. Therefore, the flow rate through the compressor (11) and the flow rate through the expander (12) can be balanced during both the cooling operation and the heating operation.

[0086] According to the eighth aspect, the specific volume or the flow rate of refrigerant flowing into the expander (12) can be controlled during the cooling operation by using the three-layered plate heat exchanger to exchange heat between the refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator and the refrigerant after passing through the heat-source side heat exchanger (21) serving as a gas cooler. Therefore, the flow rate through the compressor (11) and the flow rate through the expander (12) can be balanced during both the cooling operation and the heating operation.

[0087] According to the ninth aspect, since the temperature controller (23) allows to cool the high-pressure refrigerant flowing towards the expander (12) only during the cooling operation but stops the cooling of the high-pressure refrigerant during the heating operation, the density ρ_e of refrigerant flowing into the expander (12) during the cooling operation can be increased. Therefore,

even if the mass flow rate M_c of refrigerant passing through the compressor (11) becomes larger during the cooling operation than during the heating operation, the refrigerant to be introduced into the expander (12) can be accordingly cooled to increase the mass flow rate M_e of refrigerant passing through the expander (12). This balances both the refrigerant mass flow rates M_c and M_e . Hence, the expander (12) and the compressor (11) can be designed to run at high efficiency during both the cooling operation and the heating operation. Furthermore, according to this aspect, since there is not need for the refrigerant flowing towards the expander (12) to bypass the expander (12), the power extracted from the expander (12) is not reduced.

[0088] According to the tenth aspect, during the cooling operation, the internal heat exchanger (23) is used to cool the high-pressure refrigerant by heat exchange with the low-pressure refrigerant. Thus, through the cooling of the high-pressure refrigerant flowing towards the expander (12) only during the cooling operation, the mass flow rate M_e of refrigerant passing through the expander (12) can be increased to balance it with the mass flow rate M_c of refrigerant passing through the compressor (11). Therefore, the refrigeration system can be operated with high efficiency during both the cooling operation and the heating operation.

[0089] According to the eleventh aspect, the internal heat exchanger (23) is configured so that during the heating operation high-pressure refrigerant flows through both the channels (24, 25) to avoid heat exchange and that during the cooling operation high-pressure refrigerant and low-pressure refrigerant flow through the associated channels to allow heat exchange. Thus, through the cooling of the high-pressure refrigerant flowing towards the expander (12) only during the cooling operation, the mass flow rate M_e of refrigerant passing through the expander (12) can be increased to balance it with the mass flow rate M_c of refrigerant passing through the compressor (11). Therefore, the refrigeration system can be operated with high efficiency during both the cooling operation and the heating operation.

[0090] According to the twelfth aspect, the internal heat exchanger (23) is configured so that during the heating operation the high-pressure refrigerant bypasses it and that during the cooling operation both the high-pressure refrigerant and the low-pressure refrigerant flow through the associated channels to allow heat exchange. Thus, through the cooling of the high-pressure refrigerant flowing towards the expander (12) only during the cooling operation, the mass flow rate M_e of refrigerant passing through the expander (12) can be increased to balance it with the mass flow rate M_c of refrigerant passing through the compressor (11). Therefore, the refrigeration system can be operated with high efficiency during both the cooling operation and the heating operation.

[0091] According to the thirteenth aspect, the internal heat exchanger (23) is configured so that during the heating operation the low-pressure refrigerant bypasses it

and that during the cooling operation both the high-pressure refrigerant and the low-pressure refrigerant flow through the associated channels to allow heat exchange. Thus, through the cooling of the high-pressure refrigerant flowing towards the expander (12) only during the cooling operation, the mass flow rate M_e of refrigerant passing through the expander (12) can be increased to balance it with the mass flow rate M_c of refrigerant passing through the compressor (11). Therefore, the refrigeration system can be operated with high efficiency during both the cooling operation and the heating operation.

[0092] According to the fourteenth aspect, during the cooling operation, the high-pressure refrigerant after passing through the heat-source side heat exchanger (21) is cooled in the internal heat exchanger (23) by heat exchange with the low-pressure refrigerant before passing through the utilization side heat exchanger (22). Thus, through the cooling of the high-pressure refrigerant flowing towards the expander (12) only during the cooling operation, the mass flow rate M_e of refrigerant passing through the expander (12) can be increased to balance it with the mass flow rate M_c of refrigerant passing through the compressor (11). Therefore, the refrigeration system can be operated with high efficiency during both the cooling operation and the heating operation.

[0093] According to the fifteenth aspect, during the cooling operation, the high-pressure refrigerant after passing through the heat-source side heat exchanger (21) is cooled in the internal heat exchanger (23) by heat exchange with the low-pressure refrigerant after passing through the utilization side heat exchanger (22). Thus, through the cooling of the high-pressure refrigerant flowing towards the expander (12) only during the cooling operation, the mass flow rate M_e of refrigerant passing through the expander (12) can be increased to balance it with the mass flow rate M_c of refrigerant passing through the compressor (11). Therefore, the refrigeration system can be operated with high efficiency during both the cooling operation and the heating operation.

[0094] According to the sixteenth aspect, during the cooling operation, since the high-pressure refrigerant and low-pressure refrigerant flow through the internal heat exchanger (23) in opposite directions to each other, the high-pressure refrigerant can be effectively cooled. Therefore, during the cooling operation, the mass flow rate M_e of refrigerant passing through the expander (12) can be increased to balance it with the mass flow rate M_c of refrigerant passing through the compressor (11).

[0095] According to the seventeenth aspect, since carbon dioxide is used as the refrigerant for the refrigerant circuit (10), the differential pressure between the high-side pressure and low-side pressure in the refrigeration cycle can be increased as compared with other kinds of refrigerants. Therefore, the recovery power of the compressor (11) can be increased, thereby further improving the COP of the refrigeration system.

[0096] According to the eighteenth aspect, the density ρ of refrigerant flowing into the expander (12), i.e., the

refrigerant mass flow rate M_e , can be increased by heat exchange in the internal heat exchange part (50) between the liquid refrigerant separated in the gas-liquid separator (51) and the refrigerant to be introduced into the expander (12). Therefore, through the heat exchange of refrigerant at an appropriate amount of heat exchange in the internal heat exchange part (50), the refrigerant mass flow rates (M_e and M_c) through the compressor (11) and the expander (12), respectively, can be balanced. This provides a desired refrigeration cycle in the refrigeration system.

[0097] Unlike Patent Document 2, according to this aspect, the refrigerant mass flow rates M_e and M_c can be balanced without part of the refrigerant bypassing the expander. To be specific, according to the refrigeration system in Patent Document 2, the expansion power from the expander is reduced and the COP is thereby deteriorated. According to this aspect, since the refrigerant can be fully introduced into the expander (12), such deterioration in the COP can be avoided.

[0098] Furthermore, according to this aspect, heat is exchanged between the liquid refrigerant separated in the gas-liquid separator (51) and the refrigerant to be introduced into the expander (12). Because refrigerant in liquid form has a higher overall heat transfer coefficient than refrigerants in two-phase form and gas form of the same kind, it can enhance the heat exchanger efficiency in the internal heat exchange part (50). Therefore, the refrigerant to be introduced into the expander (12) can be effectively cooled, resulting in providing a compact design of the internal heat exchange part (50) and the gas-liquid separator (51).

[0099] Furthermore, according to this aspect, the gas-liquid separator (51) serves also as the internal heat exchanger (50). Therefore, the refrigeration system of this aspect can be downsized as compared with the case where the gas-liquid separator (51) and the internal heat exchanger (50) are separately provided.

[0100] Furthermore, according to this aspect, the liquid refrigerant separated in the gas-liquid separator (51) can be sent to the particular pipe or particular heat exchanger. Therefore, the pressure loss in the pipes can be reduced, for example, as compared with the case where refrigerant in two-phase form flows through the pipe or the heat exchanger. Furthermore, although the flow of refrigerant in two-phase form through the pipe or the heat exchanger is likely to cause sounds of refrigerant passing through it to be noises, this can be prevented according to this aspect.

[0101] According to the nineteenth aspect, the heat exchange control mechanism (60) is provided to control the amount of heat exchange in the internal heat exchange part (50) according to the operating conditions. Therefore, in the refrigeration system, the refrigerant mass flow rates (M_e and M_c) through the compressor (11) and the expander (12) can be balanced according to changes in the operating conditions.

[0102] According to the twentieth aspect, the heat

transfer tube (50) is provided in the liquid storage section (52) of the gas-liquid separator (51) to surely provide heat exchange between the refrigerant to be introduced into the expander (12) and the liquid refrigerant separated in the gas-liquid separator (51). Therefore, the density of refrigerant flowing into the expander (12) can be surely increased to balance the refrigerant mass flow rates (Me and Mc) through the compressor (11) and the expander (12).

[0103] According to the twenty-first aspect; heat exchange of refrigerant in the internal heat exchange part (50) is made only during the cooling operation in which the refrigerant mass flow rate Me through the expander (12) is likely to be smaller than the refrigerant mass flow rate Mc through the compressor (11). Therefore, during the cooling operation, the refrigerant mass flow rates (Me and Mc) through the compressor (11) and the expander (12) can be surely balanced.

[0104] On the other hand, if the cylinder volume ratio between the expander (12) and the compressor (11) is designed according to the density ratio between the density d_e of refrigerant flowing into the expander (12) and the density d_c of refrigerant flowing into the compressor (11), the refrigerant mass flow rates (Me and Mc) through the expander (12) and the compressor (11) can be balanced also in the heating operation.

[0105] According to the twenty-second aspect, the first and second motor-operated valves (36, 37) and the bypass pipe (57) are provided as the heat exchange control mechanism (60). In addition, the amount of heat exchange in the heat transfer tube (50) is controlled by controlling the openings of the first and second motor-operated valves (36, 37). Therefore, the refrigerant mass flow rates (Me and Mc) through the expander (12) and the compressor (11) can be balanced with high accuracy according to the operating conditions.

[0106] Furthermore, when the first motor-operated valve (36) is fully opened and the second motor-operated valve (37) is fully closed, the refrigerant can flow, only during the cooling operation, through the heat transfer tube (50) to provide heat exchange of refrigerant. Therefore, the same operations and effects as according to the twenty-first aspect can be obtained.

[0107] According to the twenty-third aspect, the four-way selector valve (32) is provided as the heat exchange control mechanism (60). In addition, the flow of refrigerant can be changed into either the state to allow the flow of refrigerant through the heat transfer tube (50) or the state to inhibit it by position change of the four-way selector valve (32). Therefore, through the position change of the four-way selector valve (32), the refrigerant can flow, only during the cooling operation, through the heat transfer tube (50) to provide heat exchange of refrigerant. Hence, the same operations and effects as according to the twenty-first aspect can be obtained.

[0108] According to the twenty-fourth aspect, the first and second solenoid shut-off valves (34, 35) and the bypass pipe (57) are provided as the heat exchange control

mechanism (60). In addition, when in the cooling operation the first solenoid shut-off valve (34) is turned open and the second solenoid shut-off valve (35) is turned closed, this provides, only during the cooling operation, the flow of refrigerant through the heat transfer tube (50) and thereby heat exchange of refrigerant in the heat transfer tube (50). Therefore, the same operations and effects as according to the twenty-first aspect can be obtained.

[0109] According to the twenty-fifth aspect, the particular pipe lines and the check valves (81, 82, 83, 84) are provided as the heat exchange control mechanism (60). Thus, through a combination of these pipe lines and check valves (81, 82, 83, 84), the refrigeration system is designed so that the refrigerant can flow through the heat transfer tube (50) only during the cooling operation and does not flow through the heat transfer tube (50) during the heating operation. Therefore, the effects of the twenty-first aspect can be obtained with a simple control to change the circulation direction of refrigerant using the refrigerant switching mechanism (31).

[0110] According to the twenty-sixth aspect, the gas refrigerant separated in the gas-liquid separator (51) can be sent to the suction side of the compressor (11), thereby providing gas injection. Therefore, the refrigeration system can control the degree of superheat of refrigerant to be sucked into the compressor (11), thereby providing an optimum control over the refrigeration cycle.

[0111] According to the twenty-seventh aspect, the liquid refrigerant separated in the gas-liquid separator (51) can be sent to the suction side of the compressor (11), thereby providing liquid injection. Therefore, the same effects as according to the twenty-sixth aspect can be obtained. Furthermore, combination of gas injection according to the twenty-sixth aspect and liquid injection according to this aspect provides a finer-tuned control over the refrigeration cycle.

[0112] Furthermore, according to this aspect, refrigerator oil contained in the refrigerant flowing out of the expander (12) can be returned, together with the liquid refrigerant separated in the gas-liquid separator (51), to the suction side of the compressor (11).

[0113] According to the twenty-eighth aspect, since the refrigeration system is provided with the plurality of utilization side heat exchangers (22a, 22b, 22c), it can be applied to a so-called multi-type air conditioner (1). Furthermore, since the respective flow rates of refrigerant flowing into the utilization side heat exchangers (22a, 22b, 22c) can be controlled by the respective flow control valves (61a, 61b, 61c), each utilization side heat exchanger (22a, 22b, 22c) can be individually controlled as in terms of the cooling capacity.

[0114] In this case, since the liquid refrigerant separated in the gas-liquid separator (51) can be sent to each utilization side heat exchanger (22a, 22b, 22c), the flow rate can be easily controlled in each flow control valve (61a, 61b, 61c), for example, as compared with refrigerant in two-phase form. In addition, in the connection pipes

that tend to be relatively long, the pressure loss of refrigerant and noises due to sounds of refrigerant passing through them can be reduced.

[0115] According to the twenty-ninth aspect, since carbon dioxide is used as the refrigerant for the refrigerant circuit (10), the differential pressure between the high-side pressure and low-side pressure in the refrigeration cycle can be increased as compared with other kinds of refrigerants. Therefore, the recovery power from the expander (12) can be increased, thereby further improving the COP of the refrigeration system.

Brief Description of Drawings

[0116]

[Fig. 1] Figure 1 is a refrigerant circuit diagram of an air conditioner according to Embodiment 1 of the present invention.

[Fig. 2] Figure 2 is a schematic structural diagram of an internal heat exchanger.

[Fig. 3] Figure 3 is a refrigerant circuit diagram of an air conditioner according to Embodiment 2.

[Fig. 4] Figure 4 is a refrigerant circuit diagram of an air conditioner according to Embodiment 3.

[Fig. 5] Figure 5 is a refrigerant circuit diagram of an air conditioner according to Embodiment 4.

[Fig. 6] Figure 6 is a refrigerant circuit diagram of an air conditioner according to Embodiment 5.

[Fig. 7] Figure 7 is a refrigerant circuit diagram of an air conditioner according to Embodiment 6.

[Fig. 8] Figure 8 is a refrigerant circuit diagram of an air conditioner according to Embodiment 7.

[Fig. 9] Figure 9 is a refrigerant circuit diagram of an air conditioner according to Embodiment 8.

[Fig. 10] Figure 10 is a refrigerant circuit diagram of an air conditioner according to Embodiment 9.

[Fig. 11] Figure 11 is a refrigerant circuit diagram of an air conditioner according to a first modification of Embodiment 9.

[Fig. 12] Figure 12 is a refrigerant circuit diagram of an air conditioner according to a second modification of Embodiment 9.

[Fig. 13] Figure 13 is a refrigerant circuit diagram of an air conditioner according to Embodiment 10.

[Fig. 14] Figure 14 is a refrigerant circuit diagram of an air conditioner according to a first modification of Embodiment 10.

[Fig. 15] Figure 15 is a refrigerant circuit diagram of an air conditioner according to a second modification of Embodiment 10.

[Fig. 16] Figure 16 is a refrigerant circuit diagram of an air conditioner according to a third modification of Embodiment 10.

[Fig. 17] Figure 17 is a refrigerant circuit diagram of an air conditioner according to a fourth modification of Embodiment 10.

[Fig. 18] Figure 18 is a refrigerant circuit diagram of an air conditioner according to Embodiment 11.

[Fig. 19] Figure 19 is a refrigerant circuit diagram of an air conditioner according to Embodiment 12.

[Fig. 20] Figure 20 is a refrigerant circuit diagram showing the refrigerant flow of Embodiment 12 during a cooling operation.

[Fig. 21] Figure 21 is a refrigerant circuit diagram showing the refrigerant flow of Embodiment 12 during a heating operation.

[Fig. 22] Figure 22 is a refrigerant circuit diagram of an air conditioner according to a modification of Embodiment 12.

[Fig. 23] Figure 23 is a refrigerant circuit diagram of an air conditioner according to Embodiment 13.

[Fig. 24] Figure 24 is a refrigerant circuit diagram showing the refrigerant flow of Embodiment 13 during a cooling operation.

[Fig. 25] Figure 25 is a refrigerant circuit diagram showing the refrigerant flow of Embodiment 13 during a heating operation.

[Fig. 26] Figure 26 is a refrigerant circuit diagram of an air conditioner according to a modification of Embodiment 13.

[Fig. 27] Figure 27 is a refrigerant circuit diagram of an air conditioner according to Embodiment 14.

[Fig. 28] Figure 28 is a refrigerant circuit diagram showing the refrigerant flow of Embodiment 14 during a cooling operation.

[Fig. 29] Figure 29 is a refrigerant circuit diagram showing the refrigerant flow of Embodiment 14 dur-

ing a heating operation.

[Fig. 30] Figure 30 is a refrigerant circuit diagram of an air conditioner according to a modification of Embodiment 14.

Explanation of Reference Numerals

[0117]

- 1 air conditioner (refrigeration system)
- 10 refrigerant circuit
- 11 compressor
- 12 expander (expansion mechanism)
- 13 motor
- 21 outdoor heat exchanger (heat-source side heat exchanger)
- 22 indoor heat exchanger (utilization side heat exchanger)
- 23 internal heat exchanger (temperature controller)
- 24 inner channel
- 25 outer channel
- 26 heat transfer fin
- 27 first channel
- 28 second channel
- 31 first four-way selector valve (refrigerant switching mechanism)
- 32 second four-way selector valve (heat exchange control mechanism)
- 33 third four-way selector valve (refrigerant switching mechanism)
- 32a bridge circuit
- 34 first solenoid shut-off valve
- 35 second solenoid shut-off valve
- 36 first motor-operated valve
- 37 second motor-operated valve
- 38 gas control valve
- 39 liquid control valve
- 45 bypass passage
- 46 bypass passage
- 50 heat transfer tube (internal heat exchange part)
- 51 gas-liquid separator
- 52 liquid storage section
- 53 gas storage section
- 55 separated gas pipe (first injection pipe)
- 57 bypass pipe
- 59 liquid injection pipe (second injection pipe)
- 60 heat exchange control mechanism
- 61 flow control valve (61a, 61b, 61c)
- 81-84 check valve

Best Mode for Carrying Out of the Invention

[0118] Embodiments of the present invention will be described below in detail with reference to the drawings.

«Embodiment 1 of the Invention»

[0119] Embodiment 1 relates to an air conditioner (1) constituted by a refrigeration system according to the present invention. As shown in Figure 1, the air conditioner (1) includes a refrigerant circuit (10). The air conditioner (1) of Embodiment 1 is configured to circulate refrigerant through the refrigerant circuit (10) and selectively perform a cooling operation and a heating operation.

[0120] The refrigerant circuit (10) is charged with carbon dioxide (CO₂) as refrigerant. Furthermore, the refrigerant circuit (10) is provided with a compressor (11), an expander (12), an outdoor heat exchanger (heat-source side heat exchanger) (21), an indoor heat exchanger (utilization side heat exchanger) (22), an internal heat exchanger (23), a first four-way selector valve (31) and a second four-way selector valve (32).

[0121] The compressor (11) is constituted, for example, by a rolling piston fluid machine. In other words, the compressor (11) is constituted by a positive displacement fluid machine having a constant displacement volume.

[0122] The expander (12) is constituted, for example, by a rolling piston fluid machine. In other words, the expander (12) is constituted by a positive displacement fluid machine having a constant displacement volume.

[0123] Note that the fluid machine constituting each of the compressor (11) and the expander (12) is not limited to rolling piston type one. For example, scroll type positive displacement fluid machines may be used as the compressor (11) and the expander (12).

[0124] The compressor (11) is mechanically connected to the expander (12) via a motor (13). The compressor (11) is driven into rotation by both of power obtained by refrigerant expansion in the expander (12) and power obtained by turn-on of the motor (13). The compressor (11) and the expander (12) are connected to each other by a single drive shaft and thereby always have the same number of rotations. Therefore, the displacement volume ratio between the compressor (11) and the expander (12) is constant.

[0125] The outdoor heat exchanger (21) is constituted by a so-called cross fin type fin-and-tube heat exchanger. The outdoor heat exchanger (21) is supplied with outdoor air by an unshown fan. In the outdoor heat exchanger (21), heat is exchanged between the outdoor air supplied and the refrigerant in the refrigerant circuit (10).

[0126] The indoor heat exchanger (22) is constituted by a so-called cross fin type fin-and-tube heat exchanger. The indoor heat exchanger (22) is supplied with room air by an unshown fan. In the indoor heat exchanger (22), heat is exchanged between the room air supplied and the refrigerant in the refrigerant circuit (10).

[0127] As shown in Figure 2A and Figure 2B which is a cross-sectional view taken along the line B-B of Figure 2A, the internal heat exchanger (23) is constituted by a double-pipe heat exchanger in which an inner channel

(24) and an outer channel (25) are disposed adjacent each other. The internal heat exchanger (23) is configured so that, during the cooling operation, refrigerant after passing through the outdoor heat exchanger (21) serving as a gas cooler is cooled by heat exchange with refrigerant after passing through the indoor heat exchanger (22) serving as an evaporator.

[0128] The inner channel (24) of the internal heat exchanger (23) provides, during the cooling operation, a channel through which refrigerant after passing through the outdoor heat exchanger (21) serving as a gas cooler flows and also provides, during the heating operation, a channel through which refrigerant after passing through the outdoor heat exchanger (21) serving as an evaporator flows. On the other hand, the outer channel (25) of the internal heat exchanger (23) provides, during the cooling operation, a channel through which refrigerant after passing through the indoor heat exchanger (22) serving as an evaporator flows and also provides, during the heating operation, a channel through which refrigerant after passing through the indoor heat exchanger (22) serving as a gas cooler flows.

[0129] The outer channel (25) is provided with heat transfer fins (26). The internal heat exchanger (23) is configured, owing to the provision of the heat transfer fins (26), so that, during the cooling operation, the heat transfer capacity of the refrigerant channel (outer channel (25)) through which refrigerant after passing through the indoor heat exchanger (22) serving as an evaporator flows is higher than that of the other refrigerant channel (inner channel (24)) through which refrigerant after passing through the outdoor heat exchanger (21) serving as a gas cooler flows and that, during the heating operation, the heat transfer capacity of the refrigerant channel (inner channel (24)) through which refrigerant after passing through the outdoor heat exchanger (21) serving as an evaporator flows is lower than that of the other refrigerant channel (outer channel (25)) through which refrigerant after passing through the indoor heat exchanger (22) serving as a gas cooler flows. Therefore, the internal heat exchanger (23) is configured to have a larger amount of heat exchange during the cooling operation than during the heating operation and thereby increase the capacity to cool refrigerant flowing towards the expander (12) during the cooling operation.

[0130] In the refrigerant circuit (10), the discharge side of the compressor (11) is connected to a first port (P1) of the first four-way selector valve (31) and a second port (P2) of the first four-way selector valve (31) is connected to a first end of the outdoor heat exchanger (21). A second end of the outdoor heat exchanger (21) is connected via the inner channel (24) of the internal heat exchanger (23) to a first port (P1) of the second four-way selector valve (32), and a second port (P2) of the second four-way selector valve (32) is connected to the inlet side of the expander (12). The outlet side of the expander (12) is connected to a third port (P3) of the first four-way selector valve (31), and a fourth port (P4) of the first four-way

selector valve (31) is connected to a first end of the indoor heat exchanger (22). A second end of the indoor heat exchanger (22) is connected via the outer channel (25) of the internal heat exchanger (23) to a third port (P3) of the second four-way selector valve (32), and a fourth port (P4) of the second four-way selector valve (32) is connected to the suction side of the compressor (11).

[0131] The first four-way selector valve (31) switches between a position in which the first port (P1) is communicated with the second port (P2) and the third port (P3) is communicated with the fourth port (P4) (the position shown in the solid lines in Figure 1) and a position in which the first port (P1) is communicated with the fourth port (P4) and the second port (P2) is communicated with the third port (P3) (the position shown in the broken lines in Figure 1).

[0132] The second four-way selector valve (32) switches between a position in which the first port (P1) is communicated with the second port (P2) and the third port (P3) is communicated with the fourth port (P4) (the position shown in the solid lines in Figure 1) and a position in which the first port (P1) is communicated with the fourth port (P4) and the second port (P2) is communicated with the third port (P3) (the position shown in the broken lines in Figure 1).

- Operational Behavior -

[0133] Next, a description is given of the behaviors of the air conditioner (1) during cooling and heating operations.

(Cooling Operation)

[0134] In the cooling operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the solid lines in Figure 1. When the motor (13) is turned on in this state, refrigerant circulates through the refrigerant circuit (10), whereby the refrigerant circuit (10) operates in a refrigeration cycle. During this operation, the outdoor heat exchanger (21) serves as a gas cooler and the indoor heat exchanger (22) serves as an evaporator. The high-side pressure of the refrigeration cycle is set higher than the critical pressure of carbon dioxide which is the refrigerant.

[0135] The compressor (11) discharges supercritical high-pressure refrigerant. The high-pressure refrigerant flows through the first four-way selector valve (31) and into the outdoor heat exchanger (21). In the outdoor heat exchanger (21), the high-pressure refrigerant releases heat to the outdoor air to decrease its temperature.

[0136] The high-pressure refrigerant after flowing out of the outdoor heat exchanger (21) passes through the inner channel (24) of the internal heat exchanger (23) and, during the time, is cooled by heat exchange with refrigerant flowing through the outer channel (25) after passing through the evaporator. The refrigerant thus

cooled flows through the second four-way selector valve (32) and then into the expander (12). In the expander (12), the introduced high-pressure refrigerant expands, whereby the internal energy of the high-pressure refrigerant is converted into power of rotation. Because of expansion in the expander (12), the high-pressure refrigerant decreases its pressure to change from supercritical to gas-liquid two-phase form.

[0137] The low-pressure refrigerant after flowing out of the expander (12) flows through the first four-way selector valve (31) into the indoor heat exchanger (22). In the indoor heat exchanger (22), the low-pressure refrigerant takes heat from room air to evaporate. Furthermore, in the indoor heat exchanger (22), the room air is cooled by the low-pressure refrigerant and the cooled room air is fed back to the room.

[0138] The low-pressure refrigerant after flowing out of the indoor heat exchanger (22) passes through the outer channel (25) of the internal heat exchanger (23) and, during the time, is heated by heat exchange with refrigerant flowing through the inner channel (24) after passing through the outdoor heat exchanger (21). The refrigerant thus heated flows through the second four-way selector valve (32) and is then sucked into the compressor (11). The refrigerant sucked in the compressor (11) is compressed to a predetermined pressure and then discharged from the compressor (11).

[0139] In the internal heat exchanger (23), the outer channel (25) through which refrigerant after passing through the indoor heat exchanger (22) serving as an evaporator flows is provided with heat transfer fins (26) but the inner channel (24) through which refrigerant after passing through the outdoor heat exchanger (21) serving as a gas cooler flows is provided no heat transfer fin (26). In addition, the heat transfer coefficient of low-pressure gas refrigerant after passing through the indoor heat exchanger (22) is relatively low but the heat transfer coefficient of supercritical refrigerant after passing through the outdoor heat exchanger (21) is relatively high. Thus, during the cooling operation, the internal heat exchanger (23) has an increased heat transfer capacity at the outer channel (25) through which low-pressure gas refrigerant of relatively low heat transfer coefficient flows. Therefore, during the cooling operation, the supercritical refrigerant flowing through the inner channel (24) comparatively efficiently exchanges heat with the low-pressure gas refrigerant flowing through the outer channel (25) and is thereby comparatively efficiently cooled in the internal heat exchanger (23) to reduce its specific volume. As a result, the amount of refrigerant flowing into the expander (12) can be increased.

(Heating Operation)

[0140] In the heating operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the broken lines in Figure 1. When the motor (13) is turned on

in this state, refrigerant circulates through the refrigerant circuit (10), whereby the refrigerant circuit (10) operates in a refrigeration cycle. During this operation, the indoor heat exchanger (22) serves as a gas cooler and the outdoor heat exchanger (21) serves as an evaporator. The high-side pressure of the refrigeration cycle, like in the cooling operation, is set higher than the critical pressure of carbon dioxide which is the refrigerant.

[0141] The compressor (11) discharges supercritical high-pressure refrigerant. The high-pressure refrigerant flows through the first four-way selector valve (31) and into the indoor heat exchanger (22). In the indoor heat exchanger (22), the high-pressure refrigerant releases heat to room air to decrease its temperature. Furthermore, in the indoor heat exchanger (22), the room air is heated by the high-pressure refrigerant and the heated room air is fed back to the room.

[0142] The high-pressure refrigerant after flowing out of the indoor heat exchanger (22) passes through the outer channel (25) of the internal heat exchanger (23) and then flows through the second four-way selector valve (32) and into the expander (12). In the expander (12), the introduced high-pressure refrigerant expands, whereby the internal energy of the high-pressure refrigerant is converted into power of rotation. Because of expansion in the expander (12), the high-pressure refrigerant decreases its pressure to change from supercritical to gas-liquid two-phase form.

[0143] The low-pressure refrigerant after flowing out of the expander (12) flows through the first four-way selector valve (31) into the outdoor heat exchanger (21). In the outdoor heat exchanger (21), the low-pressure refrigerant takes heat from the outdoor air to evaporate.

[0144] The low-pressure refrigerant after flowing out of the outdoor heat exchanger (21) passes through the inner channel (24) of the internal heat exchanger (23), then flows through the second four-way selector valve (32) and is then sucked into the compressor (11). The refrigerant sucked in the compressor (11) is compressed to a predetermined pressure and then discharged from the compressor (11).

[0145] In the internal heat exchanger (23), the outer channel (25) through which refrigerant after passing through the indoor heat exchanger (22) serving as a gas cooler flows is provided with heat transfer fins (26) but the inner channel (24) through which refrigerant after passing through the outdoor heat exchanger (21) serving as an evaporator flows is provided no heat transfer fin (26). In addition, the heat transfer coefficient of low-pressure gas refrigerant after passing through the outdoor heat exchanger (21) is relatively low but the heat transfer coefficient of supercritical refrigerant after passing through the indoor heat exchanger (22) is relatively high. Thus, during the heating operation, the internal heat exchanger (23) has a low heat transfer capacity at the inner channel (24) through which low-pressure gas refrigerant of relatively low heat transfer coefficient flows. Therefore, during the heating operation, the supercritical refrigerant

flowing through the outer channel (25) hardly exchanges heat with the low-pressure gas refrigerant flowing through the inner channel (24).

- Effects of Embodiment 1 -

[0146] According to Embodiment 1, in the internal heat exchanger (23) during the cooling operation, refrigerant after passing through the indoor heat exchanger (22) serving as an evaporator flows through the outer channel (25) and refrigerant after passing through the outdoor heat exchanger (21) serving as a gas cooler flows through the inner channel (24). On the other hand, in the internal heat exchanger (23) during the heating operation, refrigerant after passing through the indoor heat exchanger (22) serving as a gas cooler flows through the outer channel (25) and refrigerant after passing through the outdoor heat exchanger (21) serving as an evaporator flows through the inner channel (24). In addition, the outer channel (25) is provided with heat transfer fins (26).

[0147] Thus, during the cooling operation, gas refrigerant after passing through the evaporator flows through the outer channel (25), whereby refrigerant in the inner channel (24) comparatively efficiently exchanges heat with refrigerant in the outer channel (25) and the supercritical refrigerant decreases its temperature and then flows into the expander (12). On the other hand, during the heating operation, gas refrigerant after passing through the evaporator flows through the inner channel (24), whereby refrigerant in the outer channel (25) hardly exchanges heat with refrigerant in the inner channel (24) and the supercritical refrigerant flows into the expander (12) substantially without changing its temperature.

[0148] Therefore, in the internal heat exchanger (23) during the cooling operation, refrigerant flowing towards the expander (12) is cooled more than during the heating operation to reduce its specific volume, which increases the flow rate of refrigerant into the expander (12). Hence, according to this embodiment, the specific volume or flow rate of refrigerant flowing into the expander (12) during the cooling operation is controlled, whereby the refrigerant flow rate through the compressor (11) and the refrigerant flow rate through the expander (12) can be balanced.

[0149] Furthermore, since there is no need for refrigerant to bypass the expander (12) during the cooling operation in which the refrigerant circulation amount is larger than during the heating operation, the recovery power from the expander (12) is not reduced, which prevents the COP from being deteriorated.

«Embodiment 2 of the Invention»

[0150] In Embodiment 2, a receiver (41) is additionally disposed in the refrigerant circuit (10) in Embodiment 1 between the expander (12) and the first four-way selector valve (31). In other words, in Embodiment 2, the receiver (41) is disposed to the outlet side of the expander (12).

[0151] As shown in Figure 3, the outlet side of the expander (12) is connected to an inlet port of the receiver (41) and an outlet port of the receiver (41) is connected to the third port (P3) of the first four-way selector valve (31). Furthermore, the suction side of the compressor (11) is connected to a liquid injection pipe (42) connected to the lower end of the receiver (41) and is also connected to a gas vent pipe (43) connected to the upper end of the receiver (41). The liquid injection pipe (42) and the gas vent pipe (43) are provided with a first motor-operated valve (EV1) and a second motor-operated valve (EV2), respectively. These valves are configured to control the flow rate of refrigerant.

[0152] The rest of the configuration is the same as in Embodiment 1.

- Operational Behavior -

[0153] In the cooling operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the solid lines in Figure 3. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the outdoor heat exchanger (21), the inner channel (24) of the internal heat exchanger (23), the second four-way selector valve (32), the expander (12), the receiver (41), the first four-way selector valve (31), the indoor heat exchanger (22), the outer channel (25) of the internal heat exchanger (23) and the second four-way selector valve (32) and is then sucked into the compressor (11) again.

[0154] In the internal heat exchanger (23), supercritical refrigerant after passing through the outdoor heat exchanger (21) flows through the inner channel (24) and low-pressure gas refrigerant after passing through the indoor heat exchanger (22) flows through the outer channel (25). Therefore, the refrigerant flowing through the inner channel (24) exchanges heat with the refrigerant flowing through the outer channel (25). Thus, the supercritical refrigerant is cooled into a low specific volume in the internal heat exchanger (23) and then flows in this state into the expander (12).

[0155] During the cooling operation, the compressor (11) can be controlled in terms of the degree of suction superheat and put into an oil return operation by controlling the opening of the motor-operated valve of the liquid injection pipe (42). Furthermore, the receiver (41) can be degassed by controlling the opening of the motor-operated valve of the gas vent pipe (43). Furthermore, when during operation the compressor (11) falls short of capacity, the shortage can be compensated for by controlling the openings of the first motor-operated valve (EV1) of the liquid injection pipe (42) and the second motor-operated valve (EV2) of the gas vent pipe (43).

[0156] In the heating operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the broken lines in Figure 3. Refrigerant discharged from the

compressor (11) in this state sequentially flows through the first four-way selector valve (31), the indoor heat exchanger (22), the outer channel (25) of the internal heat exchanger (23), the second four-way selector valve (32), the expander (12), the receiver (41), the first four-way selector valve (31), the outdoor heat exchanger (21), the inner channel (24) of the internal heat exchanger (23) and the second four-way selector valve (32) and is then sucked into the compressor (11) again.

[0157] In the internal heat exchanger (23), supercritical refrigerant after passing through the indoor heat exchanger (22) flows through the outer channel (25) and low-pressure gas refrigerant after passing through the outdoor heat exchanger (21) flows through the inner channel (24). Therefore, the refrigerant flowing through the outer channel (25) hardly exchanges heat with the refrigerant flowing through the inner channel (24). Thus, even when the supercritical refrigerant passes through the internal heat exchanger (23), it flows into the expander (12) substantially without changing its temperature.

- Effects of Embodiment 2 -

[0158] Also in Embodiment 2, during the cooling operation, gas refrigerant after passing through the indoor heat exchanger (22) serving as an evaporator flows through the outer channel (25). Therefore, refrigerant in the inner channel (24) comparatively efficiently exchanges heat with refrigerant in the outer channel (25) and the supercritical refrigerant decreases its temperature to reduce its specific volume and then flows in this state into the expander (12). On the other hand, during the heating operation, gas refrigerant after passing through the outdoor heat exchanger (21) serving as an evaporator flows through the inner channel (24). Therefore, refrigerant in the outer channel (25) hardly exchanges heat with refrigerant in the inner channel (24) and the supercritical refrigerant flows into the expander (12) substantially without changing its temperature.

[0159] Since, as described above, the specific volume and flow rate of refrigerant flowing into the expander (12) during the cooling operation can be controlled by controlling the temperature of the refrigerant, the refrigerant flow rate through the compressor (11) and the refrigerant flow rate through the expander (12) can be balanced, thereby preventing the COP from being deteriorated.

«Embodiment 3 of the Invention»

[0160] In Embodiment 3, a receiver (41) is additionally disposed in the refrigerant circuit (10) in Embodiment 1 at a different position from Embodiment 2. The air conditioner according to Embodiment 3 is configured so that supercritical refrigerant after passing through the gas cooler flows into the internal heat exchanger (23) and low-pressure refrigerant after passing through the evaporator flows through the receiver (41) and then into the internal heat exchanger (23).

[0161] As shown in Figure 4, the pipe connecting the second end of the indoor heat exchanger (22) with the outer channel (25) of the internal heat exchanger (23) is provided with a first solenoid valve (SV1) between the indoor heat exchanger (22) and the internal heat exchanger (23), and a pipe line branches off from the pipe on the way to the internal heat exchanger (23) short of the first solenoid valve (SV1) and is connected via a third solenoid valve (SV3) to the receiver (41). Furthermore, the pipe connecting the second end of the outdoor heat exchanger (21) with the inner channel (24) of the internal heat exchanger (23) is provided with a second solenoid valve (SV2) between the outdoor heat exchanger (21) and the internal heat exchanger (23), and a pipe line branches off from the pipe on the way to the internal heat exchanger (23) short of the second solenoid valve (SV2) and is connected via a fourth solenoid valve (SV4) to the receiver (41).

[0162] The receiver (41) has a liquid injection pipe (42) connected thereto and provided with a motor-operated valve (EV) and the liquid injection pipe (42) is connected to the suction side of the compressor (11). The receiver (41) also has a gas vent pipe (43) connected thereto and the gas vent pipe (43) is branched into two branch lines. Out of the two branch lines, a first branch line (43a) is connected to the outer channel (25) of the internal heat exchanger (23) via a first check valve (CV1) for inhibiting the flow of refrigerant towards the receiver (41) and a second branch line (43b) is connected to the inner channel (24) of the internal heat exchanger (23) via a second check valve (CV2) for inhibiting the flow of refrigerant towards the receiver (41).

[0163] The rest of the configuration is the same as in Embodiment 1.

- Operational Behavior -

[0164] In the cooling operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the solid lines in Figure 4. Furthermore, in the cooling operation, the first solenoid valve (SV1) and the fourth solenoid valve (SV4) are closed and the second solenoid valve (SV2) and the third solenoid valve (SV3) are open.

[0165] Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the outdoor heat exchanger (21), the inner channel (24) of the internal heat exchanger (23), the second four-way selector valve (32), the expander (12), the first four-way selector valve (31), the indoor heat exchanger (22), the receiver (41), the outer channel (25) of the internal heat exchanger (23) and the second four-way selector valve (32) and is then sucked into the compressor (11) again.

[0166] In the internal heat exchanger (23), supercritical refrigerant after passing through the outdoor heat exchanger (21) flows through the inner channel (24) and low-pressure gas refrigerant after passing through the

indoor heat exchanger (22) flows through the outer channel (25). Therefore, the refrigerant flowing through the inner channel (24) exchanges heat with the refrigerant flowing through the outer channel (25). Thus, the supercritical refrigerant is cooled into a low specific volume in the internal heat exchanger (23) and then flows in this state into the expander (12).

[0167] In the heating operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the broken lines in Figure 4. Furthermore, in the heating operation, the first solenoid valve (SV1) and the fourth solenoid valve (SV4) are open and the second solenoid valve (SV2) and the third solenoid valve (SV3) are closed.

[0168] Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the indoor heat exchanger (22), the outer channel (25) of the internal heat exchanger (23), the second four-way selector valve (32), the expander (12), the first four-way selector valve (31), the outdoor heat exchanger (21), the receiver (41), the inner channel (24) of the internal heat exchanger (23) and the second four-way selector valve (32) and is then sucked into the compressor (11) again.

[0169] In the internal heat exchanger (23), supercritical refrigerant after passing through the indoor heat exchanger (22) flows through the outer channel (25) and low-pressure gas refrigerant after passing through the outdoor heat exchanger (21) flows through the inner channel (24). Therefore, the refrigerant flowing through the outer channel (25) hardly exchanges heat with the refrigerant flowing through the inner channel (24). Thus, even when the supercritical refrigerant passes through the internal heat exchanger (23), it flows into the expander (12) substantially without changing its temperature.

- Effects of Embodiment 3 -

[0170] Also in Embodiment 3, during the cooling operation, gas refrigerant after passing through the indoor heat exchanger (22) serving as an evaporator flows through the outer channel (25). Therefore, refrigerant in the inner channel (24) comparatively efficiently exchanges heat with refrigerant in the outer channel (25) and the supercritical refrigerant decreases its temperature to reduce its specific volume and then flows in this state into the expander (12). On the other hand, during the heating operation, gas refrigerant after passing through the outdoor heat exchanger (21) serving as an evaporator flows through the inner channel (24). Therefore, refrigerant in the outer channel (25) hardly exchanges heat with refrigerant in the inner channel (24) and the supercritical refrigerant flows into the expander (12) substantially without changing its temperature.

[0171] Since, as described above, the specific volume and flow rate of refrigerant flowing into the expander (12) during the cooling operation can be controlled by controlling the temperature of the refrigerant, the refrigerant

flow rate through the compressor (11) and the refrigerant flow rate through the expander (12) can be balanced, thereby preventing the COP from being deteriorated.

5 «Embodiment 4 of the Invention»

[0172] Embodiment 4 is an example of an air conditioner according to the present invention configured so that the flows of refrigerant through the inner channel (24) and the outer channel (25) of the internal heat exchanger (23) are in opposite directions (in counterflow) to each other during the cooling operation and are in the same direction (in parallel flow with each other) during the heating operation.

10 [0173] As shown in Figure 5, in Embodiment 4, a third four-way selector valve (33) is disposed in a pipe line between the outdoor heat exchanger (21) and the internal heat exchanger (23) to reverse the flow direction of refrigerant in the inner channel (24) of the internal heat exchanger (23) at the change from the cooling operation to the heating operation and vice versa. To accomplish this, the second end of the outdoor heat exchanger (21) is connected to a first port (P1) of the third four-way selector valve (33), a second port (P2) of the third four-way selector valve (33) is connected via the inner channel (24) of the internal heat exchanger (23) to a third port (P3) of the third four-way selector valve (33) and a fourth port (P4) of the third four-way selector valve (33) is connected to the first port (P1) of the second four-way selector valve (32).

30 [0174] The third four-way selector valve (33) switches between a position in which the first port (P1) is communicated with the second port (P2) and the third port (P3) is communicated with the fourth port (P4) (the position shown in the solid lines in Figure 5) and a position in which the first port (P1) is communicated with the third port (P3) and the second port (P2) is communicated with the fourth port (P4) (the position shown in the broken lines in Figure 5).

35 [0175] The rest of the configuration is the same as in Embodiment 1.

- Operational Behavior -

40 [0176] In the cooling operation, the first four-way selector valve (31), the second four-way selector valve (32) and the third four-way selector valve (33) switch to their respective positions shown in the solid lines in Figure 5. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the outdoor heat exchanger (21), the third four-way selector valve (33), the inner channel (24) of the internal heat exchanger (23), the third four-way selector valve (33), the second four-way selector valve (32), the expander (12), the first four-way selector valve (31), the indoor heat exchanger (22), the outer channel (25) of the internal heat exchanger (23) and the second four-way selector valve (32) and is then sucked into the com-

pressor (11) again.

[0177] In the internal heat exchanger (23), refrigerant passing through the inner channel (24) after passing through the outdoor heat exchanger (21) and refrigerant passing through the outer channel (25) after passing through the indoor heat exchanger (22) flow in opposite directions to each other. In addition, supercritical refrigerant flows through the inner channel (24) and gas refrigerant flows through the outer channel (25). Therefore, the refrigerant flowing through the inner channel (24) efficiently exchanges heat with the refrigerant flowing through the outer channel (25). Thus, the supercritical refrigerant is cooled into a low specific volume in the internal heat exchanger (23) and then flows in this state into the expander (12).

[0178] In the heating operation, the first four-way selector valve (31), the second four-way selector valve (32) and the third four-way selector valve (33) switch to their respective positions shown in the broken lines in Figure 5. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the indoor heat exchanger (22), the outer channel (25) of the internal heat exchanger (23), the second four-way selector valve (32), the expander (12), the first four-way selector valve (31), the outdoor heat exchanger (21), the third four-way selector valve (33), the inner channel (24) of the internal heat exchanger (23), the third four-way selector valve (33) and the second four-way selector valve (32) and is then sucked into the compressor (11) again.

[0179] In the internal heat exchanger (23), refrigerant passing through the outer channel (25) after passing through the indoor heat exchanger (22) and refrigerant passing through the inner channel (24) after passing through the outdoor heat exchanger (21) flow in the same direction. In addition, supercritical refrigerant flows through the outer channel (25) and gas refrigerant flows through the inner channel (24). Therefore, the refrigerant flowing through the outer channel (25) hardly exchanges heat with the refrigerant flowing through the inner channel (24). Thus, even when the supercritical refrigerant passes through the internal heat exchanger (23), it flows into the expander (12) substantially without changing its temperature.

[0180] Specifically, assume that the heat exchanger efficiency between the counterflows is 0.8, the heat exchanger efficiency between the parallel flows is 0.3 and the overall heat transfer coefficient during the cooling operation is 2.34 times as large as that during the heating operation because of the heat transfer area difference between the outer channel (25) and the inner channel. The heat transfer capacity during the cooling operation is determined to be $2.34 \times 0.8 / 0.3 = 6.24$ times as large as that during the heating operation.

- Effects of Embodiment 4 -

[0181] According to Embodiment 4, during the cooling

operation, gas refrigerant after passing through the indoor heat exchanger (22) serving as an evaporator flows through the outer channel (25) and refrigerant in the outer channel (25) and refrigerant in the inner channel (24) flow in opposite directions to each other. Therefore, refrigerant in the inner channel (24) comparatively efficiently exchanges heat with refrigerant in the outer channel (25) and the supercritical refrigerant decreases its temperature to reduce its specific volume and then flows in this state into the expander (12). On the other hand, during the heating operation, gas refrigerant after passing through the outdoor heat exchanger (21) serving as an evaporator flows through the inner channel (24) and, during the time, refrigerant in the outer channel (25) and refrigerant in the inner channel (24) flow in the same direction. Therefore, the refrigerant in the outer channel (25) hardly exchanges heat with the refrigerant in the inner channel (24) and the supercritical refrigerant flows into the expander (12) substantially without changing its temperature.

[0182] Since, as described above, the specific volume and flow rate of refrigerant flowing into the expander (12) during the cooling operation can be controlled by controlling the temperature of the refrigerant, the refrigerant flow rate through the compressor (11) and the refrigerant flow rate through the expander (12) can be balanced, thereby preventing the COP from being deteriorated.

«Embodiment 5 of the Invention»

[0183] In Embodiment 5, instead of a double-pipe heat exchanger in Embodiment 1, a three-layered plate heat exchanger is used as the internal heat exchanger (23). This internal heat exchanger (23) has an inner channel (24) located in the center and a first outer channel (25A) and a second outer channel (25B) that are disposed adjacent and on either outside of the inner channel (24).

[0184] As shown in Figure 6, the inner channel (24) of the internal heat exchanger (23) constitutes, during the cooling operation, a channel through which refrigerant after passing through the outdoor heat exchanger (21) serving as a gas cooler flows, and constitutes, during the heating operation, a channel through which refrigerant after passing through the outdoor heat exchanger (21) serving as an evaporator flows. The second outer channel (25B) constitutes, during the cooling operation, a channel through which refrigerant after passing through the indoor heat exchanger (22) serving as an evaporator flows, and constitutes, during the heating operation, a channel through which refrigerant after passing through the indoor heat exchanger (22) serving as a gas cooler flows. The first outer channel (25A) constitutes, during the cooling operation, a channel through which low-pressure refrigerant after passing through the second outer channel (25B) flows, and constitutes, during the heating operation, a channel through which low-pressure refrigerant after passing through the inner channel (24) flows.

[0185] The first outer channel (25A) of the internal heat

exchanger (23) has heat transfer fins (26) provided on its side surface towards the inner channel (24). Through the provision of the heat transfer fins (26), the internal heat exchanger (23) is configured so that, during the cooling operation, the refrigerant channel (first outer channel (25A)) through which refrigerant after passing through the indoor heat exchanger (22) serving as an evaporator flows has a higher heat transfer capacity than the refrigerant channel (inner channel (24)) through which refrigerant after passing through the outdoor heat exchanger (21) serving as a gas cooler flows and, during the heating operation, the refrigerant channel (inner channel (24)) through which refrigerant after passing through the outdoor heat exchanger (21) serving as an evaporator flows has a lower heat transfer capacity than the refrigerant channel (first outer channel (25A)) through which refrigerant after passing through the indoor heat exchanger (22) serving as a gas cooler flows. Therefore, the internal heat exchanger (23) is configured so that the capacity to cool refrigerant flowing towards the expander (12) is higher during the cooling operation than during the heating operation.

[0186] In the refrigerant circuit (10) of this embodiment, the second end of the outdoor heat exchanger (21) is connected via the inner channel (24) of the internal heat exchanger (23) to the first port (P1) of the second four-way selector valve (32) and the second port (P2) of the second four-way selector valve (32) is connected to the inlet side of the expander (12). The second end of the indoor heat exchanger (22) is connected via the second outer channel (25B) of the internal heat exchanger (23) to the third port (P3) of the second four-way selector valve (32) and the fourth port (P4) of the second four-way selector valve (32) is connected via the first outer channel (25A) of the internal heat exchanger (23) to the suction side of the compressor (11).

[0187] The rest of the configuration is the same as in Embodiment 1.

- Operational Behavior -

[0188] In the cooling operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the solid lines in Figure 6. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the outdoor heat exchanger (21), the inner channel (24) of the internal heat exchanger (23), the second four-way selector valve (32), the expander (12), the first four-way selector valve (31), the indoor heat exchanger (22), the second outer channel (25B) of the internal heat exchanger (23), the second four-way selector valve (32) and the first outer channel (25A) of the internal heat exchanger (23) and is then sucked into the compressor (11) again.

[0189] In the internal heat exchanger (23), supercritical refrigerant passing through the inner channel (24) after passing through the outdoor heat exchanger (21) and

gas refrigerant passing through the second outer channel (25B) after passing through the indoor heat exchanger (22) have a large temperature difference but they are parallel flows. Therefore, the amount of heat exchange between them is comparatively small. On the other hand, supercritical refrigerant passing through the inner channel (24) and gas refrigerant passing through the first outer channel (25A) after passing through the second outer channel (25B) not only have a large temperature difference but also are counterflows. In addition, the gas refrigerant flows through the first outer channel (25A). Therefore, the supercritical refrigerant and the gas refrigerant efficiently exchange heat with each other. Thus, the supercritical refrigerant is cooled into a low specific volume in the internal heat exchanger (23) and then flows in this state into the expander (12).

[0190] In the heating operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the broken lines in Figure 6. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the indoor heat exchanger (22), the second outer channel (25B) of the internal heat exchanger (23), the second four-way selector valve (32), the expander (12), the first four-way selector valve (31), the outdoor heat exchanger (21), the inner channel (24) of the internal heat exchanger (23), the second four-way selector valve (32) and the first outer channel (25A) of the internal heat exchanger (23) and is then sucked into the compressor (11) again.

[0191] In the internal heat exchanger (23), supercritical refrigerant passing through the first outer channel (25B) after passing through the indoor heat exchanger (22) and low-pressure gas refrigerant passing through the inner channel (24) after passing through the outdoor heat exchanger (21) have a large temperature difference but they are parallel flows. Therefore, the amount of heat exchange between them is comparatively small. In addition, gas refrigerant passing through the inner channel and gas refrigerant passing through the first outer channel (25A) after passing through the inner channel have no temperature difference. Therefore, the amount of heat exchange between them is substantially zero. Thus, even when the supercritical refrigerant passes through the internal heat exchanger (23), it flows into the expander (12) substantially without changing its temperature.

- Effects of Embodiment 5 -

[0192] Also in this embodiment, during the cooling operation, gas refrigerant after passing through the indoor heat exchanger (22) serving as an evaporator flows through the outer channel (25) (the first outer channel (25A)) and refrigerant in the first outer channel (25A) and refrigerant in the inner channel (24) flow in opposite directions to each other. Therefore, the refrigerant in the inner channel (24) comparatively efficiently exchanges heat with the refrigerant in the first outer channel (25A)

and the supercritical refrigerant decreases its temperature to reduce its specific volume and then flows in this state into the expander (12). On the other hand, during the heating operation, gas refrigerant after passing through the outdoor heat exchanger (21) serving as an evaporator flows through the inner channel (24) and the first outer channel (25A) and, during the time, the gas refrigerant hardly exchanges heat with supercritical refrigerant in the second outer channel (25B). Therefore, the supercritical refrigerant flows into the expander (12) substantially without changing its temperature.

[0193] Since, as described above, the specific volume and flow rate of refrigerant flowing into the expander (12) during the cooling operation can be controlled by controlling the temperature of the refrigerant, the refrigerant flow rate through the compressor (11) and the refrigerant flow rate through the expander (12) can be balanced, thereby preventing the COP from being deteriorated.

«Embodiment 6 of the Invention»

[0194] Embodiment 6 is an example of an air conditioner according to the present invention configured so that, during the cooling operation, refrigerant after passing through the gas cooler and refrigerant before flowing into the evaporator exchange heat with each other in the internal heat exchanger (23) (double-pipe heat exchanger).

[0195] As shown in Figure 7, the discharge side of the compressor (11) is connected to the first port (P1) of the first four-way selector valve (31) and the second port (P2) of the first four-way selector valve (31) is connected to the first end of the outdoor heat exchanger (21). The second end of the outdoor heat exchanger (21) is connected via the inner channel (24) of the internal heat exchanger (23) to the first port (P1) of the second four-way selector valve (32) and the second port (P2) of the second four-way selector valve (32) is connected to the inlet side of the expander (12). The outlet side of the expander (12) is connected to the third port (P3) of the second four-way selector valve (32) and the fourth port (P4) of the second four-way selector valve (32) is connected via the outer channel (25) of the internal heat exchanger (23) to the first end of the indoor heat exchanger (22). The second end of the indoor heat exchanger (22) is connected to the third port (P3) of the first four-way selector valve (31) and the fourth port (P4) of the first four-way selector valve (31) is connected to the suction side of the compressor (11).

- Operational Behavior -

[0196] In the cooling operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the solid lines in Figure 7. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the outdoor heat ex-

changer (21), the inner channel (24) of the internal heat exchanger (23), the second four-way selector valve (32), the expander (12), the second four-way selector valve (32), the outer channel (25) of the internal heat exchanger (23), the indoor heat exchanger (22) and the first four-way selector valve (31) and is then sucked into the compressor (11) again.

[0197] In the internal heat exchanger (23), supercritical refrigerant after passing through the outdoor heat exchanger (21) flows through the inner channel (24) and low-pressure refrigerant before passing through the indoor heat exchanger (22) flows through the outer channel (25). Therefore, the refrigerant flowing through the inner channel (24) exchanges heat with the refrigerant flowing through the outer channel (25). Thus, the supercritical refrigerant is cooled into a low specific volume in the internal heat exchanger (23) and then flows in this state into the expander (12).

[0198] In the heating operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the broken lines in Figure 7. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the indoor heat exchanger (22), the outer channel (25) of the internal heat exchanger (23), the second four-way selector valve (32), the expander (12), the second four-way selector valve (32), the inner channel (24) of the internal heat exchanger (23), the outdoor heat exchanger (21) and the first four-way selector valve (31) and is then sucked into the compressor (11) again.

[0199] In the internal heat exchanger (23), supercritical refrigerant after passing through the indoor heat exchanger (22) flows through the outer channel (25) and low-pressure refrigerant before passing through the outdoor heat exchanger (21) flows through the inner channel (24). Therefore, the refrigerant flowing through the outer channel (25) hardly exchanges heat with the refrigerant flowing through the inner channel (24). Thus, even when the supercritical refrigerant passes through the internal heat exchanger (23), it flows into the expander (12) substantially without changing its temperature.

Effects of Embodiment 6 -

[0200] - According to Embodiment 6, during the cooling operation, refrigerant before passing through the indoor heat exchanger (22) serving as an evaporator flows through the outer channel (25). Therefore, refrigerant in the inner channel (24) comparatively efficiently exchanges heat with refrigerant in the outer channel (25) and the supercritical refrigerant decreases its temperature to reduce its specific volume and then flows in this state into the expander (12). On the other hand, during the heating operation, refrigerant before passing through the outdoor heat exchanger (21) serving as an evaporator flows through the inner channel (24). Therefore, refrigerant in the outer channel (25) hardly exchanges heat with refrig-

erant in the inner channel (24) and the supercritical refrigerant flows into the expander (12) substantially without changing its temperature.

[0201] Since, as described above, the specific volume and flow rate of refrigerant flowing into the expander (12) during the cooling operation can be controlled by controlling the temperature of the refrigerant, the refrigerant flow rate through the compressor (11) and the refrigerant flow rate through the expander (12) can be balanced, thereby preventing the COP from being deteriorated.

«Embodiment 7 of the Invention»

[0202] In Embodiment 7, in the refrigerant circuit (10) of Embodiment 6, a bridge circuit (32a) is used instead of the second four-way selector valve (32).

[0203] As shown in Figure 8, the bridge circuit (32a) is formed by connecting four pipe lines in bridges and has four ports (P1, P2, P3, P4). The four pipe lines are provided with their respective check valves (CV). The check valves (CV) are provided in their associated pipe lines to allow the refrigerant flow from the first port (P1) towards the second port (P2), the refrigerant flow from the third port (P3) towards the fourth port (P4), the refrigerant flow from the third port (P3) towards the first port (P1) and the refrigerant flow from the fourth port (P4) towards the second port (P2).

[0204] The inner channel (24) of the internal heat exchanger (23) is connected to the first port (P1) of the bridge circuit (32a). The second port (P2) of the bridge circuit (32a) is connected to the inlet side of the expander (12). The outlet side of the expander (12) is connected to the third port (P3) of the bridge circuit (32a). The fourth port (P4) of the bridge circuit (32a) is connected to the outer channel (25) of the internal heat exchanger (23).

[0205] The rest of the configuration is the same as in Embodiment 6.

- Operational Behavior -

[0206] In the cooling operation, the first four-way selector valve (31) switches to the position shown in the solid lines in Figure 8. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the outdoor heat exchanger (21), the inner channel (24) of the internal heat exchanger (23), the bridge circuit (32a), the expander (12), the bridge circuit (32a), the outer channel (25) of the internal heat exchanger (23), the indoor heat exchanger (22) and the first four-way selector valve (31) and is then sucked into the compressor (11) again.

[0207] In the internal heat exchanger (23), supercritical refrigerant after passing through the outdoor heat exchanger (21) flows through the inner channel (24) and low-pressure refrigerant before passing through the indoor heat exchanger (22) flows through the outer channel (25). Therefore, the refrigerant flowing through the inner channel (24) exchanges heat with the refrigerant flowing

through the outer channel (25). Thus, the supercritical refrigerant is cooled into a low specific volume in the internal heat exchanger (23) and then flows in this state into the expander (12).

[0208] In the heating operation, the first four-way selector valve (31) switches to the position shown in the broken lines in Figure 8. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the indoor heat exchanger (22), the outer channel (25) of the internal heat exchanger (23), the bridge circuit (32a), the expander (12), the bridge circuit (32a), the inner channel (24) of the internal heat exchanger (23), the outdoor heat exchanger (21) and the first four-way selector valve (31) and is then sucked into the compressor (11) again.

[0209] In the internal heat exchanger (23), supercritical refrigerant after passing through the indoor heat exchanger (22) flows through the outer channel (25) and low-pressure refrigerant before passing through the outdoor heat exchanger (21) flows through the inner channel (24). Therefore, the refrigerant flowing through the outer channel (25) hardly exchanges heat with the refrigerant flowing through the inner channel (24). Thus, even when the supercritical refrigerant passes through the internal heat exchanger (23), it flows into the expander (12) substantially without changing its temperature.

- Effects of Embodiment 7 -

[0210] According to Embodiment 7, during the cooling operation, refrigerant before passing through the indoor heat exchanger (22) serving as an evaporator flows through the outer channel (25). Therefore, refrigerant in the inner channel (24) comparatively efficiently exchanges heat with refrigerant in the outer channel (25) and the supercritical refrigerant decreases its temperature to reduce its specific volume and then flows in this state into the expander (12). On the other hand, during the heating operation, refrigerant before passing through the outdoor heat exchanger (21) serving as an evaporator flows through the inner channel (24). Therefore, refrigerant in the outer channel (25) hardly exchanges heat with refrigerant in the inner channel (24) and the supercritical refrigerant flows into the expander (12) substantially without changing its temperature.

[0211] Since, as described above, the specific volume and flow rate of refrigerant flowing into the expander (12) during the cooling operation can be controlled by controlling the temperature of the refrigerant, the refrigerant flow rate through the compressor (11) and the refrigerant flow rate through the expander (12) can be balanced, thereby preventing the COP from being deteriorated.

] «Embodiment 8 of the Invention»

[0212] Embodiment 8 is an example of an air conditioner according to the present invention configured so that in the air conditioner of Embodiment 6 the flows of

refrigerant through the inner channel (24) and the outer channel (25) of the internal heat exchanger (23) are in opposite directions to each other during the cooling operation and are in the same direction during the heating operation.

[0213] As shown in Figure 9, in Embodiment 8, a third four-way selector valve (33) is disposed in the refrigerant circuit (10) of Embodiment 6 between the outdoor heat exchanger (21) and the internal heat exchanger (23) to reverse the flow direction of refrigerant in the outer channel (25) of the internal heat exchanger (23) but hold the flow direction of refrigerant in the inner channel (24) thereof when the air conditioner switches from the cooling operation to the heating operation and vice versa. To accomplish this, the second end of the outdoor heat exchanger (21) is connected to a first port (P1) of the third four-way selector valve (33), a second port (P2) of the third four-way selector valve (33) is connected via the inner channel (24) of the internal heat exchanger (23) to a third port (P3) of the third four-way selector valve (33) and a fourth port (P4) of the third four-way selector valve (33) is connected to the first port (P1) of the second four-way selector valve (32).

[0214] The third four-way selector valve (33) switches between a position in which the first port (P1) is communicated with the second port (P2) and the third port (P3) is communicated with the fourth port (P4) (the position shown in the solid lines in Figure 9) and a position in which the first port (P1) is communicated with the third port (P3) and the second port (P2) is communicated with the fourth port (P4) (the position shown in the broken lines in Figure 9).

[0215] The rest of the configuration is the same as in Embodiment 6.

- Operational Behavior -

[0216] In the cooling operation, the first four-way selector valve (31), the second four-way selector valve (32) and the third four-way selector valve (33) switch to their respective positions shown in the solid lines in Figure 9. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the outdoor heat exchanger (21), the third four-way selector valve (33), the inner channel (24) of the internal heat exchanger (23), the third four-way selector valve (33), the second four-way selector valve (32), the expander (12), the second four-way selector valve (32), the outer channel (25) of the internal heat exchanger (23), the indoor heat exchanger (22) and the first four-way selector valve (31) and is then sucked into the compressor (11) again.

[0217] In the internal heat exchanger (23), refrigerant passing through the inner channel (24) after passing through the outdoor heat exchanger (21) and refrigerant passing through the outer channel (25) before passing through the indoor heat exchanger (22) flow in opposite directions to each other. In addition, supercritical refrigerant

flows through the inner channel (24) and low-pressure refrigerant flows through the outer channel (25). Therefore, the refrigerant flowing through the inner channel (24) efficiently exchanges heat with the refrigerant flowing through the outer channel (25). Thus, the supercritical refrigerant is cooled into a low specific volume in the internal heat exchanger (23) and then flows in this state into the expander (12).

[0218] In the heating operation, the first four-way selector valve (31), the second four-way selector valve (32) and the third four-way selector valve (33) switch to their respective positions shown in the broken lines in Figure 9. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the indoor heat exchanger (22), the outer channel (25) of the internal heat exchanger (23), the second four-way selector valve (32), the expander (12), the second four-way selector valve (32), the third four-way selector valve (33), the inner channel (24) of the internal heat exchanger (23), the third four-way selector valve (33), the outdoor heat exchanger (21) and the first four-way selector valve (31) and is then sucked into the compressor (11) again.

[0219] In the internal heat exchanger (23), refrigerant passing through the outer channel (25) after passing through the indoor heat exchanger (22) and refrigerant passing through the inner channel (24) before passing through the outdoor heat exchanger (21) flow in the same direction. In addition, supercritical refrigerant flows through the outer channel (25) and low-pressure refrigerant flows through the inner channel (24). Therefore, the refrigerant flowing through the outer channel (25) hardly exchanges heat with the refrigerant flowing through the inner channel (24). Thus, even when the supercritical refrigerant passes through the internal heat exchanger (23), it flows into the expander (12) substantially without changing its temperature.

- Effects of Embodiment 8 -

[0220] According to Embodiment 8, during the cooling operation, low-pressure refrigerant before passing through the indoor heat exchanger (22) serving as an evaporator flows through the outer channel (25) and refrigerant in the outer channel (25) and refrigerant in the inner channel (24) flow in opposite directions to each other. Therefore, refrigerant in the inner channel (24) comparatively efficiently exchanges heat with refrigerant in the outer channel (25) and the supercritical refrigerant decreases its temperature to reduce its specific volume and then flows in this state into the expander (12). On the other hand, during the heating operation, low-pressure refrigerant before passing through the outdoor heat exchanger (21) serving as an evaporator flows through the inner channel (24) and, during the time, refrigerant in the outer channel (25) and refrigerant in the inner channel (24) flow in the same direction. Therefore, the refrigerant in the outer channel (25) hardly exchanges heat

with the refrigerant in the inner channel (24) and the supercritical refrigerant flows into the expander (12) substantially without changing its temperature.

[0221] Since, as described above, the specific volume and flow rate of refrigerant flowing into the expander (12) during the cooling operation can be controlled by controlling the temperature of the refrigerant, the refrigerant flow rate through the compressor (11) and the refrigerant flow rate through the expander (12) can be balanced, thereby preventing the COP from being deteriorated;

«Embodiment 9 of the Invention»

[0222] Embodiment 9 relates to an air conditioner (1) constituted by a refrigeration system according to the present invention. As shown in Figure 10, the air conditioner (1) includes a refrigerant circuit (10). The refrigerant circuit (10) operates in a vapor compression refrigeration cycle by compressing refrigerant into supercritical form. The air conditioner (1) of Embodiment 9 is configured to circulate refrigerant through the refrigerant circuit (10) and selectively perform a cooling operation and a heating operation.

[0223] The refrigerant circuit (10) is charged with carbon dioxide (CO₂) as refrigerant. Furthermore, the refrigerant circuit (10) is provided with a compressor (11), an expander (12), an outdoor heat exchanger (heat-source side heat exchanger) (21), an indoor heat exchanger (utilization side heat exchanger) (22), an internal heat exchanger (23), a first four-way selector valve (31) and a second four-way selector valve (32).

[0224] The compressor (11) and the expander (12) are constituted by individual rotary piston fluid machines having respective specific cylinder volumes. The compressor (11) and the expander (12) are connected to each other by the rotation shaft of a motor (13). The compressor (11) is driven into rotation by both of power obtained by refrigerant expansion in the expander (12) (expansion power) and power obtained by turn-on of the motor (13).

[0225] Since the compressor (11) and the expander (12) are connected to each other by the rotation shaft, they always have the same number of rotations. Therefore, in the refrigerant circuit (10), the ratio (Ve/Vc) between the circulation volume Ve of refrigerant passing through the expander (12) and the circulation volume Vc of refrigerant passing through the compressor (11) is a fixed value determined by the cylinder volume ratio between the fluid machines (11, 12). The cylinder volume ratio is designed so that the ratio Ve/Vc is equal to the density ratio de/dc during the heating operation of the air conditioner (1) between the density de of refrigerant flowing into the expander (12) and the density dc of refrigerant sucked into the compressor (11), i.e., so that the mass flow rate Me of refrigerant passing through the expander (12) is equal to the mass flow rate Mc of refrigerant passing through the compressor (11).

[0226] Note that the fluid machine constituting each of the compressor (11) and the expander (12) is not limited

to rolling piston type one. For example, scroll type positive displacement fluid machines may be used as the compressor (11) and the expander (12).

[0227] The outdoor heat exchanger (21) is constituted by a so-called cross fin type fin-and-tube heat exchanger. The outdoor heat exchanger (21) is supplied with outdoor air by an unshown fan. In the outdoor heat exchanger (21), heat is exchanged between the outdoor air supplied and the refrigerant in the refrigerant circuit (10).

[0228] The indoor heat exchanger (22) is constituted by a so-called cross fin type fin-and-tube heat exchanger. The indoor heat exchanger (22) is supplied with room air by an unshown fan. In the indoor heat exchanger (22), heat is exchanged between the room air supplied and the refrigerant in the refrigerant circuit (10).

[0229] The internal heat exchanger (23) includes a first channel (27) and a second channel (28) disposed adjacent to each other and is configured to be capable of exchanging heat between refrigerant flowing through the first channel (27) and refrigerant flowing through the second channel (28). The internal heat exchanger (23) is also configured so that, during the cooling operation, high-pressure refrigerant is cooled by heat exchange with low-pressure refrigerant.

[0230] The internal heat exchanger (23) is also configured to provide, during the cooling operation, a counterflow arrangement in which high-pressure refrigerant flows through the first channel (27) and low-pressure refrigerant flows through the second channel (28) in an opposite direction to the high-pressure refrigerant and provide, during the heating operation, a parallel flow arrangement in which high-pressure refrigerant flows through both the channels (27, 28) in the same direction. During the cooling operation, high-pressure refrigerant after passing through the outdoor heat exchanger (21) serving as a gas cooler is cooled by heat exchange with low-pressure refrigerant before passing through the indoor heat exchanger (22) serving as an evaporator. During the heating operation, high-pressure refrigerant after passing through the indoor heat exchanger (22) serving as a gas cooler sequentially flows through the second channel (28) and the first channel (27) in each of which the high-pressure refrigerant is not cooled.

[0231] In the refrigerant circuit (10), the discharge side of the compressor (11) is connected to a first port (P1) of the first four-way selector valve (31) and a second port (P2) of the first four-way selector valve (31) is connected to a first end of the outdoor heat exchanger (21). A second end of the outdoor heat exchanger (21) is connected to a first port (P1) of the second four-way selector valve (32), and a second port (P2) of the second four-way selector valve (32) is connected via the first channel (27) of the internal heat exchanger (23) to the inlet side of the expander (12). The outlet side of the expander (12) is connected to a third port (P3) of the second four-way selector valve (32), and a fourth port (P4) of the second four-way selector valve (32) is connected via the second channel (28) of the internal heat exchanger (23) to a first

end of the indoor heat exchanger (22). A second end of the indoor heat exchanger (22) is connected to a third port (P3) of the first four-way selector valve (31), and a fourth port (P4) of the first four-way selector valve (31) is connected to the suction side of the compressor (11).

[0232] The first four-way selector valve (31) switches between a position in which the first port (P1) is communicated with the second port (P2) and the third port (P3) is communicated with the fourth port (P4) (the position shown in the solid lines in Figure 10) and a position in which the first port (P1) is communicated with the third port (P3) and the second port (P2) is communicated with the fourth port (P4) (the position shown in the broken lines in Figure 10).

[0233] The second four-way selector valve (32) switches between a position in which the first port (P1) is communicated with the second port (P2) and the third port (P3) is communicated with the fourth port (P4) (the position shown in the solid lines in Figure 10) and a position in which the first port (P1) is communicated with the third port (P3) and the second port (P2) is communicated with the fourth port (P4) (the position shown in the broken lines in Figure 10).

- Operational Behavior -

[0234] Next, a description is given of the behaviors of the air conditioner (1) during cooling and heating operations.

(Cooling Operation)

[0235] In the cooling operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the solid lines in Figure 10. When the motor (13) is turned on in this state, refrigerant circulates through the refrigerant circuit (10), whereby the refrigerant circuit (10) operates in a refrigeration cycle. During this operation, the outdoor heat exchanger (21) serves as a gas cooler and the indoor heat exchanger (22) serves as an evaporator. The high-side pressure of the refrigeration cycle is set higher than the critical pressure of carbon dioxide which is the refrigerant.

[0236] The compressor (11) discharges supercritical high-pressure refrigerant. As shown in the solid arrows, the high-pressure refrigerant flows through the first four-way selector valve (31) and into the outdoor heat exchanger (21). In the outdoor heat exchanger (21), the high-pressure refrigerant releases heat to the outdoor air to decrease its temperature.

[0237] The high-pressure refrigerant after flowing out of the outdoor heat exchanger (21) passes through the second four-way selector valve (32) and then through the first channel (27) of the internal heat exchanger (23). In the internal heat exchanger (23), the high-pressure refrigerant is cooled by heat exchange with low-pressure refrigerant flowing through the second channel (28). The

high-pressure refrigerant then flows into the expander (12). In the expander (12), the introduced high-pressure refrigerant expands, whereby the internal energy of the high-pressure refrigerant is converted into power of rotation. Because of expansion in the expander (12), the high-pressure refrigerant decreases its pressure to change from supercritical to gas-liquid two-phase form.

[0238] The low-pressure refrigerant after flowing out of the expander (12) passes via the second four-way selector valve (32) through the second channel (28) of the internal heat exchanger (23) and, during the time, is heated by heat exchange with high-pressure refrigerant flowing through the first channel (27). The low-pressure refrigerant flows into the indoor heat exchanger (22). In the indoor heat exchanger (22), the low-pressure refrigerant takes heat from room air to evaporate. Furthermore, in the indoor heat exchanger (22), the room air is cooled by the low-pressure refrigerant and the cooled room air is fed back to the room.

[0239] The low-pressure refrigerant after flowing out of the indoor heat exchanger (22) flows through the first four-way selector valve (31) and is then sucked into the compressor (11). The refrigerant sucked in the compressor (11) is compressed to a predetermined pressure and then discharged from the compressor (11).

(Heating Operation)

[0240] In the heating operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the broken lines in Figure 10. When the motor (13) is turned on in this state, refrigerant circulates through the refrigerant circuit (10), whereby the refrigerant circuit (10) operates in a refrigeration cycle. During this operation, the indoor heat exchanger (22) serves as a gas cooler and the outdoor heat exchanger (21) serves as an evaporator. The high-side pressure of the refrigeration cycle, like in the cooling operation, is set higher than the critical pressure of carbon dioxide which is the refrigerant.

[0241] The compressor (11) discharges supercritical high-pressure refrigerant. As shown in the broken arrows, the high-pressure refrigerant flows through the first four-way selector valve (31) and into the indoor heat exchanger (22). In the indoor heat exchanger (22), the high-pressure refrigerant releases heat to room air to decrease its temperature. Furthermore, in the indoor heat exchanger (22), the room air is heated by the high-pressure refrigerant and the heated room air is fed back to the room.

[0242] The high-pressure refrigerant after flowing out of the indoor heat exchanger (22) passes through the second channel (28) of the internal heat exchanger (23) and then flows via the second four-way selector valve (32) through the first channel (27) of the internal heat exchanger (23). During the time, the refrigerant temperature in the internal heat exchanger (23) does not change since the high-pressure refrigerant after flowing out of

the indoor heat exchanger (22) sequentially flows the second channel (28) and the first channel (27).

[0243] The high-pressure refrigerant after flowing out of the first channel (27) of the internal heat exchanger (23) flows into the expander (12). In the expander (12), the introduced high-pressure refrigerant expands, whereby the internal energy of the high-pressure refrigerant is converted into power of rotation. Because of expansion in the expander (12), the high-pressure refrigerant decreases its pressure to change from supercritical to gas-liquid two-phase form.

[0244] The low-pressure refrigerant after flowing out of the expander (12) flows through the second four-way selector valve (32) into the outdoor heat exchanger (21). In the outdoor heat exchanger (21), the low-pressure refrigerant takes heat from the outdoor air to evaporate. The low-pressure refrigerant after flowing out of the outdoor heat exchanger (21) flows through the first four-way selector valve (31) and is then sucked into the compressor (11). The refrigerant sucked in the compressor (11) is compressed to a predetermined pressure and then discharged from the compressor (11).

- Effects of Embodiment 9 -

[0245] According to Embodiment 9, in the internal heat exchanger (23) during the cooling operation, high-pressure refrigerant after passing through the outdoor heat exchanger (21) serving as a gas cooler flows through the first channel (27) and low-pressure refrigerant before passing through the indoor heat exchanger (22) serving as an evaporator flows through the second channel (28). Therefore, the high-pressure refrigerant is cooled. On the other hand, in the internal heat exchanger (23) during the heating operation, high-pressure refrigerant after passing through the indoor heat exchanger (22) serving as a gas cooler sequentially flows through the second channel (28) and the first channel (27). Therefore, the high-pressure refrigerant does not change its temperature.

[0246] Thus, the internal heat exchanger (23) functions only during the cooling operation. Therefore, during the cooling operation, high-pressure refrigerant to be introduced into the expander (12) can be cooled to increase the density of refrigerant flowing into the expander (12). As a result, unlike the conventional refrigeration system in which, during the cooling operation, the mass flow rate M_c of refrigerant through the compressor (11) is larger than the mass flow rate M_e of refrigerant through the expander (12) for the above-mentioned reason, the refrigeration system of Embodiment 9 can increase the mass flow rate M_e of refrigerant passing through the expander (12) to balance the refrigerant mass flow rates M_c and M_e .

[0247] Furthermore, according to Embodiment 9, the refrigerant mass flow rates M_e and M_c are balanced without part of the refrigerant bypassing the expander (12). Therefore, unlike the conventional case in which part of

refrigerant bypasses the expander (12) to reduce the expansion power from the expander (12) and thereby deteriorate the COP, the refrigeration system of this embodiment can introduce all the refrigerant into the expander (12) to avoid the deterioration of the COP.

[0248] Although in Embodiment 9 the heat exchanger efficiency during the cooling operation is enhanced by allowing high-pressure refrigerant and low-pressure refrigerant to flow through the internal heat exchanger (23) in opposite directions, the internal heat exchanger (23) may be arranged so that high-pressure refrigerant and low-pressure refrigerant flow therethrough in the same direction, because the low-pressure refrigerant is liquid refrigerant before passing through the evaporator and has a high heat transfer coefficient. Also in this case, the high-pressure refrigerant can be cooled.

- Modifications of Embodiment 9 -

(First Modification)

[0249] In a first modification of Embodiment 9, a receiver (41) is additionally disposed in the refrigerant circuit (10) in Embodiment 9 between the expander (12) and the second four-way selector valve (32). In other words, in the first modification, the receiver (41) is disposed to the outlet side of the expander (12).

[0250] As shown in Figure 11, the outlet side of the expander (12) is connected to an inlet port of the receiver (41) and an outlet port of the receiver (41) is connected to the third port (P3) of the second four-way selector valve (32). Furthermore, the suction side of the compressor (11) is connected to a liquid injection pipe (42) connected to the lower end of the receiver (41) and is also connected to a gas vent pipe (43) connected to an upper part of the receiver (41). The liquid injection pipe (42) and the gas vent pipe (43) are provided with a first motor-operated valve (EV1) and a second motor-operated valve (EV2), respectively. These valves are configured to control the flow rate of refrigerant.

[0251] The rest of the configuration is the same as in Embodiment 9 shown in Figure 10.

[0252] In the cooling operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the solid lines in Figure 11. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the outdoor heat exchanger (21), the second four-way selector valve (32), the first channel (27) of the internal heat exchanger (23), the expander (12), the receiver (41), the second four-way selector valve (32), the second channel (28) of the internal heat exchanger (23), the indoor heat exchanger (22) and the first four-way selector valve (31) and is then sucked into the compressor (11) again.

[0253] In the internal heat exchanger (23), high-pressure refrigerant after passing through the outdoor heat exchanger (21) flows through the first channel (27) and

low-pressure refrigerant before passing through the indoor heat exchanger (22) flows through the second channel (28). Therefore, the high-pressure refrigerant exchanges heat with the low-pressure refrigerant. Thus, the high-pressure refrigerant is cooled in the internal heat exchanger (23) and then flows into the expander (12).

[0254] During the cooling operation, the compressor (11) can be controlled in terms of the degree of suction superheat and put into an oil return operation by controlling the opening of the first motor-operated valve (EV1) of the liquid injection pipe (42). Furthermore, the receiver (41) can be degassed by controlling the opening of the second motor-operated valve (EV2) of the gas vent pipe (43). Furthermore, when during operation the compressor (11) falls short of capacity, the shortage can be compensated for by controlling the openings of the first motor-operated valve (EV1) of the liquid injection pipe (42) and the second motor-operated valve (EV2) of the gas vent pipe (43).

[0255] In the heating operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the broken lines in Figure 11. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the indoor heat exchanger (22), the second channel (28) of the internal heat exchanger (23), the second four-way selector valve (32), the first channel (27) of the internal heat exchanger (23), the expander (12), the receiver (41), the second four-way selector valve (32), the outdoor heat exchanger (21) and the first four-way selector valve (31) and is then sucked into the compressor (11) again.

[0256] In the internal heat exchanger (23), high-pressure refrigerant after passing through the indoor heat exchanger (22) serving as a gas cooler sequentially flows through the second channel (28) and the first channel (27). Therefore, the high-pressure refrigerant does not change its temperature. Thus, the high-pressure refrigerant flows into the expander (12) without being cooled.

[0257] Also in this modification, the internal heat exchanger (23) functions only during the cooling operation. Therefore, during the cooling operation, high-pressure refrigerant to be introduced into the expander (12) can be cooled to increase the density of refrigerant flowing into the expander (12). As a result, unlike the conventional refrigeration system in which, during the cooling operation, the mass flow rate M_c of refrigerant through the compressor (11) is larger than the mass flow rate M_e of refrigerant through the expander (12) for the above-mentioned reason, the refrigeration system according to the first modification of Embodiment 9 can increase the mass flow rate M_e of refrigerant through the expander (12) to balance the refrigerant mass flow rates M_c and M_e .

[0258] Furthermore, since, like Embodiment 9, the refrigerant mass flow rates M_e and M_c are balanced without part of the refrigerant bypassing the expander (12), the refrigeration system of this modification can introduce all

the refrigerant into the expander (12) to avoid the deterioration of the COP.

(Second Modification)

[0259] In a second modification of Embodiment 9, in the refrigerant circuit (10) of Embodiment 9, a bridge circuit (32a) is used instead of the second four-way selector valve (32).

[0260] As shown in Figure 12, the bridge circuit (32a) is formed by connecting four pipe lines in bridges and has four ports (P1, P2, P3, P4). The four pipe lines are provided with their respective check valves (CV). The check valves (CV) are provided in their associated pipe lines to allow the refrigerant flow from the first port (P1) towards the second port (P2), the refrigerant flow from the third port (P3) towards the fourth port (P4), the refrigerant flow from the third port (P3) towards the first port (P1) and the refrigerant flow from the fourth port (P4) towards the second port (P2).

[0261] The second end of the outdoor heat exchanger (21) is connected to the first port (P1) of the bridge circuit (32a). The second port (P2) of the bridge circuit (32a) is connected via the first channel (27) of the internal heat exchanger (23) to the inlet side of the expander (12). The outlet side of the expander (12) is connected to the third port (P3) of the bridge circuit (32a). The fourth port (P4) of the bridge circuit (32a) is connected via the second channel (28) of the internal heat exchanger (23) to the first end of the indoor heat exchanger (22).

[0262] The rest of the configuration is the same as in Embodiment 9 shown in Figure 10.

[0263] In the cooling operation, the first four-way selector valve (31) switches to the position shown in the solid lines in Figure 12. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the outdoor heat exchanger (21), the bridge circuit (32a), the first channel (27) of the internal heat exchanger (23), the expander (12), the bridge circuit (32a), the second channel (28) of the internal heat exchanger (23), the indoor heat exchanger (22) and the first four-way selector valve (31) and is then sucked into the compressor (11) again.

[0264] In the internal heat exchanger (23), high-pressure refrigerant after passing through the outdoor heat exchanger (21) flows through the first channel (27) and low-pressure refrigerant before passing through the indoor heat exchanger (22) flows through the second channel (28). Therefore, the high-pressure refrigerant exchanges heat with the low-pressure refrigerant. Thus, the high-pressure refrigerant is cooled in the internal heat exchanger (23) and then flows into the expander (12).

[0265] In the heating operation, the first four-way selector valve (31) switches to the position shown in the broken lines in Figure 12. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the indoor heat exchanger (22), the second channel (28) of the in-

ternal heat exchanger (23), the bridge circuit (32a), the first channel (27) of the internal heat exchanger (23), the expander (12), the bridge circuit (32a), the outdoor heat exchanger (21) and the first four-way selector valve (31) and is then sucked into the compressor (11) again.

[0266] In the internal heat exchanger (23), high-pressure refrigerant after passing through the indoor heat exchanger (22) serving as a gas cooler sequentially flows through the second channel (28) and the first channel (27). Therefore, the high-pressure refrigerant does not change its temperature. Thus, the high-pressure refrigerant flows into the expander (12) without being cooled.

[0267] Also in this modification, the internal heat exchanger (23) functions only during the cooling operation. Therefore, during the cooling operation, high-pressure refrigerant to be introduced into the expander (12) can be cooled to increase the density of refrigerant flowing into the expander (12). As a result, unlike the conventional refrigeration system in which, during the cooling operation, the mass flow rate M_c of refrigerant through the compressor (11) is larger than the mass flow rate M_e of refrigerant through the expander (12) for the above-mentioned reason, the refrigeration system according to the second modification of Embodiment 9 can increase the mass flow rate M_e of refrigerant through the expander (12) to balance the refrigerant mass flow rates M_c and M_e .

[0268] Furthermore, since, like Embodiment 9, the refrigerant mass flow rates M_e and M_c are balanced without part of the refrigerant bypassing the expander (12), the refrigeration system of this modification can introduce all the refrigerant into the expander (12) to avoid the deterioration of the COP.

«Embodiment 10 of the Invention»

[0269] As shown in Figure 13, Embodiment 10 is different in the configuration of the refrigerant circuit (10) from Embodiment 9. In this embodiment, the position of the internal heat exchanger (23) is different from that in Embodiment 9 and a bypass passage (45) is provided which allows high-pressure refrigerant to bypass the internal heat exchanger (23) during the heating operation.

[0270] In the refrigerant circuit (10), the discharge side of the compressor (11) is connected to the first port (P1) of the first four-way selector valve (31) and the second port (P2) of the first four-way selector valve (31) is connected to the first end of the outdoor heat exchanger (21). The second end of the outdoor heat exchanger (21) is connected to the first port (P1) of the second four-way selector valve (32) and the second port (P2) of the second four-way selector valve (32) is connected via the first channel (27) of the internal heat exchanger (23) to the inlet side of the expander (12).

[0271] A first shut-off valve (SV1) is disposed in a pipe line between the second port (P2) of the second four-way selector valve (32) and the first channel (27) of the internal heat exchanger (23). One end of the bypass pas-

sage (45) with a second shut-off valve (SV2) is connected to a pipe between the second port (P2) of the second four-way selector valve (32) and the first shut-off valve (SV1). The other end of the bypass passage (45) joins a pipe connecting between the first channel (27) of the internal heat exchanger (23) and the inlet side of the expander (21).

[0272] The outlet side of the expander (12) is connected to the third port (P3) of the second four-way selector valve (32) and the fourth port (P4) of the second four-way selector valve (32) is connected to the first end of the indoor heat exchanger (22). The second end of the indoor heat exchanger (22) is connected to the third port (P3) of the first four-way selector valve (31) and the fourth port (P4) of the first four-way selector valve (31) is connected via the second channel (28) of the internal heat exchanger (23) to the suction side of the compressor (11).

[0273] With the above configuration, the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure refrigerant flows through the first channel (27) and low-pressure refrigerant flows through the second channel (28). Furthermore, during the cooling operation, high-pressure refrigerant after passing through the outdoor heat exchanger (21) is cooled by heat exchange with low-pressure refrigerant after passing through the indoor heat exchanger (22).

[0274] In the above configuration, a solenoid shut-off valve or a motor-operated valve may be used as each of the first shut-off valve (SV1) and the second shut-off valve (SV2). The first shut-off valve (SV1) may be disposed either upstream or downstream of the internal heat exchanger (23).

35 - Operational Behavior -

[0275] In the cooling operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the solid lines in Figure 13. Furthermore, the first shut-off valve (SV1) is opened and the second shut-off valve (SV2) is closed. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the outdoor heat exchanger (21), the second four-way selector valve (32), the first channel (27) of the internal heat exchanger (23), the expander (12), the second four-way selector valve (32), the indoor heat exchanger (22), the first four-way selector valve (31) and the second channel (28) of the internal heat exchanger (23) and is then sucked into the compressor (11) again.

[0276] In the internal heat exchanger (23), high-pressure refrigerant after passing through the outdoor heat exchanger (21) flows through the first channel (27) and low-pressure refrigerant after passing through the indoor heat exchanger (22) flows through the second channel (28). Therefore, the high-pressure refrigerant exchanges heat with the low-pressure refrigerant. Thus, the high-pressure refrigerant is cooled in the internal heat ex-

changer (23) and then flows into the expander (12).

[0277] In the heating operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the broken lines in Figure 13. Furthermore, the first shut-off valve (SV1) is closed and the second shut-off valve (SV2) is opened. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the indoor heat exchanger (22), the second four-way selector valve (32), the bypass passage (45), the expander (12), the second four-way selector valve (32), the outdoor heat exchanger (21), the first four-way selector valve (31) and the second channel (28) of the internal heat exchanger (23) and is then sucked into the compressor (11) again.

[0278] In the internal heat exchanger (23), high-pressure refrigerant after passing through the indoor heat exchanger (22) does not flow but only low-pressure refrigerant after passing through the outdoor heat exchanger (21) flows through the second channel (28). Therefore, the high-pressure refrigerant does not change its temperature. Thus, the high-pressure refrigerant flows into the expander (12) without being cooled.

- Effects of Embodiment 10 -

[0279] Also in Embodiment 10, the internal heat exchanger (23) functions only during the cooling operation. Therefore, during the cooling operation, high-pressure refrigerant to be introduced into the expander (12) can be cooled to increase the density of refrigerant flowing into the expander (12). As a result, unlike the conventional refrigeration system in which, during the cooling operation, the mass flow rate M_c of refrigerant through the compressor (11) is larger than the mass flow rate M_e of refrigerant through the expander (12), the refrigeration system of Embodiment 10 can increase the mass flow rate M_e of refrigerant through the expander (12) to balance the refrigerant mass flow rates M_c and M_e .

[0280] Furthermore, since, like Embodiment 9, the refrigerant mass flow rates M_e and M_c are balanced without part of the refrigerant bypassing the expander (12), the refrigeration system of this embodiment can introduce all the refrigerant into the expander (12) to avoid the deterioration of the COP.

- Modifications of Embodiment 10 -

(First Modification)

[0281] In a first modification of Embodiment 10, a receiver (41) is additionally disposed in the refrigerant circuit (10) in Embodiment 10 shown in Figure 13 between the outlet side of the evaporator and the low-pressure side of the internal heat exchanger (23).

[0282] As shown in Figure 14, the fourth port (P4) of the first four-way selector valve (31) is connected to an inlet port of the receiver (41) and an outlet port of the

receiver (41) is connected via the second channel (28) of the internal heat exchanger (23) to the suction side of the compressor (11). Furthermore, the suction side of the compressor (11) is connected to a liquid injection pipe (42) connected to the lower end of the receiver (41). The liquid injection pipe (42) is provided with a first motor-operated valve (EV1) and configured to control the flow rate of refrigerant.

[0283] In this modification, saturated gas comes out of the outlet port of the receiver (41). Therefore, the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure refrigerant and low-pressure refrigerant flow in opposite directions to each other.

[0284] The rest of the configuration is the same as in Embodiment 10 shown in Figure 13.

[0285] In the cooling operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the solid lines in Figure 14. Furthermore, the first shut-off valve (SV1) is opened and the second shut-off valve (SV2) is closed. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the outdoor heat exchanger (21), the second four-way selector valve (32), the first channel (27) of the internal heat exchanger (23), the expander (12), the second four-way selector valve (32), the indoor heat exchanger (22), the first four-way selector valve (31), the receiver (41) and the second channel (28) of the internal heat exchanger (23) and is then sucked into the compressor (11) again.

[0286] In the internal heat exchanger (23), high-pressure refrigerant after passing through the outdoor heat exchanger (21) flows through the first channel (27) and low-pressure refrigerant after passing through the indoor heat exchanger (22) and the receiver (41) flows through the second channel (28). Therefore, the high-pressure refrigerant exchanges heat with the low-pressure refrigerant. Thus, the high-pressure refrigerant is cooled in the internal heat exchanger (23) and then flows into the expander (12).

[0287] In the heating operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the broken lines in Figure 14. Furthermore, the first shut-off valve (SV1) is closed and the second shut-off valve (SV2) is opened. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the indoor heat exchanger (22), the second four-way selector valve (32), the bypass passage (45), the expander (12), the second four-way selector valve (32), the outdoor heat exchanger (21), the first four-way selector valve (31), the receiver (41) and the second channel (28) of the internal heat exchanger (23) and is then sucked into the compressor (11) again.

[0288] In the internal heat exchanger (23), high-pressure refrigerant after passing through the indoor heat exchanger (22) does not flow but only low-pressure refrigerant after passing through the outdoor heat exchanger

(21) and the receiver (41) flows through the second channel (28). Therefore, the high-pressure refrigerant does not change its temperature. Thus, the high-pressure refrigerant flows into the expander (12) without being cooled.

[0289] Also in this modification, the internal heat exchanger (23) functions only during the cooling operation. Therefore, during the cooling operation, high-pressure refrigerant to be introduced into the expander (12) can be cooled to increase the density ρ of refrigerant flowing into the expander (12). As a result, unlike the conventional refrigeration system in which, during the cooling operation, the mass flow rate M_c of refrigerant through the compressor (11) is larger than the mass flow rate M_e of refrigerant through the expander (12), the refrigeration system of this modification can increase the mass flow rate M_e of refrigerant through the expander (12) to balance the refrigerant mass flow rates M_c and M_e .

[0290] Furthermore, since, like Embodiment 9, the refrigerant mass flow rates M_e and M_c are balanced without part of the refrigerant bypassing the expander (12), the refrigeration system of this modification can introduce all the refrigerant into the expander (12) to avoid the deterioration of the COP.

(Second Modification)

[0291] A second modification of Embodiment 10 is a modified example of the configuration in which refrigerant bypasses the internal heat exchanger (23) in the refrigerant circuit (10) in Embodiment 10 shown in Figure 13.

[0292] As shown in Figure 15, the first shut-off valve (SV1) in the refrigerant circuit (10) is not in a pipe line between the second four-way selector valve (32) and the first channel (27) of the internal heat exchanger (23). Furthermore, the refrigerant circuit (10) is not provided with the bypass passage (high-pressure side bypass passage) (45) as shown in Figure 13 for allowing, during the heating operation, high-pressure refrigerant to bypass the first channel (27).

[0293] The first shut-off valve (SV1) is instead disposed in a pipe line between the fourth port (P4) of the first four-way selector valve (31) and the second channel (28) of the internal heat exchanger (23). Furthermore, one end of a bypass passage (low-pressure side bypass passage) (46) with a second shut-off valve (SV2) is connected to a pipe between the fourth port (P4) of the first four-way selector valve (31) and the first shut-off valve (SV1). The other end of the bypass passage (46) joins a pipe connecting between the second channel (28) of the internal heat exchanger (23) and the suction side of the compressor (11).

[0294] The rest of the configuration is the same as in Embodiment 10 shown in Figure 13.

[0295] In the cooling operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the solid lines in Figure 15. Furthermore, the first shut-off valve

(SV1) is opened and the second shut-off valve (SV2) is closed. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the outdoor heat exchanger (21), the second four-way selector valve (32), the first channel (27) of the internal heat exchanger (23), the expander (12), the second four-way selector valve (32), the indoor heat exchanger (22), the first four-way selector valve (31) and the second channel (28) of the internal heat exchanger (23) and is then sucked into the compressor (11) again.

[0296] In the internal heat exchanger (23), high-pressure refrigerant after passing through the outdoor heat exchanger (21) flows through the first channel (27) and low-pressure refrigerant after passing through the indoor heat exchanger (22) flows through the second channel (28). Therefore, the high-pressure refrigerant exchanges heat with the low-pressure refrigerant. Thus, the high-pressure refrigerant is cooled in the internal heat exchanger (23) and then flows into the expander (12).

[0297] In the heating operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the broken lines in Figure 15. Furthermore, the first shut-off valve (SV1) is closed and the second shut-off valve (SV2) is opened. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the indoor heat exchanger (22), the second four-way selector valve (32), the first channel (27) of the internal heat exchanger (23), the expander (12), the second four-way selector valve (32), the outdoor heat exchanger (21), the first four-way selector valve (31) and the bypass passage (46) and is then sucked into the compressor (11) again.

[0298] In the internal heat exchanger (23), high-pressure refrigerant after passing through the indoor heat exchanger (22) flows through the first channel (27) but low-pressure refrigerant after passing through the outdoor heat exchanger (21) does not flow. Therefore, the high-pressure refrigerant does not change its temperature. Thus, the high-pressure refrigerant flows into the expander (12) without being cooled.

[0299] Also in this modification, the internal heat exchanger (23) functions only during the cooling operation. Therefore, during the cooling operation, high-pressure refrigerant to be introduced into the expander (12) can be cooled to increase the density ρ of refrigerant flowing into the expander (12). As a result, unlike the conventional refrigeration system in which, during the cooling operation, the mass flow rate M_c of refrigerant through the compressor (11) is larger than the mass flow rate M_e of refrigerant through the expander (12), the refrigeration system of this modification can increase the mass flow rate M_e of refrigerant through the expander (12) to balance the refrigerant mass flow rates M_c and M_e .

[0300] Furthermore, since, like Embodiment 9, the refrigerant mass flow rates M_e and M_c are balanced without part of the refrigerant bypassing the expander (12), the refrigeration system of this modification can introduce all

the refrigerant into the expander (12) to avoid the deterioration of the COP.

(Third Modification)

[0301] A third modification of Embodiment 10 is an example of an air conditioner in which the second four-way selector valve (32) is not used in the refrigerant circuit in Embodiment 10 shown in Figure 13.

[0302] As shown in Figure 16, in the refrigerant circuit (10), the second end of the outdoor heat exchanger (21) is connected via a third check valve (CV3) and the first channel (27) of the internal heat exchanger (23) to the inlet side of the expander (12). The outlet side of the expander (12) branches into two lines. One of the branch lines is connected via a first check valve (CV1) to a pipe between the outdoor heat exchanger (21) and the third check valve (CV3), while the other branch line is connected via a second check valve (CV2) to the first end of the indoor heat exchanger (22). Furthermore, one end of a bypass passage (45) with a fourth check valve (CV4) is connected to a pipe between the second check valve (CV2) and the indoor heat exchanger (22). The other end of the bypass passage (45) joins a pipe connecting between the first channel (27) of the internal heat exchanger (23) and the inlet side of the expander (21).

[0303] The first check valve (CV1) and the second check valve (CV2) are valves allowing the outflow of refrigerant from the expander (12). Alternatively, other types of valves, such as solenoid shut-off valves, may be substituted for them and configured to switch their on-off position at the change from the cooling operation to the heating operation and vice versa. The third check valve (CV3) and the fourth check valve (CV4) are valves allowing the inflow of refrigerant into the expander (12). Alternatively, like the first check valve (CV1) and the second check valve (CV2), other types of valves, such as solenoid shut-off valves, may be substituted for them.

[0304] The rest of the configuration is the same as in Embodiment 10 shown in Figure 13.

- Operational Behavior -

[0305] In the cooling operation, the first four-way selector valve (31) switches to the position shown in the solid lines in Figure 16. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the outdoor heat exchanger (21), the third check valve (CV3), the first channel (27) of the internal heat exchanger (23), the expander (12), the second check valve (CV2), the indoor heat exchanger (22), the first four-way selector valve (31) and the second channel (28) of the internal heat exchanger (23) and is then sucked into the compressor (11) again.

[0306] In the internal heat exchanger (23), high-pressure refrigerant after passing through the outdoor heat exchanger (21) flows through the first channel (27) and low-pressure refrigerant after passing through the indoor

heat exchanger (22) flows through the second channel (28). Therefore, the high-pressure refrigerant exchanges heat with the low-pressure refrigerant. Thus, the high-pressure refrigerant is cooled in the internal heat exchanger (23) and then flows into the expander (12).

[0307] In the heating operation, the first four-way selector valve (31) switches to the position shown in the broken lines in Figure 16. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the indoor heat exchanger (22), the bypass passage (45) (the fourth check valve (CV4)), the expander (12), the first check valve (CV1), the outdoor heat exchanger (21), the first four-way selector valve (31) and the second channel (28) of the internal heat exchanger (23) and is then sucked into the compressor (11) again.

[0308] In the internal heat exchanger (23), high-pressure refrigerant after passing through the indoor heat exchanger (22) does not flow but low-pressure refrigerant after passing through the outdoor heat exchanger (21) flows through the second channel (28). Therefore, the high-pressure refrigerant does not change its temperature. Thus, the high-pressure refrigerant flows into the expander (12) without being cooled.

[0309] Also in this modification, the internal heat exchanger (23) functions only during the cooling operation. Therefore, during the cooling operation, high-pressure refrigerant to be introduced into the expander (12) can be cooled to increase the density of refrigerant flowing into the expander (12). As a result, unlike the conventional refrigeration system in which, during the cooling operation, the mass flow rate M_c of refrigerant through the compressor (11) is larger than the mass flow rate M_e of refrigerant through the expander (12), the refrigeration system of this modification can increase the mass flow rate M_e of refrigerant through the expander (12) to balance the refrigerant mass flow rates M_c and M_e .

[0310] Furthermore, since, like Embodiment 9, the refrigerant mass flow rates M_e and M_c are balanced without part of the refrigerant bypassing the expander (12), the refrigeration system of this modification can introduce all the refrigerant into the expander (12) to avoid the deterioration of the COP.

(Fourth Modification)

[0311] A fourth modification of Embodiment 10 is an example of an air conditioner configured so that, during the cooling operation, high-pressure refrigerant and low-pressure refrigerant flow through the internal heat exchanger (23) in opposite directions in the refrigerant circuit (10) in Embodiment 10 shown in Figure 13.

[0312] As shown in Figure 17, the second port (P2) of the second four-way selector valve (32) is connected, as opposed to the case in Figure 13, to the right end of the first channel (27) of the internal heat exchanger (23) when viewed in the figure. The left end of the first channel (27) of the internal heat exchanger (23) when viewed in

Figure 17 is connected via the first shut-off valve (SV1) to the inlet side of the expander (12). Furthermore, the bypass passage (45) with the second shut-off valve (SV2) is connected to a pipe between the second port (P2) of the second four-way selector valve (32) and the internal heat exchanger (23) and a pipe between the first shut-off valve (SV1) and the expander (12).

[0313] The rest of the configuration is the same as in Embodiment 10 shown in Figure 13.

[0314] According to this modification, the same effects as according to Embodiment 10 shown in Figure 13 can be exhibited. In addition, since high-pressure refrigerant and low-pressure refrigerant flow in opposite directions to each other in the internal heat exchanger (23) during the cooling operation, the high-pressure refrigerant can be more effectively cooled.

«Embodiment 11 of the Invention»

[0315] As shown in Figure 18, Embodiment 11 is different in the configuration of the refrigerant circuit (10) from Embodiments 9 and 10.

[0316] In the refrigerant circuit (10), the discharge side of the compressor (11) is connected to the first port (P1) of the first four-way selector valve (31) and the second port (P2) of the first four-way selector valve (31) is connected to the first end of the outdoor heat exchanger (21). The second end of the outdoor heat exchanger (21) is connected to the first port (P1) of the second four-way selector valve (32) and the second port (P2) of the second four-way selector valve (32) is connected via the first channel (27) of the internal heat exchanger (23) to the inlet side of the expander (12).

[0317] The outlet side of the expander (12) is connected to the third port (P3) of the first four-way selector valve (31) and the fourth port (P4) of the first four-way selector valve (31) is connected to the first end of the indoor heat exchanger (22). The second end of the indoor heat exchanger (22) is connected to the third port (P3) of the second four-way selector valve (32) and the fourth port (P4) of the second four-way selector valve (32) is connected via the second channel (28) of the internal heat exchanger (23) to the suction side of the compressor (11).

[0318] A first shut-off valve (SV1) is disposed in a pipe line between the second channel (28) of the internal heat exchanger (23) and the suction side of the compressor (11). Furthermore, a bypass passage (46) with a second shut-off valve (SV2) is connected to a pipe between the fourth port (P4) of the second four-way selector valve (32) and the second channel (28) of the internal heat exchanger (23) and a pipe between the first shut-off valve (SV1) and the suction side of the compressor (11).

[0319] With the above configuration, the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure refrigerant flows through the first channel (27) and low-pressure refrigerant flows through the second channel (28). Furthermore, during

the cooling operation, high-pressure refrigerant after passing through the outdoor heat exchanger (21) is cooled by heat exchange with low-pressure refrigerant after passing through the indoor heat exchanger (22).

[0320] Each of the first four-way selector valve (31) and the second four-way selector valve (32) switches between a position in which the first port (P1) is communicated with the second port (P2) and the third port (P3) is communicated with the fourth port (P4) (the position shown in the solid lines in Figure 18) and a position in which the first port (P1) is communicated with the fourth port (P4) and the second port (P2) is communicated with the third port (P3) (the position shown in the broken lines in Figure 18).

[0321] Also in Embodiment 11, a receiver may be disposed to the outlet side of the expander (12) or between the evaporator and the low-pressure side of the internal heat exchanger (23). A high-pressure side bypass passage (45) may be provided instead of the low-pressure side bypass passage (46). The internal heat exchanger (23) may be configured to provide, during the cooling operation, a counterflow arrangement in which high-pressure refrigerant and low-pressure refrigerant flow in opposite directions.

- Operational Behavior -

[0322] In the cooling operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the solid lines in Figure 18. Furthermore, the first shut-off valve (SV1) is opened and the second shut-off valve (SV2) is closed. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the outdoor heat exchanger (21), the second four-way selector valve (32), the first channel (27) of the internal heat exchanger (23), the expander (12), the first four-way selector valve (31), the indoor heat exchanger (22), the second four-way selector valve (32) and the second channel (28) of the internal heat exchanger (23) and is then sucked into the compressor (11) again.

[0323] In the internal heat exchanger (23), high-pressure refrigerant after passing through the outdoor heat exchanger (21) flows through the first channel (27) and low-pressure refrigerant after passing through the indoor heat exchanger (22) flows through the second channel (28). Therefore, the high-pressure refrigerant exchanges heat with the low-pressure refrigerant. Thus, the high-pressure refrigerant is cooled in the internal heat exchanger (23) and then flows into the expander (12).

[0324] In the heating operation, the first four-way selector valve (31) and the second four-way selector valve (32) switch to their respective positions shown in the broken lines in Figure 18. Furthermore, the first shut-off valve (SV1) is closed and the second shut-off valve (SV2) is opened. Refrigerant discharged from the compressor (11) in this state sequentially flows through the first four-way selector valve (31), the indoor heat exchanger (22),

the second four-way selector valve (32), the first channel (27) of the internal heat exchanger (23), the expander (12), the first four-way selector valve (31), the outdoor heat exchanger (21), the second four-way selector valve (32) and the bypass passage (46) and is then sucked into the compressor (11) again.

[0325] In the internal heat exchanger (23), high-pressure refrigerant after passing through the indoor heat exchanger (22) flows through the first channel (27) but low-pressure refrigerant after passing through the outdoor heat exchanger (21) does not flow through the second channel (28). Therefore, the high-pressure refrigerant does not change its temperature. Thus, the high-pressure refrigerant flows into the expander (12) without being cooled.

- Effects of Embodiment 11 -

[0326] Also in Embodiment 11, the internal heat exchanger (23) functions only during the cooling operation. Therefore, during the cooling operation, high-pressure refrigerant to be introduced into the expander (12) can be cooled to increase the density d_e of refrigerant flowing into the expander (12). As a result, unlike the conventional refrigeration system in which, during the cooling operation, the mass flow rate M_c of refrigerant through the compressor (11) is larger than the mass flow rate M_e of refrigerant through the expander (12), the refrigeration system of Embodiment 11 can increase the mass flow rate M_e of refrigerant through the expander (12) to balance the refrigerant mass flow rates M_c and M_e .

[0327] Furthermore, since, like Embodiment 9, the refrigerant mass flow rates M_e and M_c are balanced without part of the refrigerant bypassing the expander (12), the refrigeration system of this embodiment can introduce all the refrigerant into the expander (12) to avoid the deterioration of the COP.

«Embodiment 12 of the Invention»

[0328] A refrigeration system according to Embodiment 12 is applied to an air conditioner (1). The air conditioner (1) is configured to selectively perform a cooling operation for cooling a room and a heating operation for heating the room.

[0329] As shown in Figure 19, the air conditioner (1) includes a refrigerant circuit (10). The refrigerant circuit (10) operates in a vapor compression refrigeration cycle by circulating refrigerant therethrough. The refrigerant circuit (10) is charged with carbon dioxide (CO_2) as refrigerant.

[0330] Furthermore, the refrigerant circuit (10) includes a compressor (11), an expander (12), an outdoor heat exchanger (21), an indoor heat exchanger (22), a gas-liquid separator (51), a first four-way selector valve (31) and a second four-way selector valve (32) which are connected therein.

[0331] The compressor (11) and the expander (12) are

constituted by individual rotary piston fluid machines having respective specific cylinder volumes. The compressor (11) and the expander (12) are connected to each other by the rotation shaft of a motor (13). The compressor (11) is driven into rotation by both of power obtained by refrigerant expansion in the expander (12) (expansion power) and power obtained by turn-on of the motor (13). Since the compressor (11) and the expander (12) are connected to each other by the rotation shaft, they always have the same number of rotations. Therefore, in the refrigerant circuit (10), the ratio (V_e/V_c) between the circulation volume V_e of refrigerant passing through the expander (12) and the circulation volume V_c of refrigerant passing through the compressor (11) is a fixed value determined by the cylinder volume ratio between the fluid machines (11, 12). The cylinder volume ratio is designed so that the ratio V_e/V_c is equal to the density ratio d_e/d_c during the heating operation of the air conditioner (1) between the density d_e of refrigerant flowing into the expander (12) and the density d_c of refrigerant sucked into the compressor (11), i.e., so that the mass flow rate M_e of refrigerant passing through the expander (12) is equal to the mass flow rate M_c of refrigerant passing through the compressor (11).

[0332] Each of the outdoor heat exchanger (21) and the indoor heat exchanger (22) is constituted by a so-called cross fin type fin-and-tube heat exchanger. The outdoor heat exchanger (21) is supplied with outdoor air by an unshown fan. In the outdoor heat exchanger (21), heat is exchanged between outdoor air and refrigerant. On the other hand, the indoor heat exchanger (22) is supplied with room air by an unshown fan. In the indoor heat exchanger (22), heat is exchanged between room air and refrigerant.

[0333] The outlet side of the expander (12) is connected to the gas-liquid separator (51). The gas-liquid separator (51) is a closed container for separating two-phase refrigerant expanded by the expander (12) into a liquid refrigerant and a gas refrigerant. The interior of the gas-liquid separator (51) has a liquid storage section (52) formed in a lower space thereof to store the separated liquid refrigerant and a gas storage section (53) formed in an upper space thereof to store the separated gas refrigerant.

[0334] The liquid storage section (52) of the gas-liquid separator (51) is connected to a separated liquid pipe (54), while the gas storage section (53) thereof is connected to a separated gas pipe (55). The separated liquid pipe (54) is a pipe for sending the liquid refrigerant separated by the gas-liquid separator (51) into the second four-way selector valve (32). The separated gas pipe (55) is a so-called gas injection pipe (a first injection pipe) for sending the gas refrigerant separated by the gas-liquid separator (51) into the suction side of the compressor (11). The separated gas pipe (55) is provided with a gas control valve (38) for controlling the flow rate of the gas refrigerant to be sent into the section side of the compressor (11).

[0335] Furthermore, the gas-liquid separator (51) is provided with a heat transfer tube (50) passing through the interior of the gas-liquid separator (51) to adjoin the liquid storage section (52). One end of the heat transfer tube (50) is connected to one end of the outdoor heat exchanger (21) and the other end is connected to the second four-way selector valve (32). The heat transfer tube (50) constitutes an internal heat exchange part for exchanging liquid refrigerant in the liquid storage section (52) with refrigerant in the heat transfer tube.

[0336] Each of the first four-way selector valve (31) and the second four-way selector valve (32) has first to fourth ports. The first four-way selector valve (31) has the first port (P1) connected to the discharge side of the compressor (11), the second port (P2) connected to the other end of the outdoor heat exchanger (21), the third port (P3) connected to the suction side of the compressor (11) and the fourth port (P4) connected to one end of the indoor heat exchanger (22). The second four-way selector valve (32) has the first port (P1) connected via the separated liquid pipe (54) to the liquid storage section (52) of the gas-liquid separator (51), the second port (P2) connected to the heat transfer tube (50) of the gas-liquid separator (51), the third port (P3) connected to the inlet side of the expander (12) and the fourth port (P4) connected to the other end of the indoor heat exchanger (22).

[0337] Each of the first and second four-way selector valves (31, 32) is configured to be switchable between a first position in which the first port (P1) is communicated with the second port (P2) and the third port (P3) is communicated with the fourth port (P4) (the position shown in the solid lines in Figure 19) and a second position in which the first port (P1) is communicated with the fourth port (P4) and the second port (P2) is communicated with the third port (P3) (the position shown in the broken lines in Figure 19).

[0338] The first four-way selector valve (31) constitutes a refrigerant switching mechanism for switching the circulation direction of refrigerant to selectively provide either the cooling operation or the heating operation. On the other hand, the second four-way selector valve (32) constitutes a heat exchange control mechanism (60) for changing the amount of heat exchange of refrigerant in the internal heat exchange part (50) and allows heat exchange of refrigerant in the heat transfer tube (50) only during the cooling operation of the air conditioner (1).

- Operational Behavior -

[0339] Next, a description is given of the behaviors of the air conditioner (1) according to Embodiment 12 during cooling and heating operations.

(Cooling Operation)

[0340] In the cooling operation, the first four-way selector valve (31) and the second four-way selector valve

(32) are selected to the first position and the second position, respectively, as shown in Figure 20. When the motor (13) is turned on in this state, refrigerant circulates through the refrigerant circuit (10), whereby the refrigerant circuit (10) operates in a refrigeration cycle. During this operation, the outdoor heat exchanger (21) serves as a gas cooler and the indoor heat exchanger (22) serves as an evaporator. The high-side pressure of the refrigeration cycle is set higher than the critical pressure of carbon dioxide which is the refrigerant.

[0341] The compressor (11) discharges supercritical high-pressure refrigerant. The high-pressure refrigerant flows through the first four-way selector valve (31) and into the outdoor heat exchanger (21). In the outdoor heat exchanger (21), the high-pressure refrigerant releases heat to outdoor air.

[0342] The high-pressure refrigerant having released heat in the outdoor heat exchanger (21) flows through the heat transfer tube (50) in the gas-liquid separator (51). During the time, the high-pressure refrigerant is cooled by heat exchange with the liquid refrigerant stored in the liquid storage section (52) of the gas-liquid separator (51). The high-pressure refrigerant after flowing out of the heat transfer tube (50) flows through the second four-way selector valve (32) into the expander (12). In the expander (12), the high-pressure refrigerant expands, whereby the internal energy of the high-pressure refrigerant is converted into power of rotation for the compressor (11). Because of expansion in the expander (12), the high-pressure refrigerant decreases its pressure to change from supercritical to gas-liquid two-phase form.

[0343] The low-pressure refrigerant obtained by pressure reduction in the expander (12) flows into the container of the gas-liquid separator (51). In the gas-liquid separator (51), the low-pressure refrigerant in gas-liquid two-phase form is separated into a liquid refrigerant and a gas refrigerant. The low-pressure liquid refrigerant stored in the liquid storage section (52) is heated by heat exchange with the high-pressure refrigerant flowing through the heat transfer tube (50). On the other hand, the low-pressure gas refrigerant stored in the gas storage section (53) flows through the separated gas pipe (55) back to the suction side of the compressor (11) by opening the gas control valve (38) to an appropriate opening at appropriate times.

[0344] The low-pressure liquid refrigerant in the liquid storage section (52) passes through the separated liquid pipe (54) and the second four-way selector valve (32) and then flows into the indoor heat exchanger (22). In the indoor heat exchanger (22), the low-pressure refrigerant takes heat from room air to evaporate. Then, the room air cooled by the low-pressure refrigerant is fed to the room. The low-pressure refrigerant evaporated in the indoor heat exchanger (22) passes through the first four-way selector valve (31) and is then sucked into the compressor (11).

(Heating Operation)

[0345] In the heating operation, the first four-way selector valve (31) and the second four-way selector valve (32) are selected to the second position and the first position, respectively, as shown in Figure 21. When the motor (13) is turned on in this state, refrigerant circulates through the refrigerant circuit (10), whereby the refrigerant circuit (10) operates in a refrigeration cycle. During this operation, the indoor heat exchanger (22) serves as a gas cooler and the outdoor heat exchanger (21) serves as an evaporator. The high-side pressure of the refrigeration cycle, like in the cooling operation, is set higher than the critical pressure of carbon dioxide which is the refrigerant.

[0346] The compressor (11) discharges supercritical high-pressure refrigerant. The high-pressure refrigerant flows through the first four-way selector valve (31) and into the indoor heat exchanger (22). In the indoor heat exchanger (22), the high-pressure refrigerant releases heat to room air. Then, the room air heated by the high-pressure refrigerant is fed to the room.

[0347] The high-pressure refrigerant having released heat in the indoor heat exchanger (22) flows through the second four-way selector valve (32) into the expander (12). In the expander (12), the high-pressure refrigerant expands, whereby the internal energy of the high-pressure refrigerant is converted into power of rotation for the compressor (11). Because of expansion in the expander (12), the high-pressure refrigerant decreases its pressure to change from supercritical to gas-liquid two-phase form.

[0348] The low-pressure refrigerant obtained by pressure reduction in the expander (12) flows into the container of the gas-liquid separator (51). In the gas-liquid separator (51), the low-pressure refrigerant in gas-liquid two-phase form is separated into a liquid refrigerant and a gas refrigerant. The low-pressure liquid refrigerant stored in the liquid storage section (52) passes through the separated liquid pipe (54) and the second four-way selector valve (32) and then flows through the heat transfer tube (50). In this case, the liquid refrigerant in the liquid storage section (52) and the liquid refrigerant in the heat transfer tube (50) have substantially the same temperature and, therefore, hardly exchange heat with each other.

[0349] The low-pressure refrigerant after flowing out of the heat transfer tube (50) flows into the outdoor heat exchanger (21). In the outdoor heat exchanger (21), the low-pressure refrigerant takes heat from outdoor air to evaporate. The low-pressure refrigerant evaporated in the outdoor heat exchanger (21) flows through the first four-way selector valve (31) and is then sucked into the compressor (11).

- Effects of Embodiment 12 -

[0350] In Embodiment 12, the gas-liquid separator (51)

is provided with a heat transfer tube (50) as an internal heat exchange part. In addition, the refrigeration system of Embodiment 12 is configured to allow, only during the cooling operation, heat exchange between refrigerant flowing through the heat transfer tube (50) for introduction into the expander (12) and liquid refrigerant separated in the gas-liquid separator (51) by position change of the second four-way selector valve (32). Therefore, during the cooling operation, refrigerant to be introduced into the expander (12) can be cooled to increase the density of refrigerant flowing into the expander (12). As a result, unlike the conventional refrigeration system in which, during the cooling operation, the mass flow rate M_c of refrigerant through the compressor (11) is larger than the mass flow rate M_e of refrigerant through the expander (12) for the above-mentioned reason, the refrigeration system of this embodiment can increase the mass flow rate M_e of refrigerant passing through the expander to balance the refrigerant mass flow rates M_c and M_e . Therefore, the refrigeration system can operate in a desired refrigeration cycle.

[0351] According to this embodiment, the refrigerant mass flow rates M_e and M_c are balanced, unlike the technique in Patent Document 2, without part of the refrigerant bypassing the expander (12). Therefore, unlike the refrigeration system of Patent Document 2 in which the expansion power from the expander (12) is reduced to deteriorate the COP, the refrigeration system of this embodiment can introduce all the refrigerant into the expander (12) to avoid the deterioration of the COP.

[0352] According to this embodiment, heat is exchanged between the liquid refrigerant separated in the gas-liquid separator (51) and the refrigerant to be introduced into the expander (12). Because refrigerant in liquid form has a higher overall heat transfer coefficient than refrigerants in two-phase form and gas form of the same kind, it can enhance the heat exchanger efficiency in the internal heat exchange part (50). Therefore, the refrigerant to be introduced into the expander (12) can be effectively cooled, resulting in providing a compact design of the internal heat exchange part (50).

[0353] Furthermore, according to this embodiment, the gas-liquid separator (51) serves also as the internal heat exchanger (50). Therefore, the refrigeration system of this embodiment can be downsized as compared with the case where the gas-liquid separator (51) and the internal heat exchanger (50) are separately provided.

[0354] Furthermore, according to this embodiment, a so-called gas injection can be made by sending the gas refrigerant separated by the gas-liquid separator (51) into the suction side of the compressor (11). Therefore, the refrigeration system can control the degree of superheat of refrigerant to be sucked into the compressor (11), thereby providing an optimum control over the refrigeration cycle.

<Modification of Embodiment 12>

[0355] Next, a description is given of a refrigeration system according to a modification of Embodiment 12. The refrigeration system according to this modification includes a plurality of indoor heat exchangers as utilization side heat exchangers of an air conditioner (1). In other words, the refrigeration system of this modification is applied to a multi-type air conditioner. The following description is given of different points from Embodiment 12.

[0356] In the refrigerant circuit (10) in this modification, first to third indoor heat exchangers (22a, 22b, 22c) are connected in parallel with each other. The indoor heat exchangers (22a, 22b, 22c) are provided with their respective fans unshown. The indoor heat exchangers (22a, 22b, 22c) are supplied with room air by the associated fans. Furthermore, the refrigerant circuit (10) includes first to third flow control valves (61a, 61b, 61c) associated with the first to third indoor heat exchangers (22a, 22b, 22c), respectively. Each flow control valve (61a, 61b, 61c) is configured to individually control the flow rate of refrigerant branchedly flowing into the associated indoor heat exchanger (22a, 22b, 22c). The operational behaviors of this modification are the same as in Embodiment 12 except that refrigerant branchedly flows into the plurality of indoor heat exchangers (22a, 22b, 22c) and the branched flows then merge together.

[0357] Also in this modification, during the cooling operation, refrigerant to be introduced into the expander (12) can be cooled to increase the density of refrigerant flowing into the expander (12) by heat exchange of refrigerant in the heat transfer tube (50). Therefore, the refrigerant mass flow rates (M_c and M_e) through the compressor (11) and the expander (12) can be balanced, whereby the refrigeration system can operate in a desired refrigeration cycle.

[0358] Furthermore, according to this modification, since the refrigeration system is provided with the plurality of indoor heat exchangers (22a, 22b, 22c), it can be applied to a so-called multi-type air conditioner (1). Furthermore, since the respective flow rates of refrigerant flowing into the indoor heat exchangers (22a, 22b, 22c) can be controlled by the respective flow control valves (61a, 61b, 61c), each indoor heat exchanger (22a, 22b, 22c) can be individually controlled in terms of the cooling capacity and heating capacity. In this case, since the liquid refrigerant separated in the gas-liquid separator (51) can be sent to each indoor heat exchanger (22a, 22b, 22c), its flow rate can be more easily controlled in each flow control valve (61a, 61b, 61c) as compared with those of refrigerants in two-phase form and gas form.

[0359] Because multi-type air conditioners are generally likely to have a long connection pipe between each of the indoor heat exchangers (22a, 22b, 22c) and the outdoor heat exchanger (21), the flow of refrigerant in two-phase form through the connection pipe could be likely to increase the pressure loss of refrigerant and

sounds of refrigerant passing through the connection pipe could be likely to be noises. In contrast, since according to this modification the liquid refrigerant separated in the gas-liquid separator (51) can flow through the connection pipe, pressure loss and noises as mentioned above can be effectively reduced.

«Embodiment 13 of the Invention»

[0360] Next, a refrigeration system according to Embodiment 13 is described. The refrigeration system of Embodiment 13 is different in the configuration of the refrigerant circuit (10) from the refrigeration system of Embodiment 12. The following description is given of different points from Embodiment 12.

[0361] As shown in Figure 23, like Embodiment 12, the refrigerant circuit (10) includes a compressor (11), an expander (12), an outdoor heat exchanger (21), an indoor heat exchanger (22), a gas-liquid separator (51), a first four-way selector valve (31) and a second four-way selector valve (33) which are connected therein.

[0362] Unlike Embodiment 12, in the gas-liquid separator (51) in Embodiment 13, one end of the heat transfer tube (50) is connected to the inlet side of the expander and the other end is connected via a liquid inflow pipe (56) to the second four-way selector valve (33). The liquid inflow pipe (56) is provided with a first solenoid shut-off valve (34) selectively allowing or inhibiting the flow of refrigerant through the heat transfer tube (50). Furthermore, one end of a bypass pipe (57) is connected to the liquid inflow pipe (56) between the first solenoid shut-off valve (34) and the second four-way selector valve (33). The other end of the bypass pipe (57) is connected to the inlet side of the expander (12). In other words, the bypass pipe (57) is a pipe for allowing refrigerant to bypass the heat transfer tube (50) and to be introduced into the expander (12). Furthermore, the bypass pipe (57) is provided with a second solenoid shut-off valve (35) selectively allowing or inhibiting the flow of refrigerant through the bypass pipe (57). With the configuration as described so far, the bypass pipe (57) and the first and second solenoid shut-off valves (34, 35) constitute a heat exchange control mechanism (60) for changing the amount of heat exchange of refrigerant in the heat transfer tube (50) and allows heat exchange of refrigerant in the heat transfer tube (50) only during the cooling operation of the air conditioner (1).

[0363] Furthermore, unlike Embodiment 12, the first four-way selector valve (31) has the first port (P1) connected to the discharge side of the compressor (11), the second port (P2) connected to one end of the outdoor heat exchanger (21), the third port (P3) connected to the suction side of the compressor (11) and the fourth port (P4) connected to one end of the indoor heat exchanger (22). The second four-way selector valve (33) has the first port (P1) connected via the separated liquid pipe (54) to the liquid storage section (52) of the gas-liquid separator (51), the second port (P2) connected to the

other end of the outdoor heat exchanger (21), the third port (P3) connected via the liquid inflow pipe (56) to the heat transfer tube (50) of the gas-liquid separator (51) and the fourth port (P4) connected to the other end of the indoor heat exchanger (22).

[0364] Each of the first and second four-way selector valves (31, 33) is configured, like Embodiment 12, to be switchable between the first position and the second position. Furthermore, the first and second four-way selector valves (31, 33) constitute a refrigerant switching mechanism for switching the circulation direction of refrigerant to selectively provide either the cooling operation or the heating operation.

- Operational Behavior -

[0365] Next, a description is given of the behaviors of the air conditioner (1) according to Embodiment 13 during cooling and heating operations.

(Cooling Operation)

[0366] In the cooling operation, the first four-way selector valve (31) and the second four-way selector valve (33) are selected to the first position and the second position, respectively, as shown in Figure 24. Furthermore, the first solenoid shut-off valve (34) is turned open and the second solenoid shut-off valve (35) is turned closed. When the motor (13) is turned on in this state, refrigerant circulates through the refrigerant circuit (10), whereby the refrigerant circuit (10) operates in a refrigeration cycle. During this operation, the outdoor heat exchanger (21) serves as a gas cooler and the indoor heat exchanger (22) serves as an evaporator. The high-side pressure of the refrigeration cycle is set higher than the critical pressure of carbon dioxide which is the refrigerant.

[0367] The compressor (11) discharges supercritical high-pressure refrigerant. The high-pressure refrigerant flows through the first four-way selector valve (31) and into the outdoor heat exchanger (21). In the outdoor heat exchanger (21), the high-pressure refrigerant releases heat to outdoor air.

[0368] The high-pressure refrigerant having released heat in the outdoor heat exchanger (21) passes through the second four-way selector valve (33) and the liquid inflow pipe (56) and then flows through the heat transfer tube (50). During the flowing through the heat transfer tube (50), the high-pressure refrigerant is cooled by heat exchange with liquid refrigerant stored in the liquid storage section (52) of the gas-liquid separator (51). The high-pressure refrigerant after flowing out of the heat transfer tube (50) flows into the expander (12). In the expander (12), the high-pressure refrigerant expands, whereby the internal energy of the high-pressure refrigerant is converted into power of rotation for the compressor (11). Because of expansion in the expander (12), the high-pressure refrigerant decreases its pressure to change from supercritical to gas-liquid two-phase form.

[0369] The low-pressure refrigerant obtained by pressure reduction in the expander (12) flows into the container of the gas-liquid separator (51). In the gas-liquid separator (51), the low-pressure refrigerant in gas-liquid two-phase form is separated into a liquid refrigerant and a gas refrigerant. The low-pressure liquid refrigerant stored in the liquid storage section (52) is heated by heat exchange with the high-pressure refrigerant flowing through the heat transfer tube (50). On the other hand, the low-pressure gas refrigerant stored in the gas storage section (53) flows through the separated gas pipe (55) back to the suction side of the compressor (11) by opening the gas control valve (38) to an appropriate opening at appropriate times.

[0370] The low-pressure liquid refrigerant in the liquid storage section (52) passes through the separated liquid pipe (54) and the second four-way selector valve (33) and then flows into the indoor heat exchanger (22). In the indoor heat exchanger (22), the low-pressure refrigerant takes heat from room air to evaporate. Then, the room air cooled by the low-pressure refrigerant is fed to the room. The low-pressure refrigerant evaporated in the indoor heat exchanger (22) passes through the first four-way selector valve (31) and is then sucked into the compressor (11).

(Heating Operation)

[0371] In the heating operation, the first four-way selector valve (31) and the second four-way selector valve (33) are selected to the second position and the first position, respectively, as shown in Figure 25. Furthermore, the first solenoid shut-off valve (34) is turned closed and the second solenoid shut-off valve (35) is turned open. When the motor (13) is turned on in this state, refrigerant circulates through the refrigerant circuit (10), whereby the refrigerant circuit (10) operates in a refrigeration cycle. During this operation, the indoor heat exchanger (22) serves as a gas cooler and the outdoor heat exchanger (21) serves as an evaporator. The high-side pressure of the refrigeration cycle, like in the cooling operation, is set higher than the critical pressure of carbon dioxide which is the refrigerant.

[0372] The compressor (11) discharges supercritical high-pressure refrigerant. The high-pressure refrigerant flows through the first four-way selector valve (31) and into the indoor heat exchanger (22). In the indoor heat exchanger (22), the high-pressure refrigerant releases heat to room air. Then, the room air heated by the high-pressure refrigerant is fed to the room.

[0373] The high-pressure refrigerant having released heat in the indoor heat exchanger (22) passes through the second four-way selector valve (33) and the bypass pipe (57) and then flows into the expander (12). In the expander (12), the high-pressure refrigerant expands, whereby the internal energy of the high-pressure refrigerant is converted into power of rotation for the compressor (11). Because of expansion in the expander (12), the

high-pressure refrigerant decreases its pressure to change from supercritical to gas-liquid two-phase form.

[0374] The low-pressure refrigerant obtained by pressure reduction in the expander (12) flows into the container of the gas-liquid separator (51). In the gas-liquid separator (51), the low-pressure refrigerant in gas-liquid two-phase form is separated into a liquid refrigerant and a gas refrigerant. In this case, refrigerant does not flow through the heat transfer tube (50). Therefore, the liquid refrigerant in the liquid storage section (52) does not exchange heat.

[0375] The low-pressure liquid refrigerant in the liquid storage section (52) passes through the separated liquid pipe (54) and the second four-way selector valve (33) and then flows into the outdoor heat exchanger (21). In the outdoor heat exchanger (21), the low-pressure refrigerant takes heat from outdoor air to evaporate. The low-pressure refrigerant evaporated in the outdoor heat exchanger (21) flows through the first four-way selector valve (31) and is then sucked into the compressor (11).

- Effects of Embodiment 13 -

[0376] In Embodiment 13, the refrigeration system is configured to allow heat exchange of refrigerant in the heat transfer tube (50) only during the cooling operation by position change of the first and second solenoid shut-off valves (34, 35). Therefore, during the cooling operation, the density ρ of refrigerant flowing into the expander (12) is increased. As a result, the refrigerant mass flow rates ($\dot{m}_c$ and $\dot{m}_e$) through the compressor (11) and the expander (12) can be balanced, whereby the refrigeration system can operate in a desired refrigeration cycle.

<Modification of Embodiment 13>

[0377] Next, a description is given of a refrigeration system according to a modification of Embodiment 13. In the refrigeration system of the modification, first and second motor-operated valves (36, 37) are provided in place of the first and second solenoid shut-off valves (34, 35) in Embodiment 13. The following description is given of different points from Embodiment 13.

[0378] As shown in Figure 26, in the refrigerant circuit (10) of this modification, the liquid inflow pipe (56) is provided with a first motor-operated valve (36) having a variable opening. The first motor-operated valve (36) is configured to be capable of controlling the flow rate of refrigerant flowing through the heat transfer tube (50). The bypass pipe (57) is provided with a second motor-operated valve (37) having a variable opening. The second motor-operated valve (37) is configured to be capable of controlling the flow rate of refrigerant flowing through the bypass pipe (57). Furthermore, the bypass pipe (57) and the first and second motor-operated valves (36, 37) constitute a heat exchange control mechanism (60) for changing the amount of heat exchange of refrigerant in the heat transfer tube (50).

[0379] According to this modification, the flow rate of refrigerant flowing through the heat transfer tube (50) can be controlled to control the amount of heat exchange of refrigerant in the heat transfer tube (50) by controlling the openings of the first and second motor-operated valves (36, 37). Therefore, the refrigerant mass flow rates ($\dot{m}_e$ and $\dot{m}_c$) through the compressor (11) and the expander (12) can be balanced with high accuracy according to the operating conditions.

[0380] Furthermore, the refrigeration system according to this modification enables, only during the cooling operation, refrigerant to flow through the heat transfer tube (50) and exchange heat therein by fully opening the first motor-operated valve (36) and concurrently fully closing the second motor-operated valve (37).

«Embodiment 14 of the Invention»

[0381] Next, a refrigeration system according to Embodiment 14 is described. The refrigeration system of Embodiment 14 is different in the configuration of the refrigerant circuit (10) from the refrigeration system of Embodiment 12. The following description is given of different points from Embodiment 12.

[0382] As shown in Figure 27, the refrigerant circuit (10) in Embodiment 14 is provided with a four-way selector valve (31) similar to the first four-way selector valve in Embodiment 12 but, unlike Embodiment 12, not provided with the second four-way selector valve (32). The four-way selector valve (31) constitutes a refrigerant switching mechanism for switching the circulation direction of refrigerant to selectively provide either the cooling operation or the heating operation.

[0383] In this embodiment, the outdoor heat exchanger (21) and the indoor heat exchanger (22) are connected to each other by a first pipe (71). The first pipe (71) is provided with a first check valve (81) located towards the outdoor heat exchanger (21) and a second check valve (82) located towards the indoor heat exchanger (22). One end of the liquid inflow pipe (56) is connected to the first pipe (71) between the outdoor heat exchanger (21) and the first check valve (81). The other end of the liquid inflow pipe (56) is connected to one end of the heat transfer tube (50). The other end of the heat transfer tube (50) is connected to the inlet side of the expander (12). Furthermore, the liquid inflow pipe (56) is provided with a third check valve (83).

[0384] The separated liquid pipe (54) in this embodiment is connected at one end thereof to the liquid storage section (52) of the gas-liquid separator (51) and connected at the other end to the first pipe (71) between the first check valve (81) and the second check valve (82). Furthermore, one end of a second pipe (72) is connected to the first pipe (71) between the second check valve (82) and the indoor heat exchanger (22). The other end of the second pipe (72) is connected to a pipe connecting between the inlet side of the expander (12) and the gas-liquid separator (51). The second pipe (72) is provided

with a fourth check valve (84).

[0385] The first check valve (81) allows only the flow of refrigerant from a connecting point of the first pipe (71) with the separated liquid pipe (54) towards a connecting point thereof with the liquid inflow pipe (56). The second check valve (82) allows only the flow of refrigerant from the connecting point of the first pipe (71) with the separated liquid pipe (54) towards a connecting point thereof with the second pipe (72). The third check valve (83) allows only the flow of refrigerant from the first pipe (71) towards the heat transfer tube (50). The fourth check valve (84) allows only the flow of refrigerant from the first pipe (71) towards the inlet side of the expander (12).

[0386] Thus, since the refrigerant circuit (10) in this embodiment includes a sub-circuit formed by connecting the first pipe (71), the second pipe (72), the liquid inflow pipe (56) and the heat transfer pipe (50) and provided with the check valves (81, 82, 83, 84), the sub-circuit constitutes a circuit resembling a so-called bridge circuit. Furthermore, the sub-circuit constitutes a heat exchange control mechanism (60) for changing the amount of heat exchange of refrigerant in the heat transfer tube (50) and allows heat exchange of refrigerant in the heat transfer tube (50) only during the cooling operation of the air conditioner (1).

- Operational Behavior -

[0387] Next, a description is given of the behaviors of the air conditioner (1) according to Embodiment 14 during cooling and heating operations.

(Cooling Operation)

[0388] In the cooling operation, the four-way selector valve (31) is selected to the first position as shown in Figure 28. When the motor (13) is turned on in this state, refrigerant circulates through the refrigerant circuit (10), whereby the refrigerant circuit (10) operates in a refrigeration cycle. During this operation, the outdoor heat exchanger (21) serves as a gas cooler and the indoor heat exchanger (22) serves as an evaporator. The high-side pressure of the refrigeration cycle is set higher than the critical pressure of carbon dioxide which is the refrigerant.

[0389] The compressor (11) discharges supercritical high-pressure refrigerant. The high-pressure refrigerant flows through the four-way selector valve (31) and into the outdoor heat exchanger (21). In the outdoor heat exchanger (21), the high-pressure refrigerant releases heat to outdoor air.

[0390] The high-pressure refrigerant having released heat in the outdoor heat exchanger (21) passes through the third check valve (83) in the liquid inflow pipe (56) and then flows through the heat transfer tube (50). During the flowing through the heat transfer tube (50), the high-pressure refrigerant is cooled by heat exchange with liquid refrigerant stored in the liquid storage section (52) of the gas-liquid separator (51). The high-pressure refrigerant

after flowing out of the heat transfer tube (50) flows into the expander (12). In the expander (12), the high-pressure refrigerant expands, whereby the internal energy of the high-pressure refrigerant is converted into power of rotation for the compressor (11). Because of expansion in the expander (12), the high-pressure refrigerant decreases its pressure to change from supercritical to gas-liquid two-phase form.

[0391] The low-pressure refrigerant obtained by pressure reduction in the expander (12) flows into the container of the gas-liquid separator (51). Then, the low-pressure refrigerant in gas-liquid two-phase form is separated into a liquid refrigerant and a gas refrigerant. The low-pressure liquid refrigerant stored in the liquid storage section (52) is heated by heat exchange with the high-pressure refrigerant flowing through the heat transfer tube (50). On the other hand, the low-pressure gas refrigerant stored in the gas storage section (53) flows through the separated gas pipe (55) back to the suction side of the compressor (11) by opening the gas control valve (38) to an appropriate opening at appropriate times.

[0392] The low-pressure liquid refrigerant in the liquid storage section (52) passes through the separated liquid pipe (54) and the second check valve (82) in the first pipe (71) and then flows into the indoor heat exchanger (22). In the indoor heat exchanger (22), the low-pressure refrigerant takes heat from room air to evaporate. Then, the room air cooled by the low-pressure refrigerant is fed to the room. The low-pressure refrigerant evaporated in the indoor heat exchanger (22) passes through the four-way selector valve (31) and is then sucked into the compressor (11).

(Heating Operation)

[0393] In the heating operation, the four-way selector valve (31) is selected to the second position as shown in Figure 29. When the motor (13) is turned on in this state, refrigerant circulates through the refrigerant circuit (10), whereby the refrigerant circuit (10) operates in a refrigeration cycle. During this operation, the indoor heat exchanger (22) serves as a gas cooler and the outdoor heat exchanger (21) serves as an evaporator. The high-side pressure of the refrigeration cycle, like in the cooling operation, is set higher than the critical pressure of carbon dioxide which is the refrigerant.

[0394] The compressor (11) discharges supercritical high-pressure refrigerant. The high-pressure refrigerant flows through the four-way selector valve (31) and into the indoor heat exchanger (22). In the indoor heat exchanger (22), the high-pressure refrigerant releases heat to room air. Then, the room air heated by the high-pressure refrigerant is fed to the room.

[0395] The high-pressure refrigerant having released heat in the indoor heat exchanger (22) passes through the first pipe (71) and the fourth check valve (84) in the second pipe (72) and then flows into the expander (12). In the expander (12), the high-pressure refrigerant ex-

pands, whereby the internal energy of the high-pressure refrigerant is converted into power of rotation for the compressor (11). Because of expansion in the expander (12), the high-pressure refrigerant decreases its pressure to change from supercritical to gas-liquid two-phase form.

[0396] The low-pressure refrigerant obtained by pressure reduction in the expander (12) flows into the container of the gas-liquid separator (51). In the gas-liquid separator (51), the low-pressure refrigerant in gas-liquid two-phase form is separated into a liquid refrigerant and a gas refrigerant. In this case, refrigerant does not flow through the heat transfer tube (50). Therefore, the liquid refrigerant in the liquid storage section (52) hardly exchanges heat.

[0397] The low-pressure liquid refrigerant in the liquid storage section (52) passes through the separated liquid pipe (54) and the first check valve (81) in the first pipe (71) and then flows into the outdoor heat exchanger (21). In the outdoor heat exchanger (21), the low-pressure refrigerant takes heat from outdoor air to evaporate. The low-pressure refrigerant evaporated in the outdoor heat exchanger (21) flows through the four-way selector valve (31) and is then sucked into the compressor (11).

- Effects of Embodiment 14 -

[0398] According to Embodiment 14, heat exchange of refrigerant in the heat transfer tube (50) can be made only during the cooling operation through a combination of the particular pipe lines and the check valves (81, 82, 83, 84). Therefore, during the cooling operation, the density of refrigerant flowing into the expander (12) is increased. As a result, the refrigerant mass flow rates (M_c and M_e) through the compressor (11) and the expander (12) can be balanced, whereby the refrigeration system can operate in a desired refrigeration cycle.

[0399] According to this embodiment, heat exchange of refrigerant in the heat transfer tube (50) can be selectively executed or not according to the switching between the cooling operation and the heating operation simply by position change control over the four-way selector valve (31). This provides an easy control operation of the refrigerant circuit (10).

«Other Embodiments»

[0400] The above embodiments of the present invention may have the following configurations.

[0401] For example, although the first to eleventh embodiments describe examples in which an internal heat exchanger (23) is provided as a temperature controller that can control the temperature of refrigerant flowing towards the expander (12), the temperature controller may be any device for controlling the refrigerant temperature other than the internal heat exchanger (23).

[0402] Furthermore, the temperature controller is not limited to those by which the capacity to cool refrigerant flowing towards the expander (12) during the cooling op-

eration is different from that during the heating operation. For example, the temperature controller may be configured to control the refrigerant temperature when the operating conditions of the refrigerant circuit (10) change.

[0403] In Embodiments 12 to 14, the refrigeration system is configured to send gas refrigerant separated in the gas-liquid separator (51) through the separated gas pipe (55) to the suction side of the compressor (11). Instead of or in addition to this, a liquid injection pipe may be provided for sending liquid refrigerant separated in the gas-liquid separator (51) to the suction side of the compressor (11).

[0404] Figure 30 indicates an example in which the refrigeration system of Embodiment 13 is provided with the above liquid injection pipe (second injection pipe) (59). The liquid injection pipe (59) is connected at one end thereof to a pipe connecting between the liquid storage section (52) and the second four-way selector valve (33) and connected at the other end to the suction pipe for the compressor (11). Furthermore, the liquid injection pipe (59) is provided with a liquid control valve (39) for controlling the flow rate of refrigerant through the liquid injection pipe (59).

[0405] With the above configuration, a so-called liquid injection can be made by sending liquid refrigerant separated in the gas-liquid separator (51) through the liquid injection pipe (59) to the suction side of the compressor (11). During the time, the refrigeration system can control the degree of superheat of refrigerant to be sucked into the compressor (11) by controlling the amount of liquid injection with the liquid control valve (39), thereby providing an optimum control over the refrigeration cycle. Furthermore, combination of gas injection using the gas injection pipe (55) and liquid injection using the liquid injection pipe (59) provides a finer-tuned control over the refrigeration cycle. Furthermore, the liquid injection pipe (59) can be used as a so-called oil return pipe for returning refrigerator oil contained in refrigerant flowing out of the expander (12), together with the liquid refrigerant separated in the gas-liquid separator (51), to the suction side of the compressor (11).

[0406] Furthermore, although in the above embodiments the compressor (11) and the expander (12) are constituted by rotary piston fluid machines, they are not limited to rotary piston fluid machines. For example, they may be constituted by positive displacement fluid machines, such as scroll type, swing type or multi-vane type, or may be constituted by a combination of a compressor and an expander of different two types selected from the above different types of positive displacement fluid machines (also including rotary piston type one).

[0407] Furthermore, although in the above embodiments carbon dioxide is used as refrigerant, the refrigerant used is not limited to this. For example, HFC refrigerant, HC refrigerant or natural refrigerant, such as water, air or ammonia, may be used.

Industrial Applicability

[0408] As seen from the above, the present invention is useful for a refrigeration system which includes a refrigerant circuit operating in a vapor compression refrigeration cycle and in which an expander constituting an expansion mechanism in the refrigerant circuit is mechanically connected to a compressor in the refrigerant circuit.

Claims

1. A refrigeration system including a refrigerant circuit (10) in which a compressor (11), a heat-source side heat exchanger (21), an expansion mechanism (12) and a utilization side heat exchanger (22) are connected to provide a vapor compression refrigeration cycle, the expansion mechanism (12) being constituted by an expander (12) for generating power by the expansion of refrigerant, the expander (12) being mechanically connected to the compressor (11), the refrigeration system further comprising a temperature controller (23) capable of controlling the temperature of refrigerant flowing towards the expander (12).
2. The refrigeration system of claim 1, wherein the refrigerant circuit (10) is configured to be capable of a heating operation in which refrigerant flowing through the utilization side heat exchanger (22) releases heat and a cooling operation in which refrigerant flowing through the utilization side heat exchanger (22) takes heat, and the temperature controller (23) is configured to have a higher capacity to cool refrigerant flowing towards the expander (12) during the cooling operation than during the heating operation.
3. The refrigeration system of claim 2, wherein the temperature controller (23) is constituted by an internal heat exchanger (23) in which, during the cooling operation, refrigerant after passing through the heat-source side heat exchanger (21) serving as a gas cooler is cooled by heat exchange with refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator.
4. The refrigeration system of claim 3, wherein the internal heat exchanger (23) is configured so that, during the cooling operation, a refrigerant channel (25) thereof through which refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator flows has a higher heat transfer capacity than a refrigerant channel (24) thereof through which refrigerant after passing through the heat-source side heat exchanger (21) serving as a gas cooler flows and that, during the

heating operation, the refrigerant channel (24) through which refrigerant before or after passing through the heat-source side heat exchanger (21) serving as an evaporator flows has a lower heat transfer capacity than the refrigerant channel (25) through which refrigerant after passing through the utilization side heat exchanger (22) serving as a gas cooler flows.

5. The refrigeration system of claim 4, wherein the internal heat exchanger (23) includes a heat transfer fin (26) provided on the refrigerant channel (25) through which, during the cooling operation, refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator flows and, during the heating operation, refrigerant after passing through the utilization side heat exchanger (22) serving as a gas cooler flows.
6. The refrigeration system of claim 3, wherein the internal heat exchanger (23) is configured so that, during the cooling operation, refrigerant before or after passing through the utilization side heat exchanger (22) serving as an evaporator and refrigerant after passing through the heat-source side heat exchanger (21) serving as a gas cooler flow therethrough in opposite directions to each other and that, during the heating operation, refrigerant before or after passing through the heat-source side heat exchanger (21) serving as an evaporator and refrigerant after passing through the utilization side heat exchanger (22) serving as a gas cooler flow therethrough in the same direction.
7. The refrigeration system of claim 3, wherein the internal heat exchanger (23) is constituted by a double-pipe heat exchanger including an inner channel (24) and an outer channel (25) disposed adjacent each other.
8. The refrigeration system of claim 3, wherein the internal heat exchanger (23) is constituted by a three-layered plate heat exchanger including an inner channel (24), a first outer channel (25A) disposed adjacent an outside of the inner channel (24) and a second outer channel (25B) disposed adjacent another outside of the inner channel (24).
9. A refrigeration system including a refrigerant circuit (10) in which a compressor (11), a heat-source side heat exchanger (21), an expansion mechanism (12) and a utilization side heat exchanger (22) are connected to provide a vapor compression refrigeration cycle, the refrigerant circuit (10) being configured to be capable of a heating operation in which refrigerant flowing through the utilization side heat exchanger (22) releases heat and a cooling operation in which refrigerant flowing through the utilization side heat

- exchanger (22) takes heat, the expansion mechanism (12) being constituted by an expander (12) for generating power by the expansion of refrigerant, the expander (12) being mechanically connected to the compressor (11), the refrigeration system further comprising
- a temperature controller (23) capable of controlling the temperature of high-pressure refrigerant flowing towards the expander (12),
- the temperature controller (23) being configured to cool the high-pressure refrigerant only during the cooling operation but stop the cooling of the high-pressure refrigerant during the heating operation.
10. The refrigeration system of claim 9, wherein the temperature controller (23) is constituted by an internal heat exchanger (23) in which during the cooling operation the high-pressure refrigerant is cooled by heat exchange with low-pressure refrigerant.
11. The refrigeration system of claim 10, wherein the internal heat exchanger (23) includes a first channel (27) and a second channel (28) and is configured to be capable of heat exchange between refrigerant flowing through the first channel (27) and refrigerant flowing through the second channel (28), and the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure refrigerant flows through the first channel (27) and low-pressure refrigerant flows through the second channel (28) and that, during the heating operation, high-pressure refrigerant flows through both the channels (27, 28).
12. The refrigeration system of claim 10, wherein the internal heat exchanger (23) includes a first channel (27) and a second channel (28) and is configured to be capable of heat exchange between refrigerant flowing through the first channel (27) and refrigerant flowing through the second channel (28), the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure refrigerant flows through the first channel (27) and low-pressure refrigerant flows through the second channel (28), and the refrigeration system further comprises a bypass passage (45) that, during the heating operation, allows high-pressure refrigerant to bypass the internal heat exchanger (23).
13. The refrigeration system of claim 10, wherein the internal heat exchanger (23) includes a first channel (27) and a second channel (28) and is configured to be capable of heat exchange between refrigerant flowing through the first channel (27) and refrigerant flowing through the second channel (28), the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure re-
- frigerant flows through the first channel (27) and low-pressure refrigerant flows through the second channel (28), and the refrigeration system further comprises a bypass passage (46) that, during the heating operation, allows low-pressure refrigerant to bypass the internal heat exchanger (23).
14. The refrigeration system of claim 10, wherein the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure refrigerant after passing through the heat-source side heat exchanger (21) is cooled therein by heat exchange with low-pressure refrigerant before passing through the utilization side heat exchanger (22).
15. The refrigeration system of claim 10, wherein the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure refrigerant after passing through the heat-source side heat exchanger (21) is cooled therein by heat exchange with low-pressure refrigerant after passing through the utilization side heat exchanger (22).
16. The refrigeration system of claim 10, wherein the internal heat exchanger (23) is configured so that, during the cooling operation, high-pressure refrigerant and low-pressure refrigerant flow therethrough in opposite directions to each other.
17. The refrigeration system of claim 9, wherein refrigerant in the refrigerant circuit (10) is carbon dioxide.
18. A refrigeration system including a refrigerant circuit (10) in which a compressor (11), a heat-source side heat exchanger (21), an expander (12) and a utilization side heat exchanger (22) are connected to provide a refrigeration cycle, the compressor (11) being mechanically connected to the expander (12) to recover expansion power from the expander (12), the refrigeration system further comprising a gas-liquid separator (51) for separating refrigerant expanded by the expander (12) into a liquid refrigerant and a gas refrigerant and temporarily storing the liquid and gas refrigerants, the gas-liquid separator (51) comprising an internal heat exchange part (50) for exchanging heat between the liquid refrigerant separated in the gas-liquid separator (51) and refrigerant to be introduced into the expander (12).
19. The refrigeration system of claim 18, further comprising a heat exchange control mechanism (60) for changing the amount of heat exchange of refrigerant in the internal heat exchange part (50) according to the operating conditions.
20. The refrigeration system of claim 19, wherein

the gas-liquid separator (51) further comprises a liquid storage section (52) for storing the separated liquid refrigerant and a heat transfer tube (50) which is disposed adjacent the liquid storage section (52) and through which the refrigerant to be introduced into the expander (12) flows, and the heat transfer tube (50) constitutes an internal heat exchange part for exchanging heat between the liquid refrigerant in the liquid storage section (52) and the refrigerant in the heat transfer tube (50).

21. The refrigeration system of claim 20, further comprising a refrigerant switching mechanism (31, 33) for switching the circulation direction of refrigerant in the refrigerant circuit (10) to selectively provide either the cooling operation or the heating operation, wherein the heat exchange control mechanism (60) allows heat exchange of refrigerant in the internal heat exchange part (50) only during the cooling operation.
22. The refrigeration system of claim 21, wherein the heat exchange control mechanism (60) is constituted by a bypass pipe (57) allowing refrigerant to bypass the heat transfer tube (50) and then flow into the expander (12), a first motor-operated valve (36) for controlling the flow rate of refrigerant flowing through the heat transfer tube (50), and a second motor-operated valve (37) for controlling the flow rate of refrigerant through the bypass pipe (57).
23. The refrigeration system of claim 21, wherein the heat exchange control mechanism (60) is constituted by a four-way selector valve (32).
24. The refrigeration system of claim 21, wherein the heat exchange control mechanism (60) is constituted by a bypass pipe (57) allowing refrigerant to bypass the heat transfer tube (50) and then flow into the expander (12), a first solenoid shut-off valve (34) selectively allowing or inhibiting the flow of refrigerant through the heat transfer tube (50), and a second solenoid shut-off valve (35) selectively allowing or inhibiting the flow of refrigerant through the bypass pipe (57).
25. The refrigeration system of claim 21, wherein the heat exchange control mechanism (60) is constituted by a combination of pipes and check valves (81, 82, 83, 84).
26. The refrigeration system of claim 18, wherein the refrigerant circuit (10) further includes a first injection pipe (55) for sending the gas refrigerant in the gas-liquid separator (51) to the suction side of the compressor (11) and a gas control valve (38) for controlling the flow rate of refrigerant through the first injection

pipe (55).

27. The refrigeration system of claim 18, wherein the refrigerant circuit (10) further includes a second injection pipe (59) for sending the liquid refrigerant in the gas-liquid separator (51) to the suction side of the compressor (11) and a liquid control valve (39) for controlling the flow rate of refrigerant through the second injection pipe (59).
28. The refrigeration system of claim 18, wherein a plurality of said utilization side heat exchangers (22a, 22b, 22c) are connected in parallel with each other in the refrigerant circuit (10), and the refrigeration system further comprises a plurality of flow control valves (61a, 61b, 61c) each for controlling the flow rate of refrigerant flowing into an associated one of the plurality of utilization side heat exchangers (22a, 22b, 22c).
29. The refrigeration system of claim 18, wherein carbon dioxide is used as the refrigerant in the refrigerant circuit (10).

FIG. 1

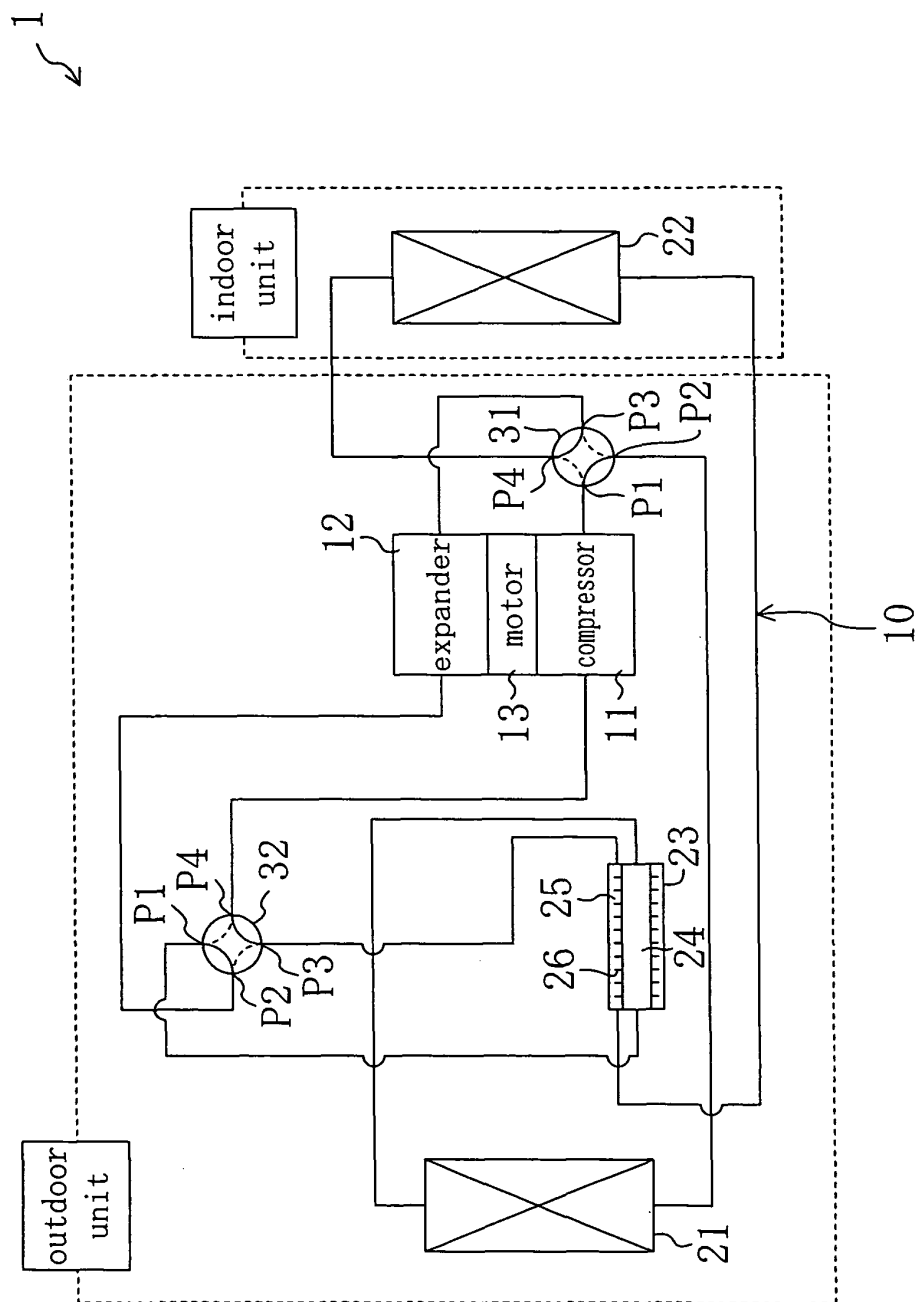


FIG. 2A

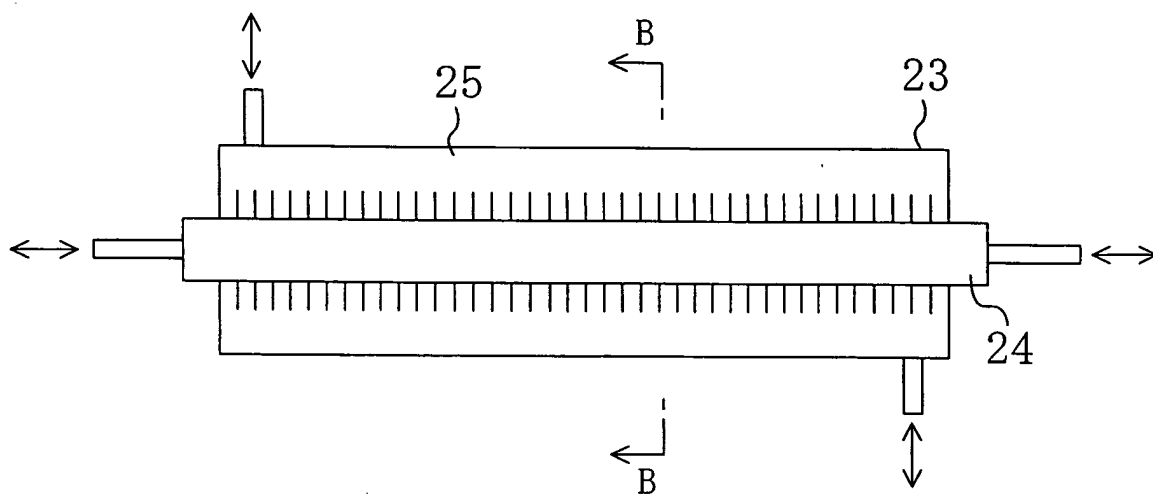


FIG. 2B

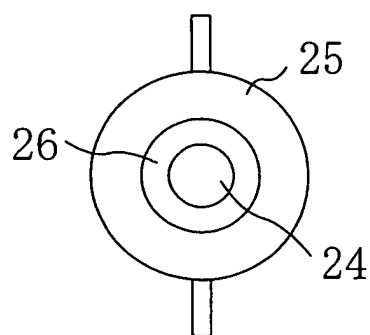


FIG. 3

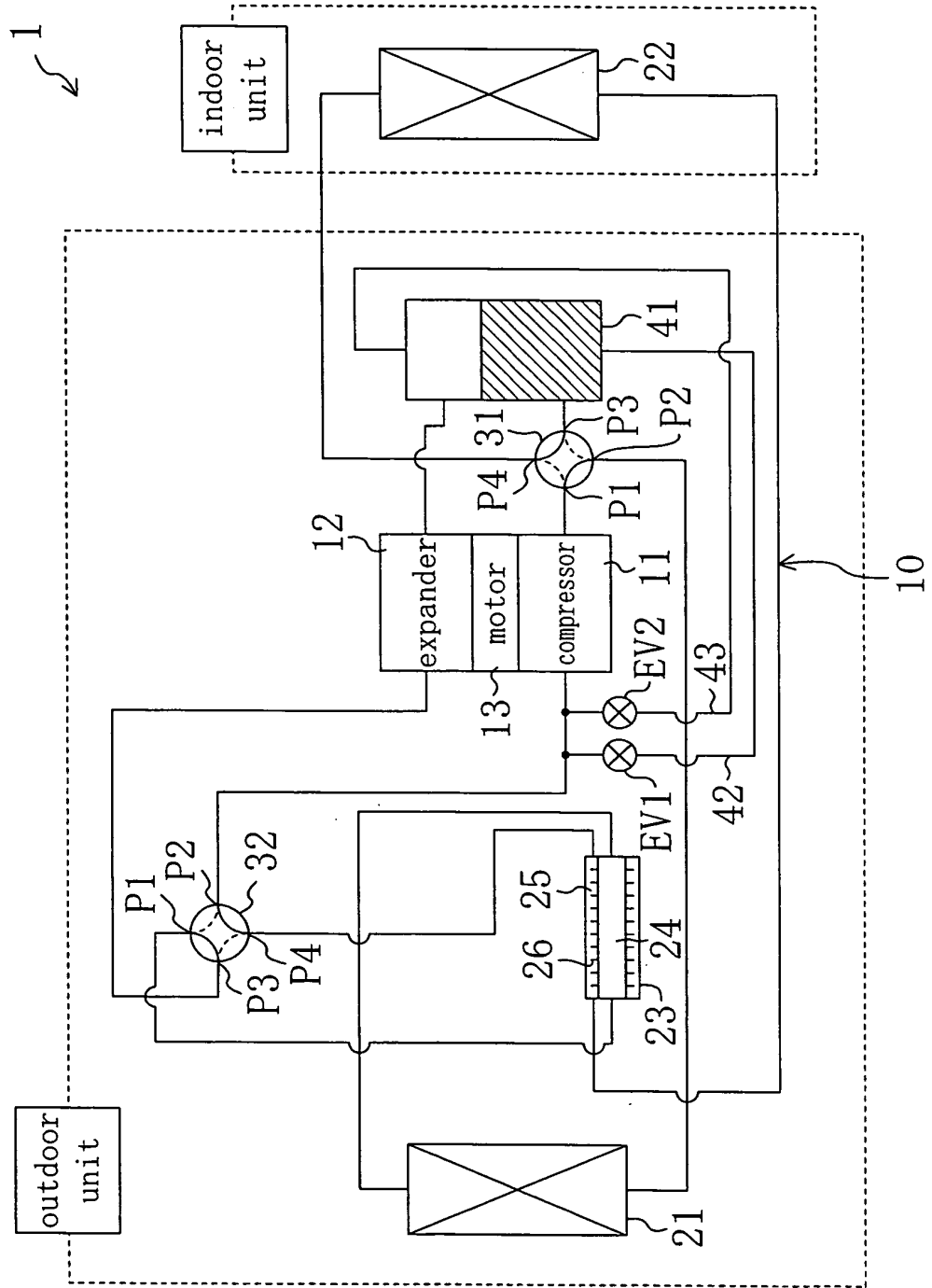


FIG. 4

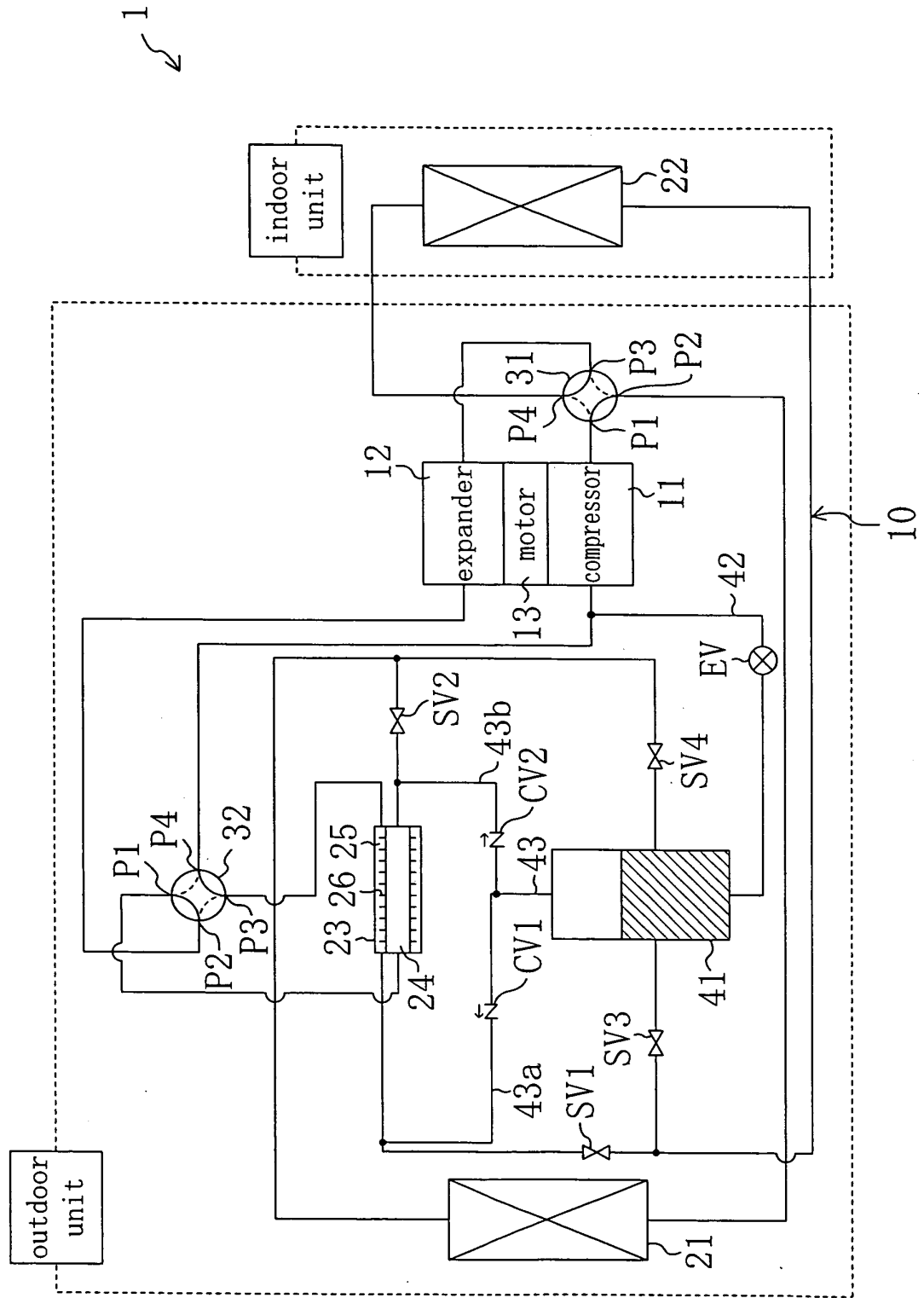


FIG. 5

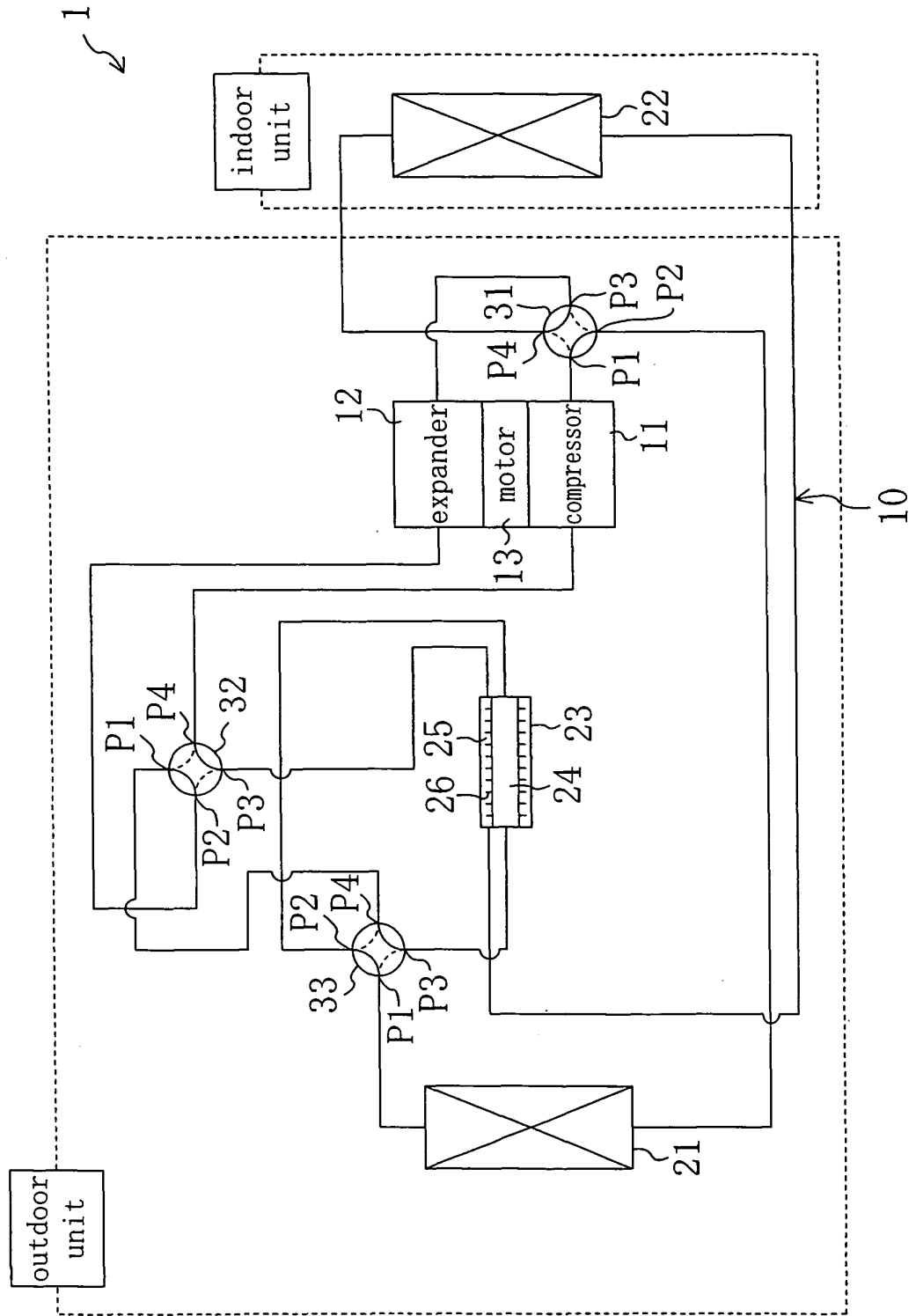


FIG. 6

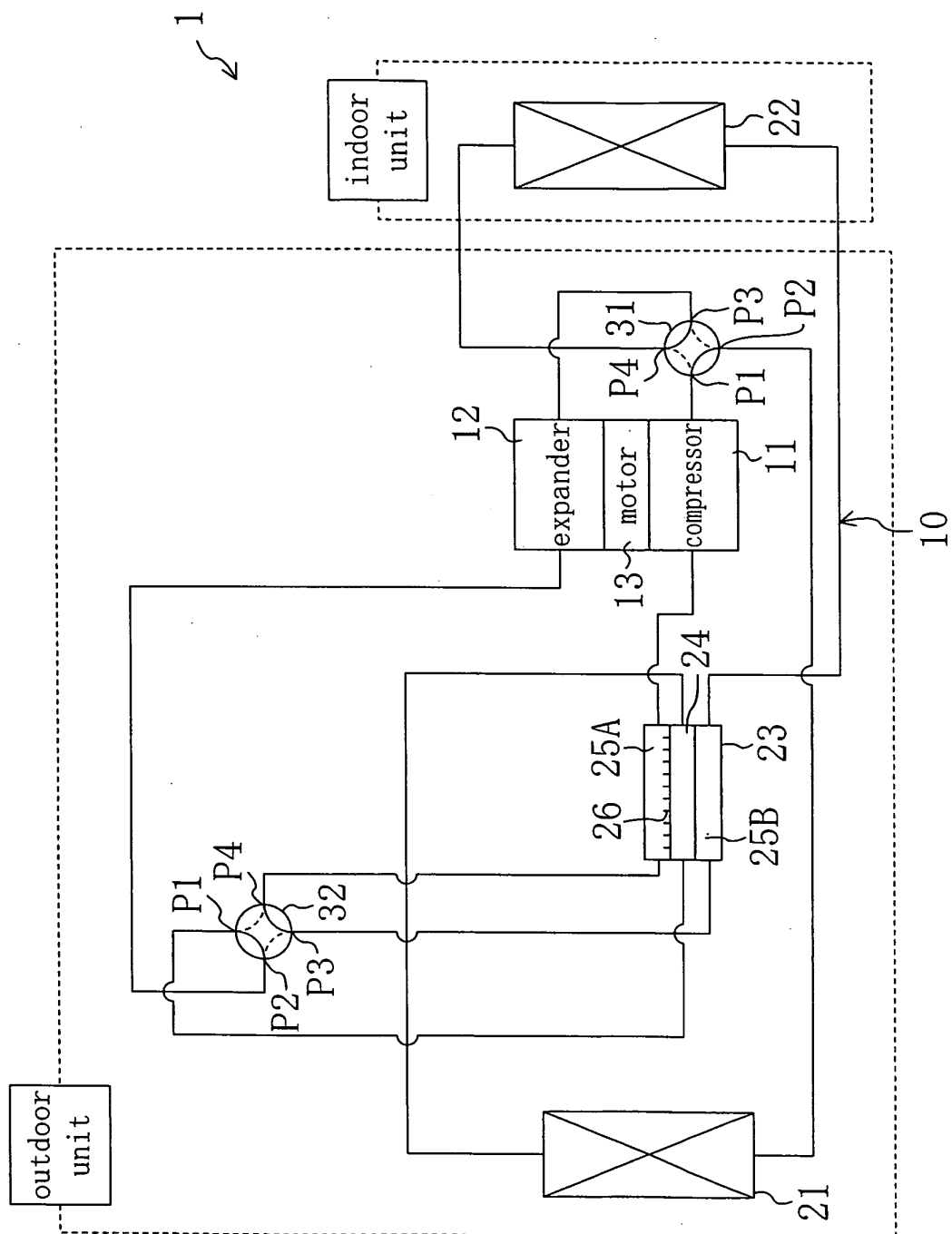


FIG. 7

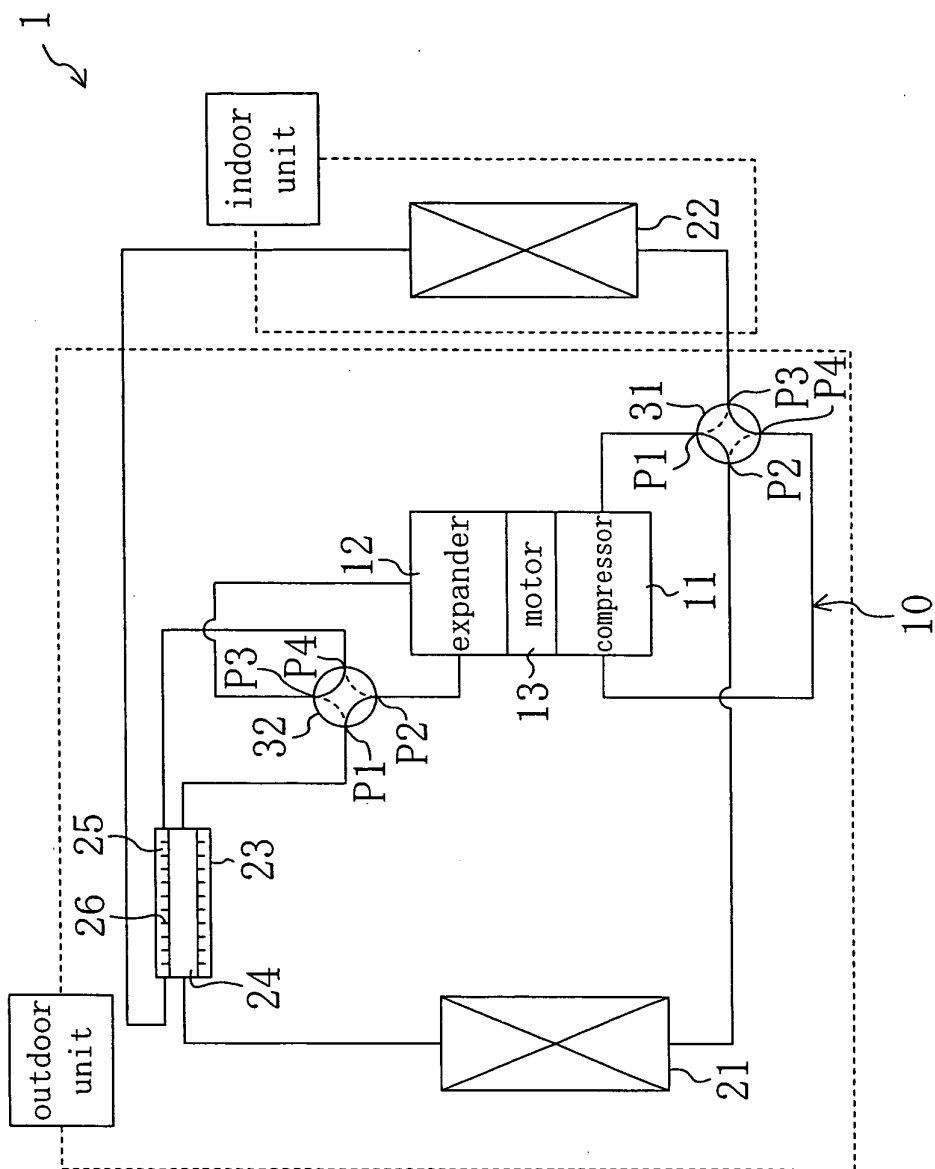


FIG. 8

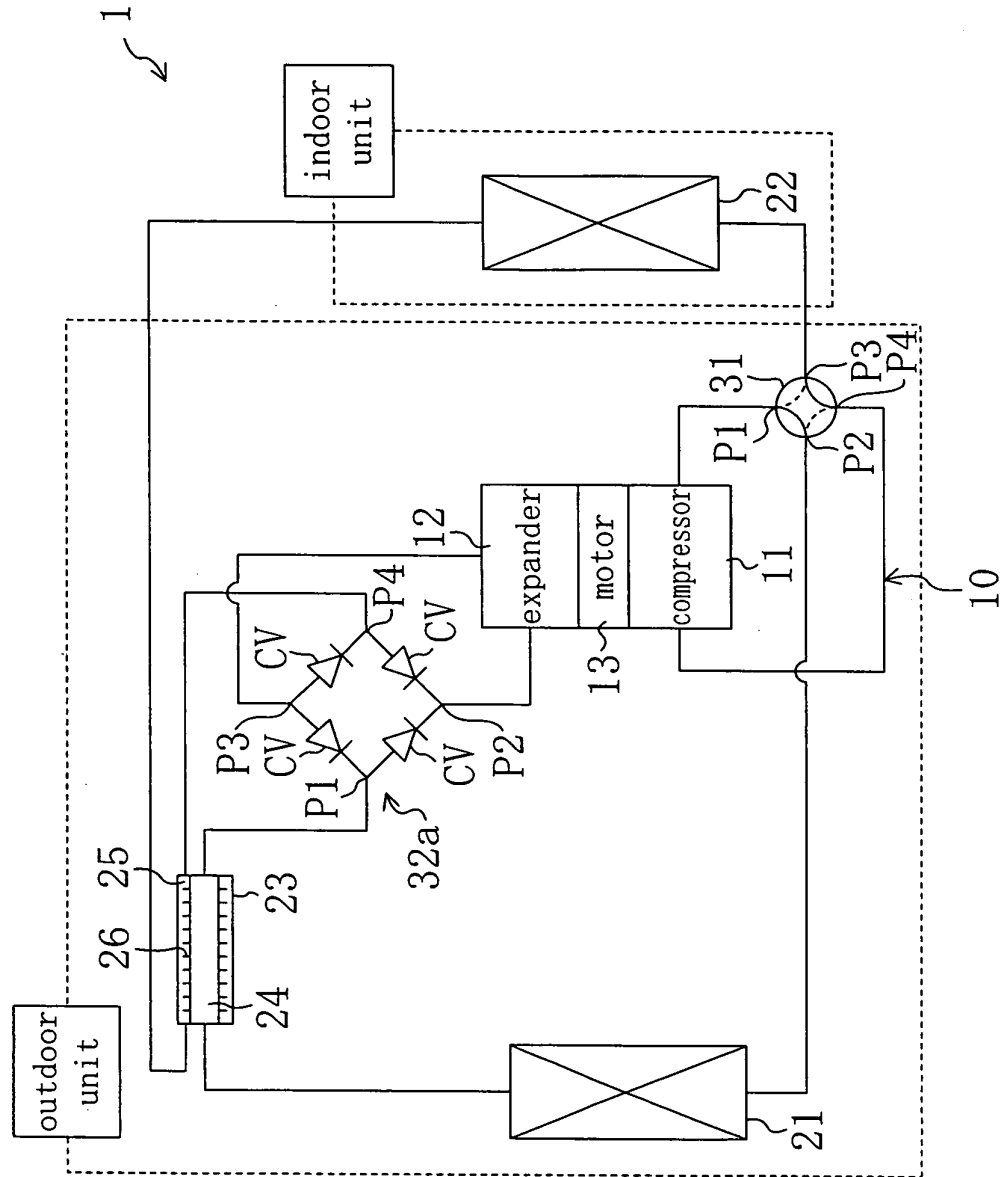


FIG. 9

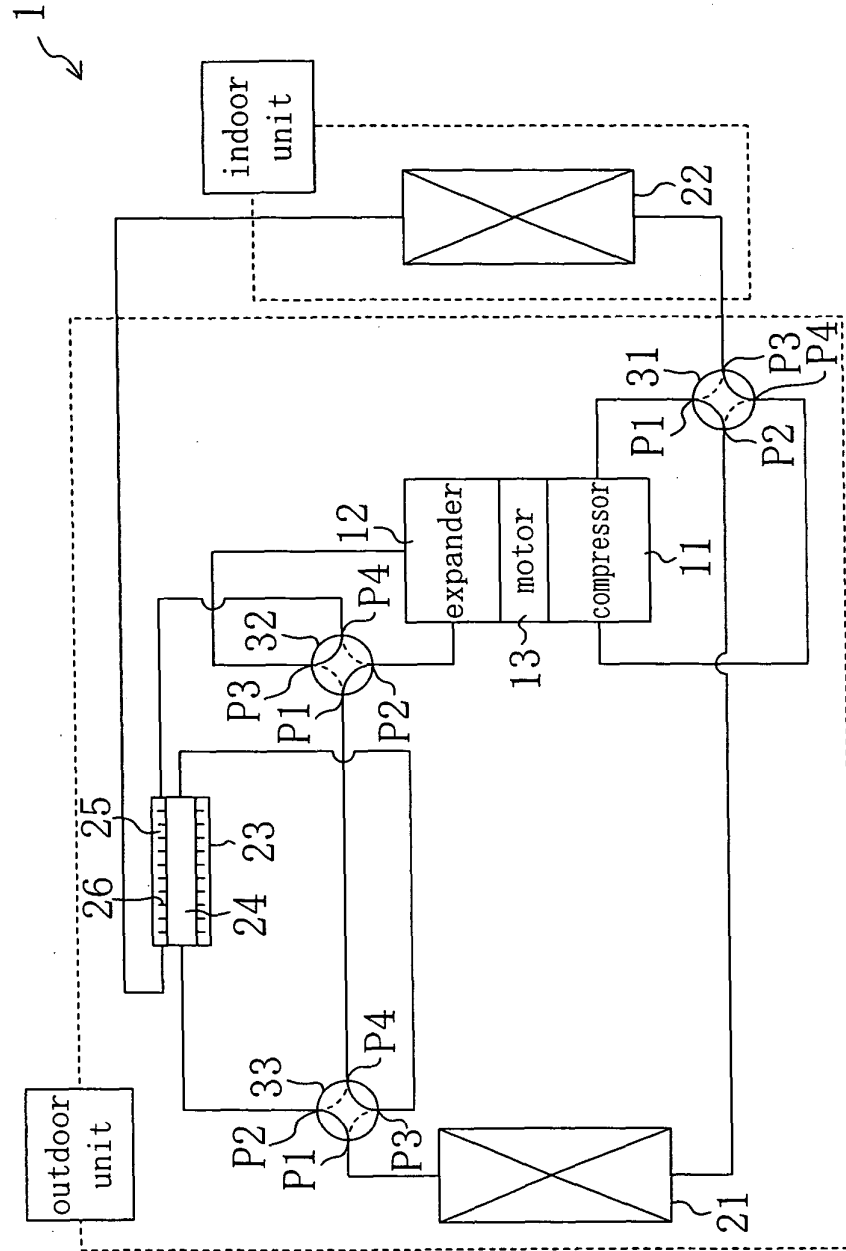


FIG. 10

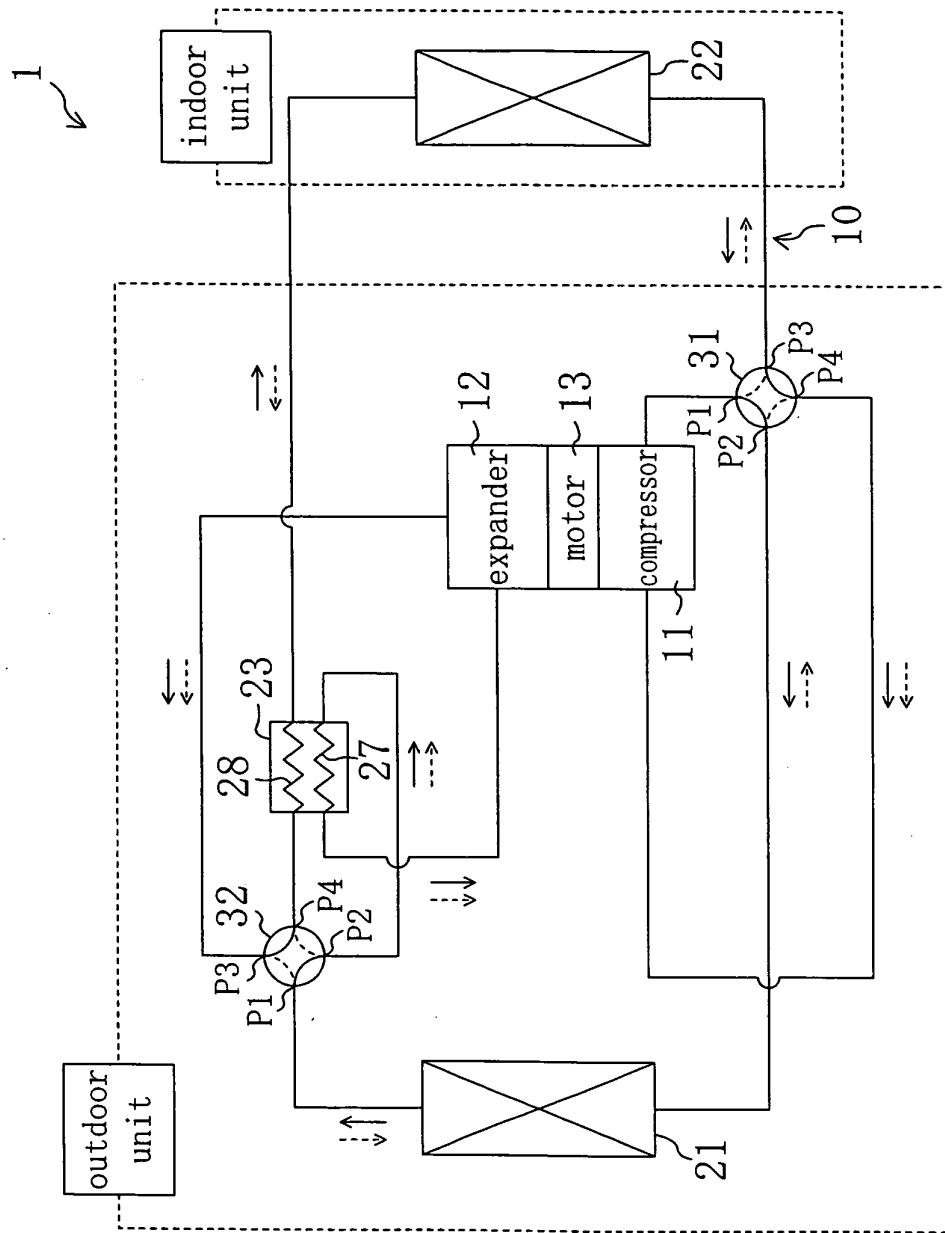


FIG. 11

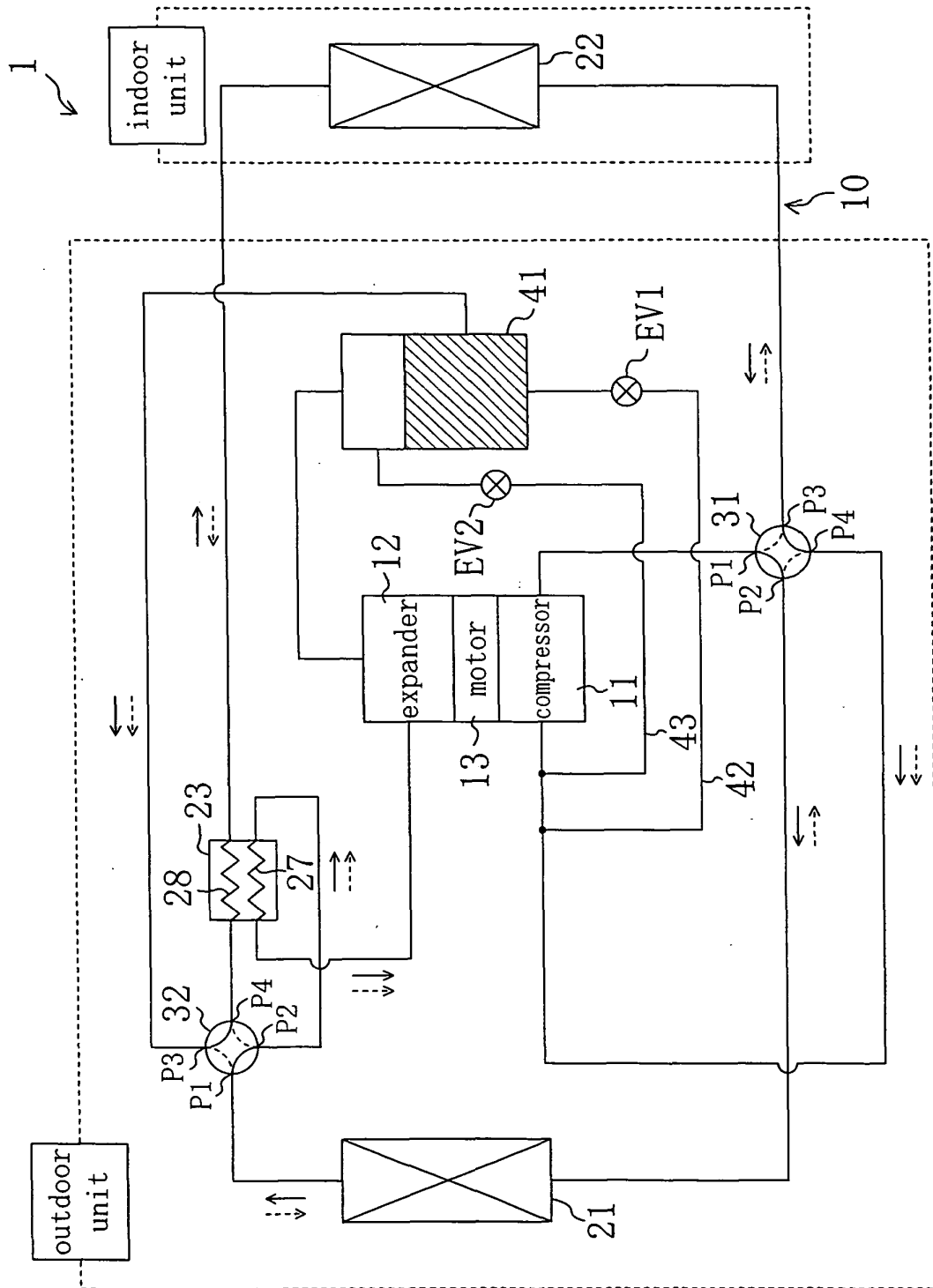


FIG. 12

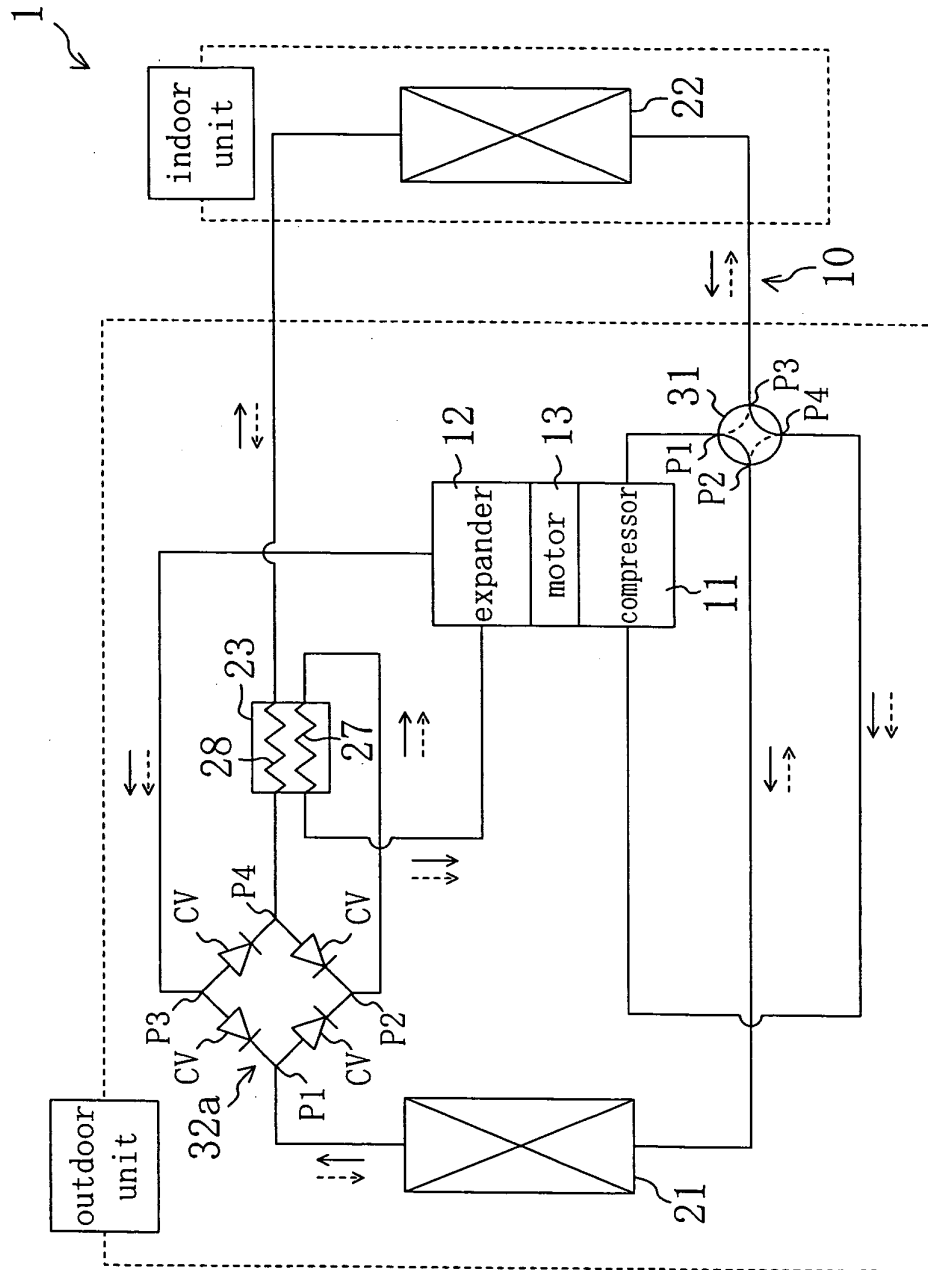


FIG. 13

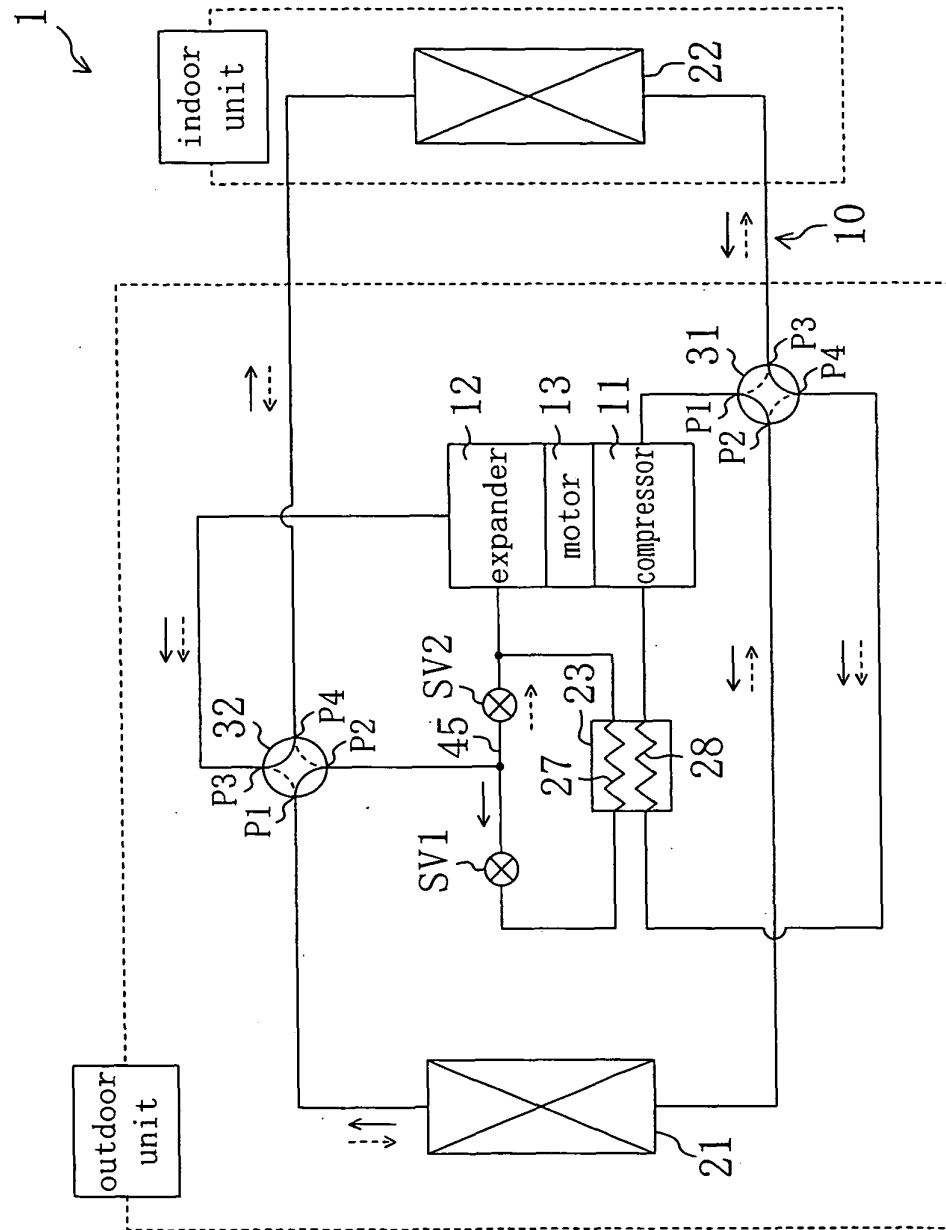


FIG. 14

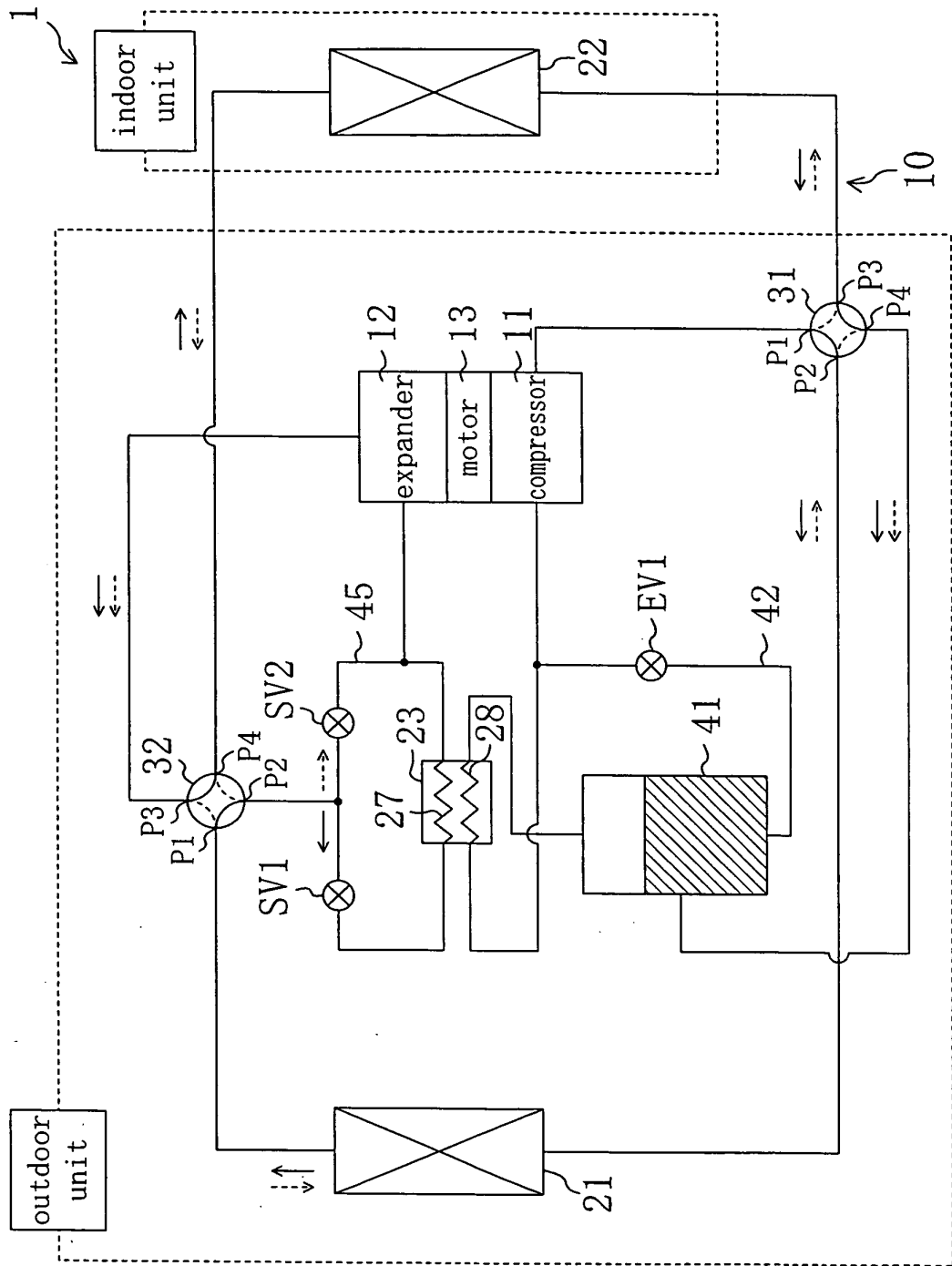


FIG. 15

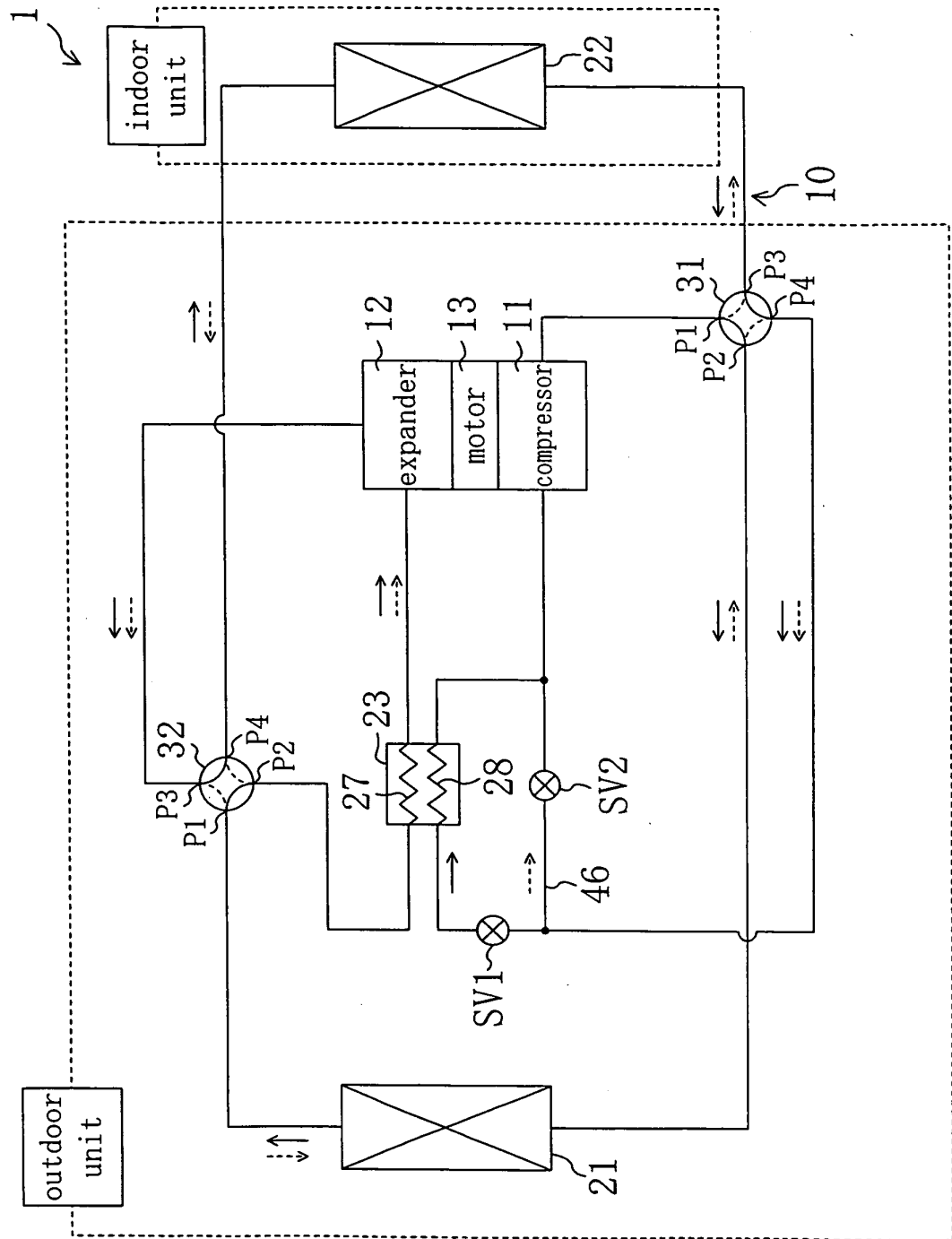


FIG. 16

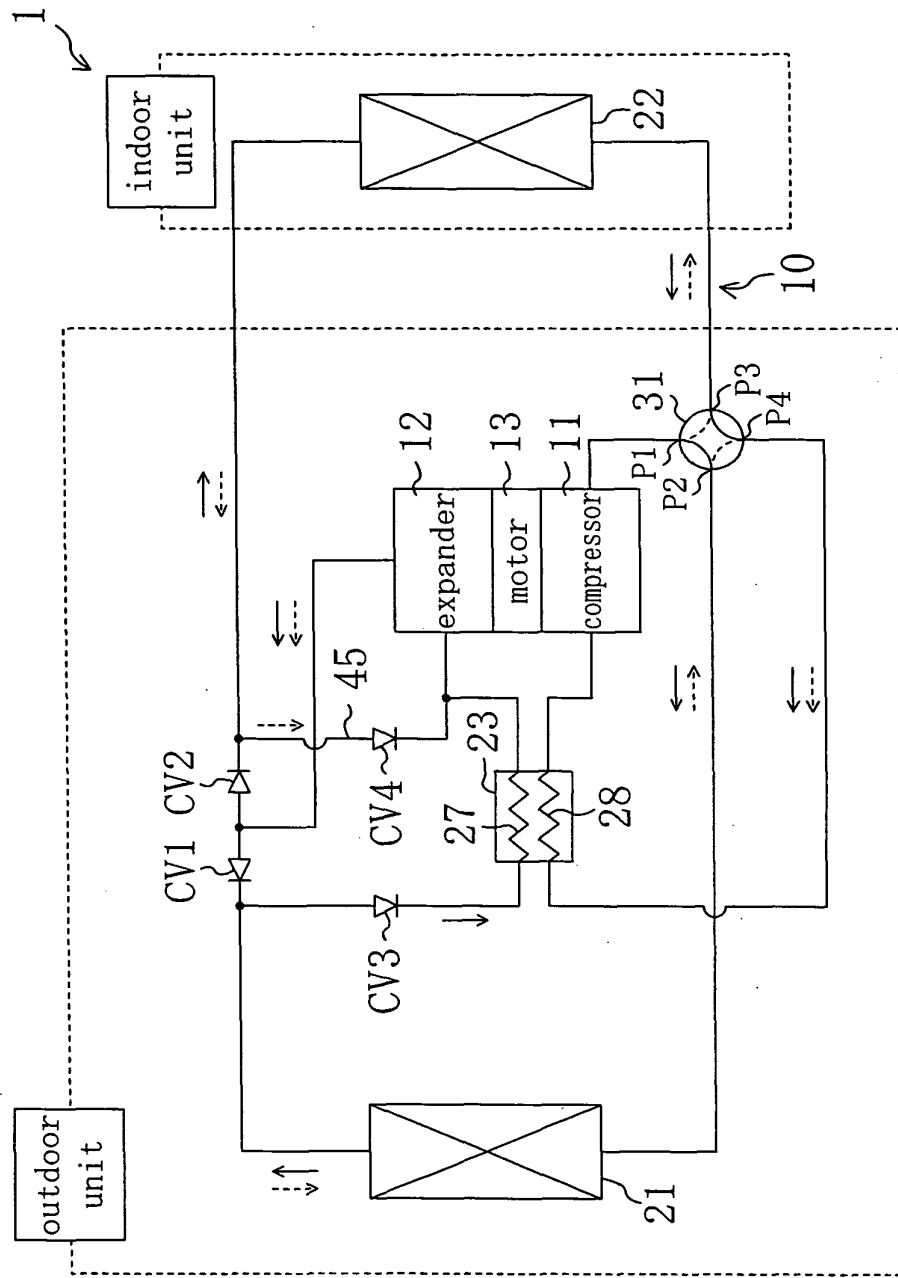


FIG. 17

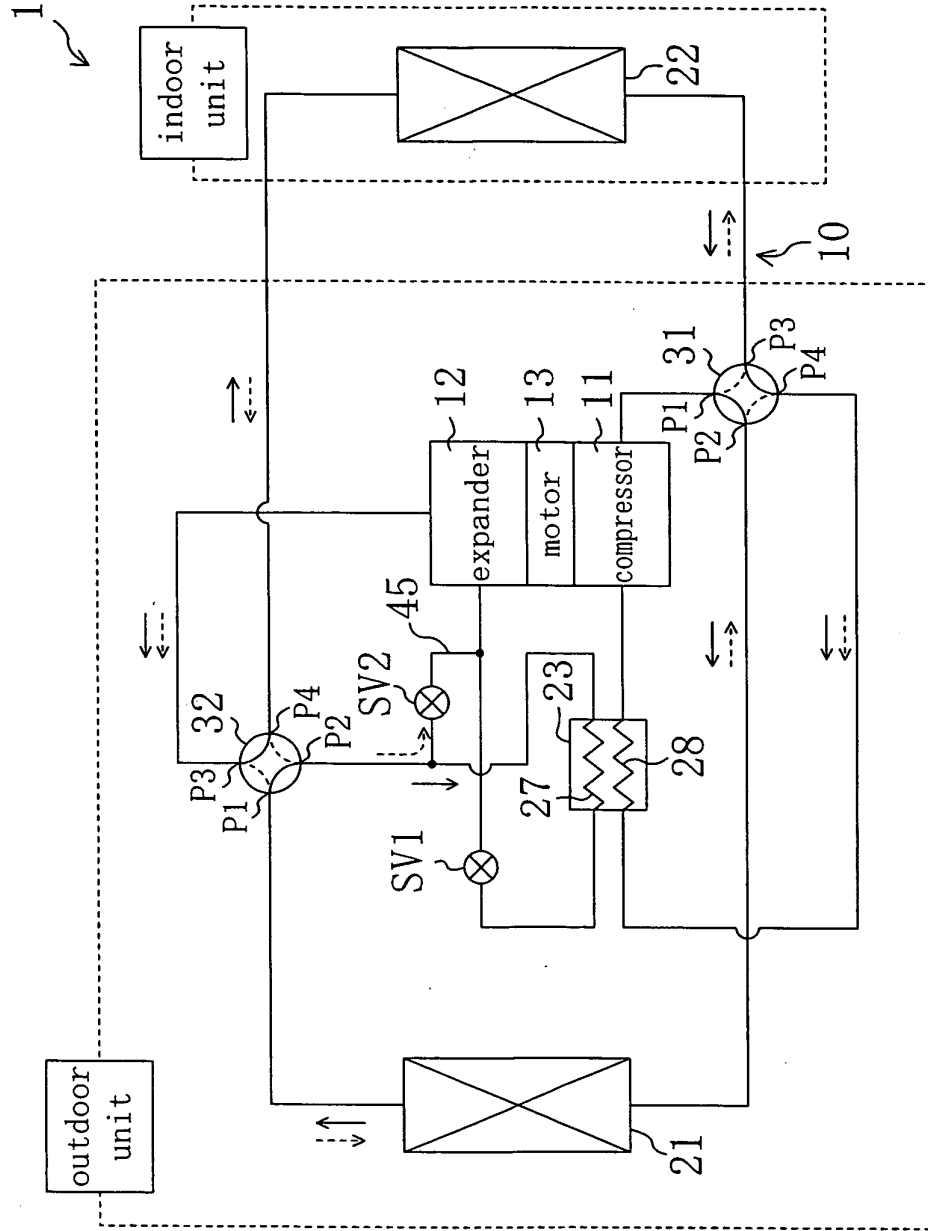


FIG. 18

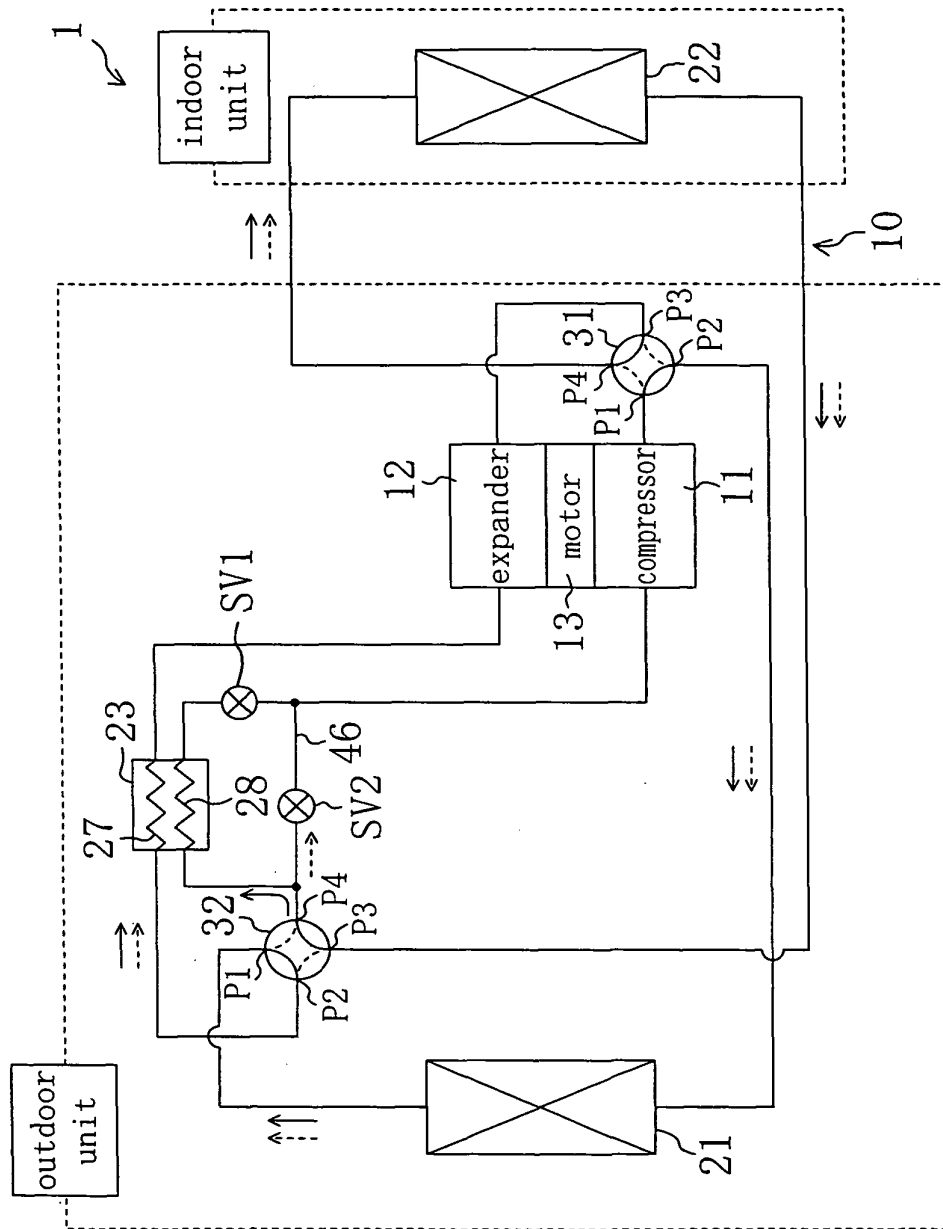
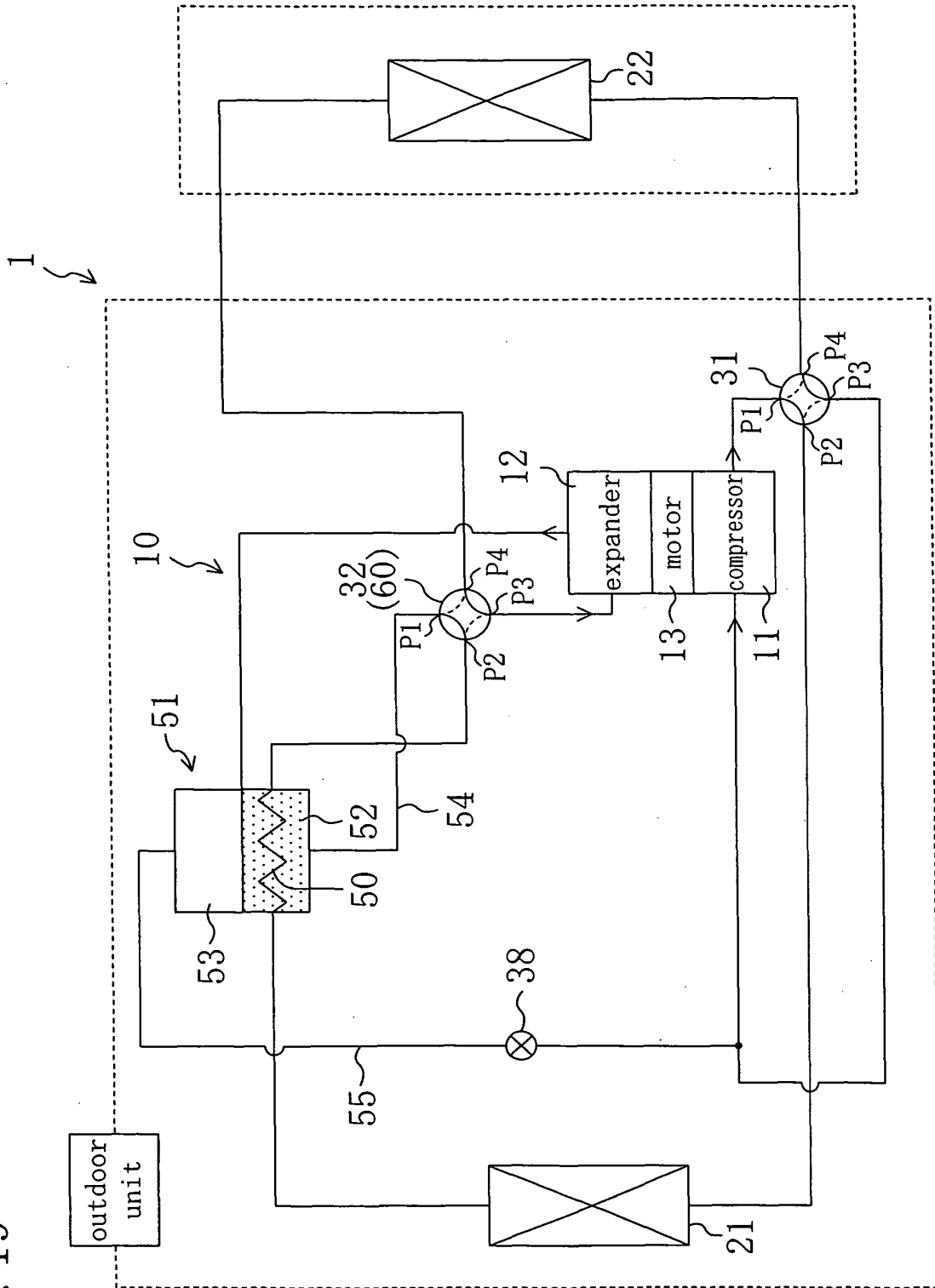


FIG. 19



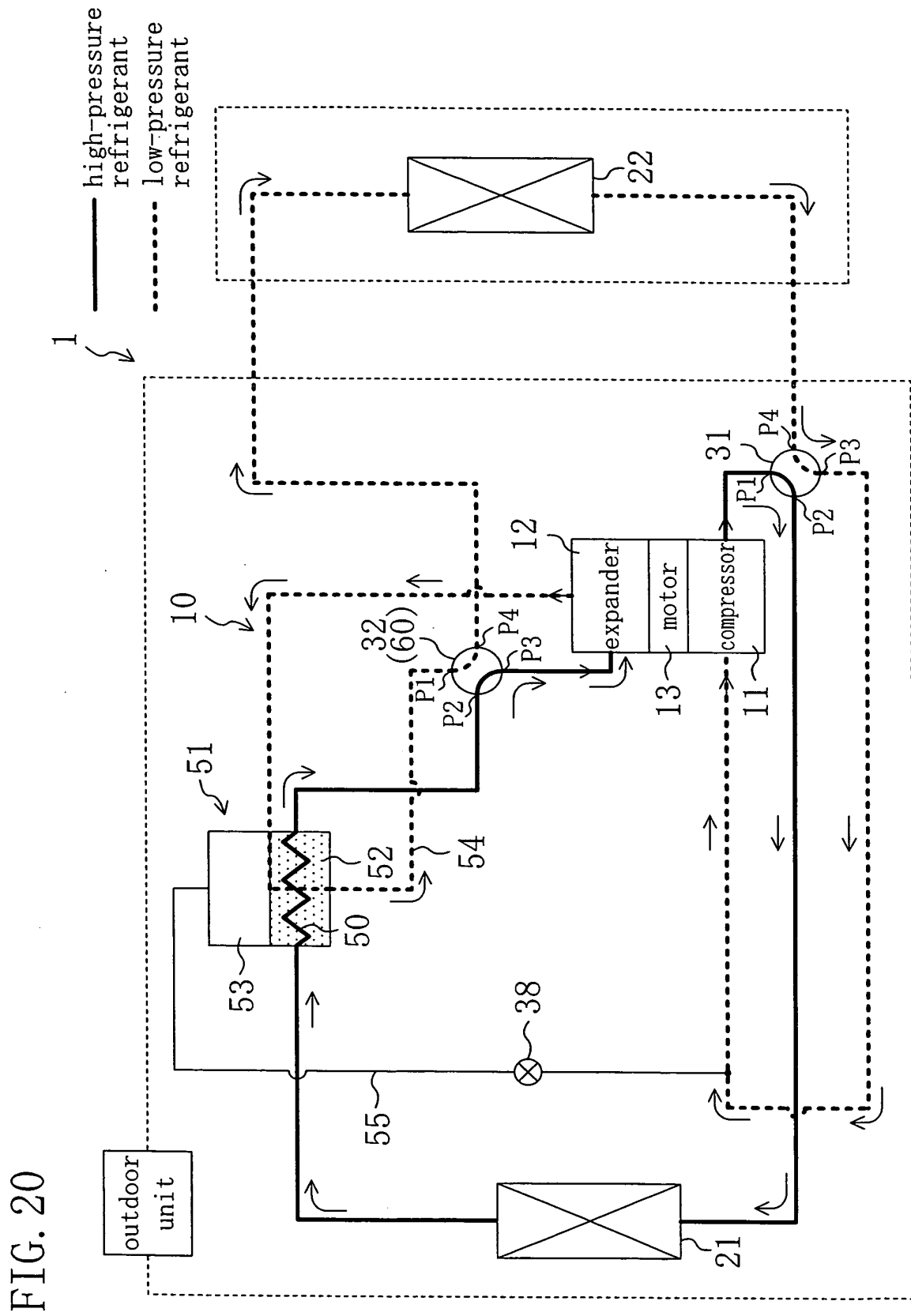
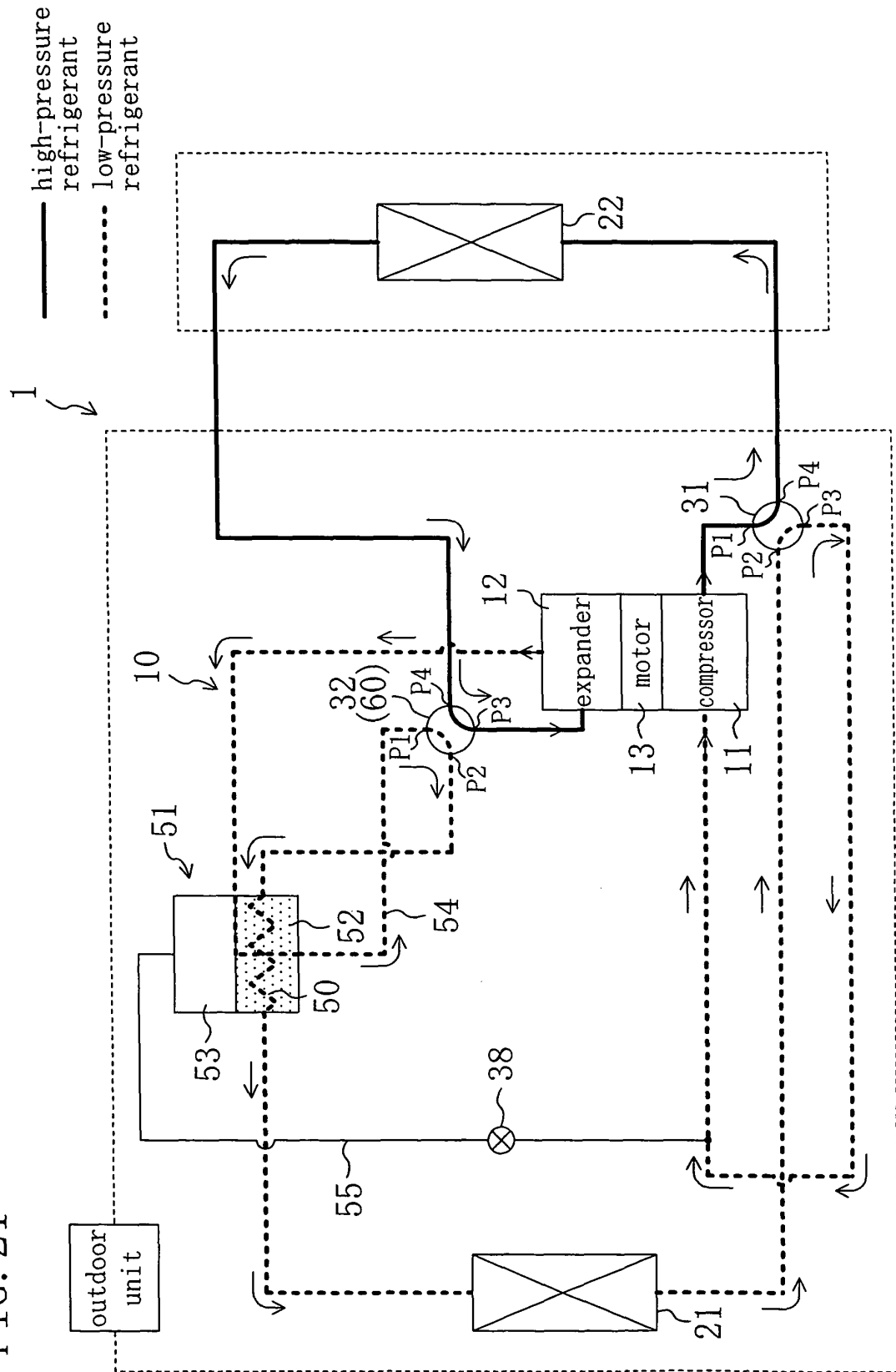


FIG. 21



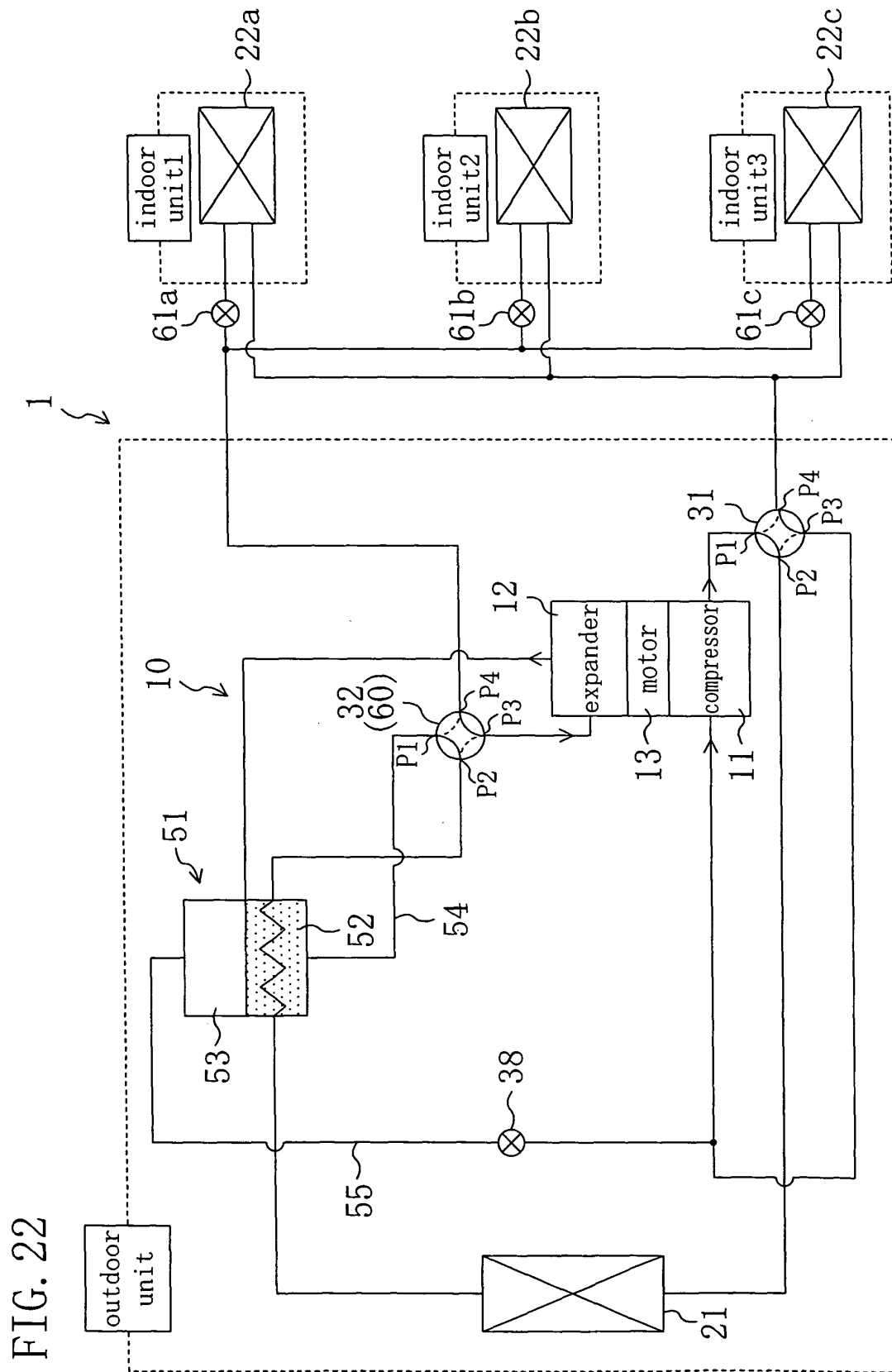


FIG. 23

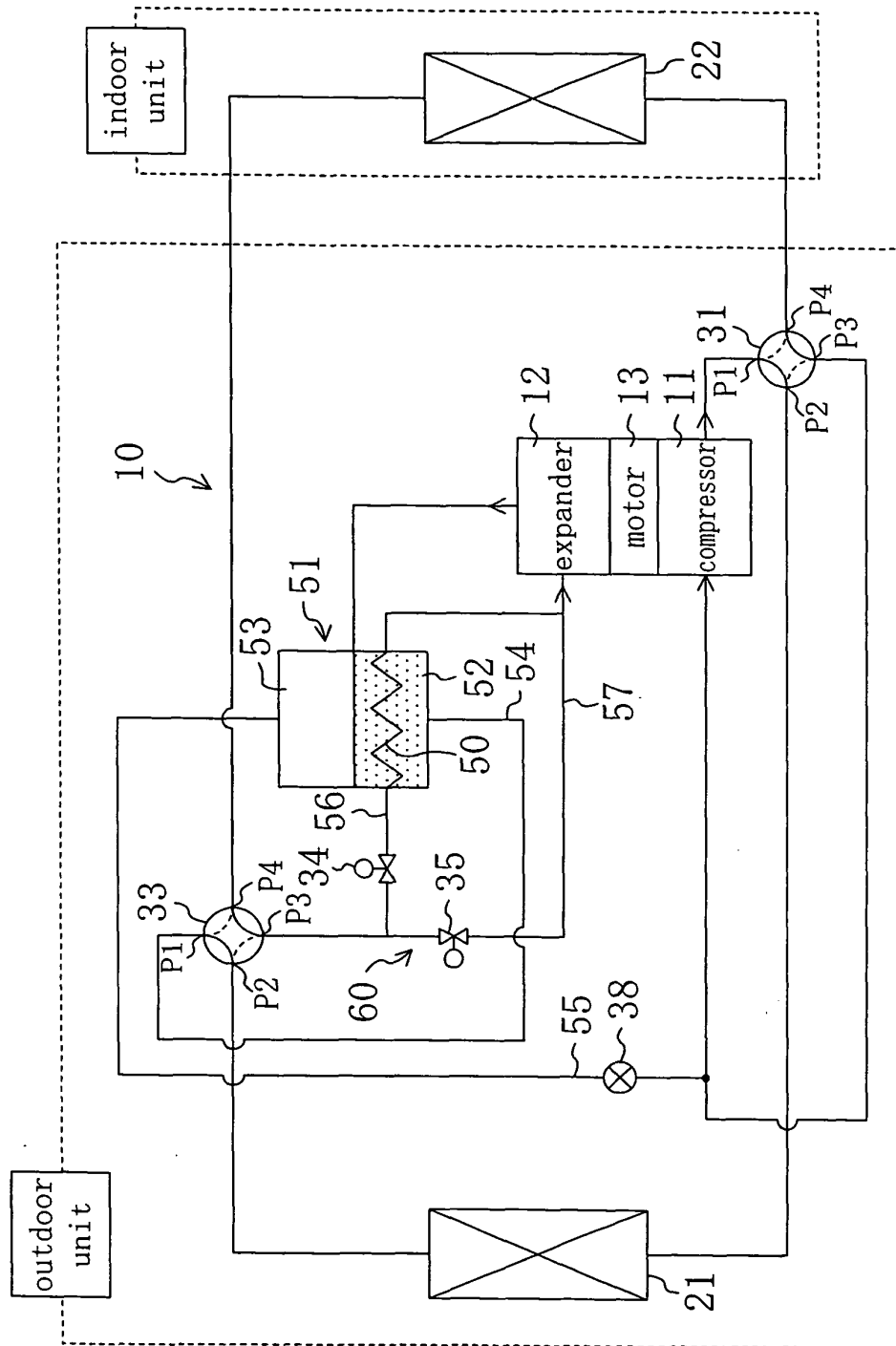


FIG. 24

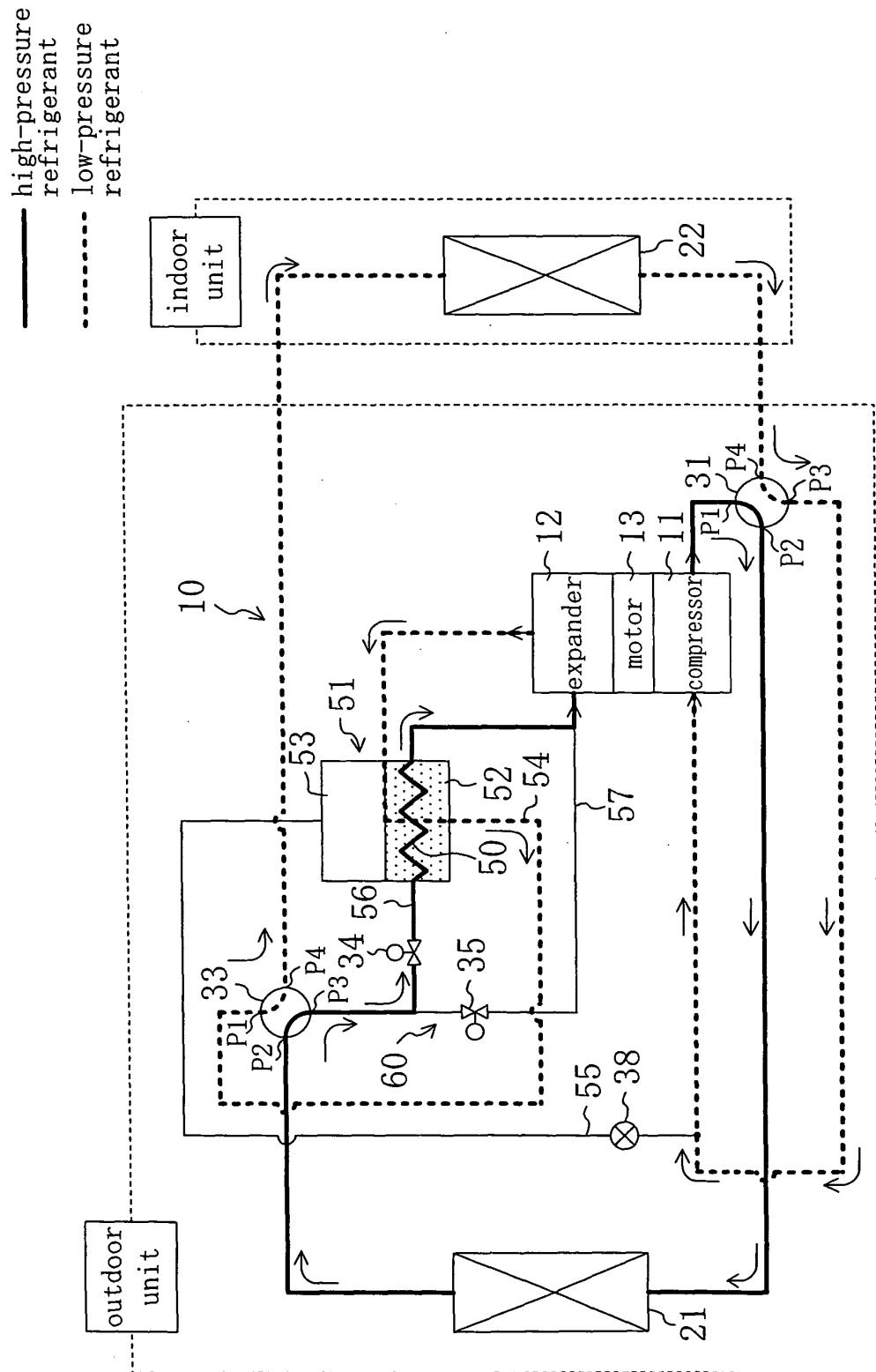


FIG. 25

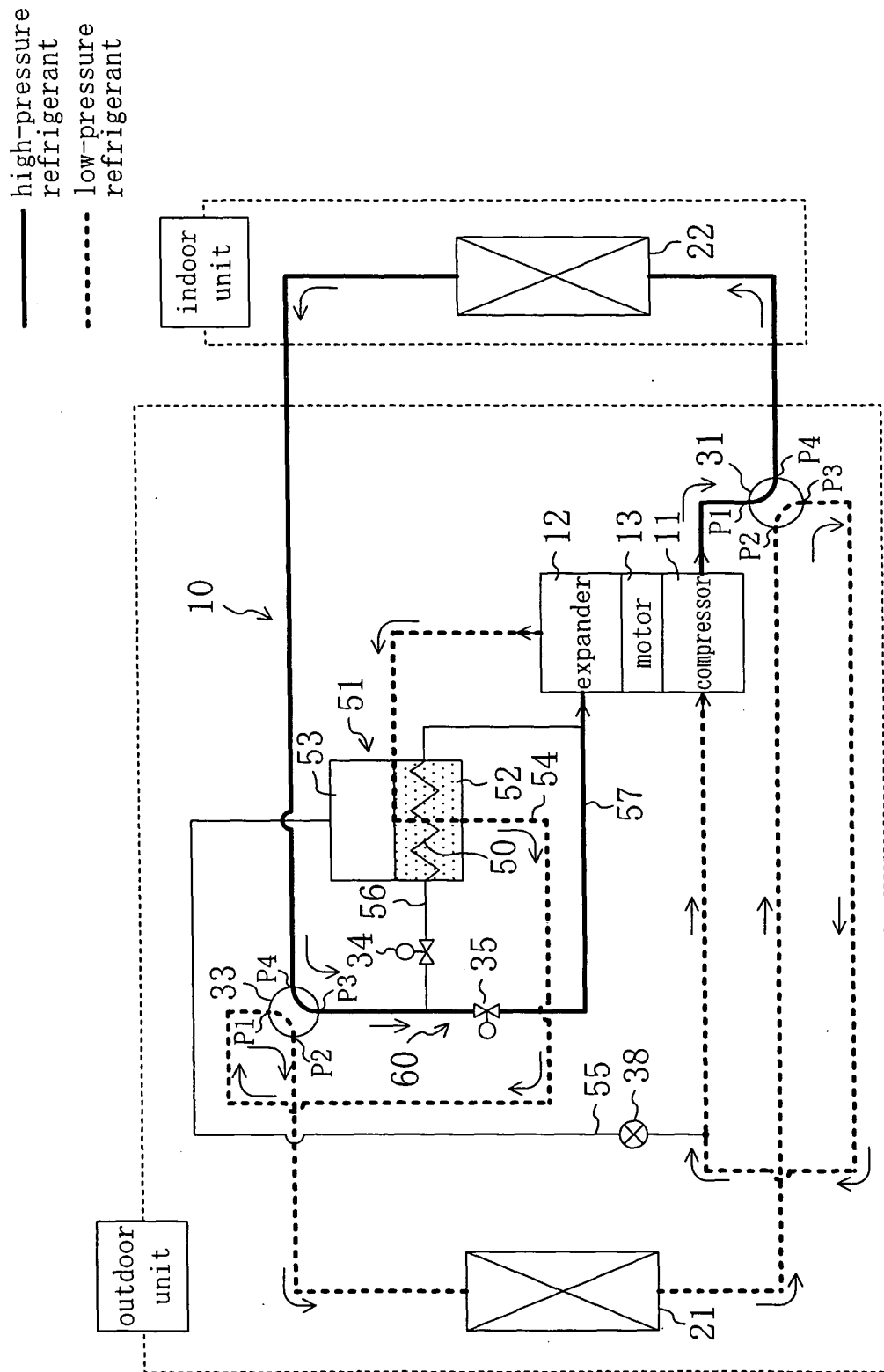
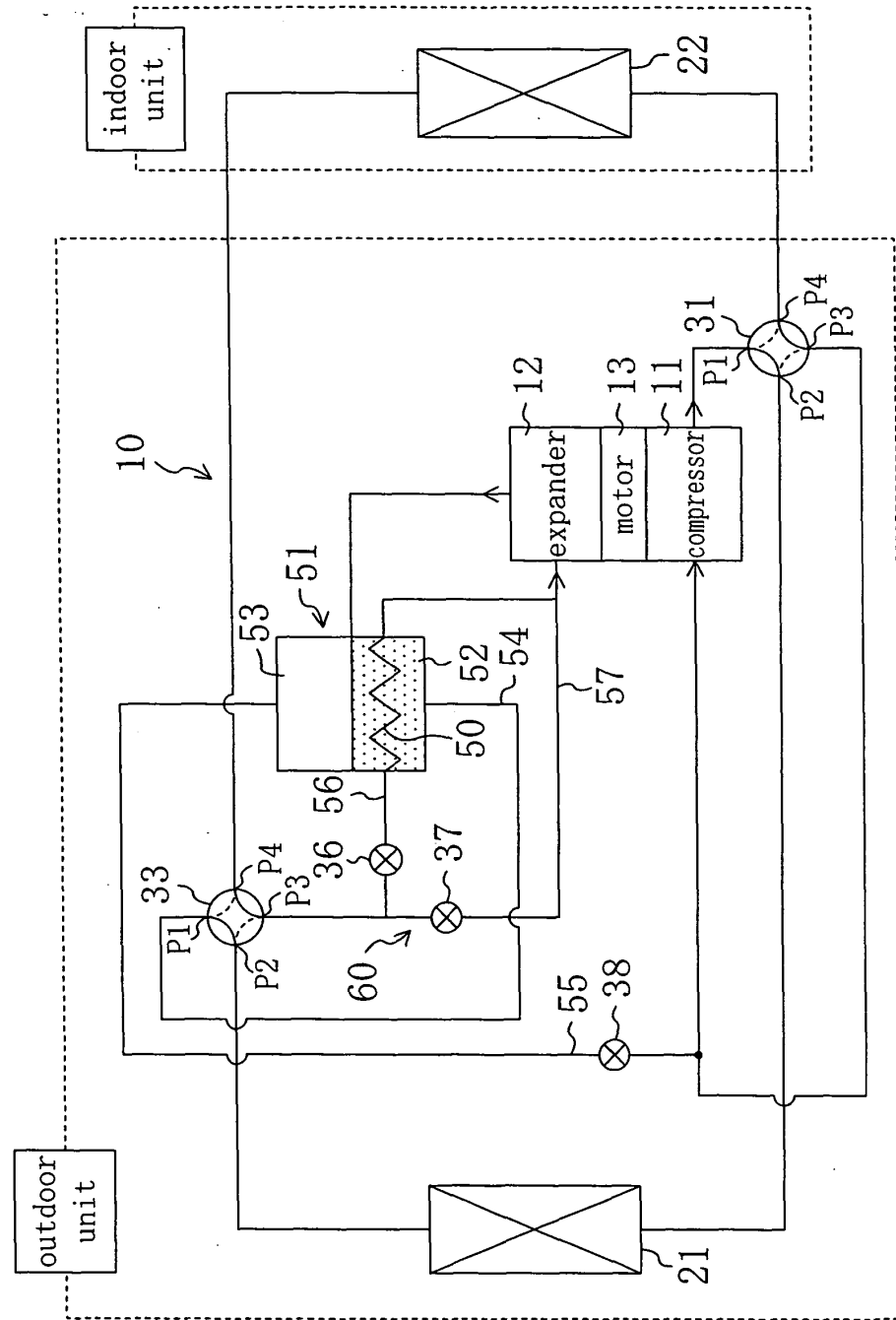


FIG. 26



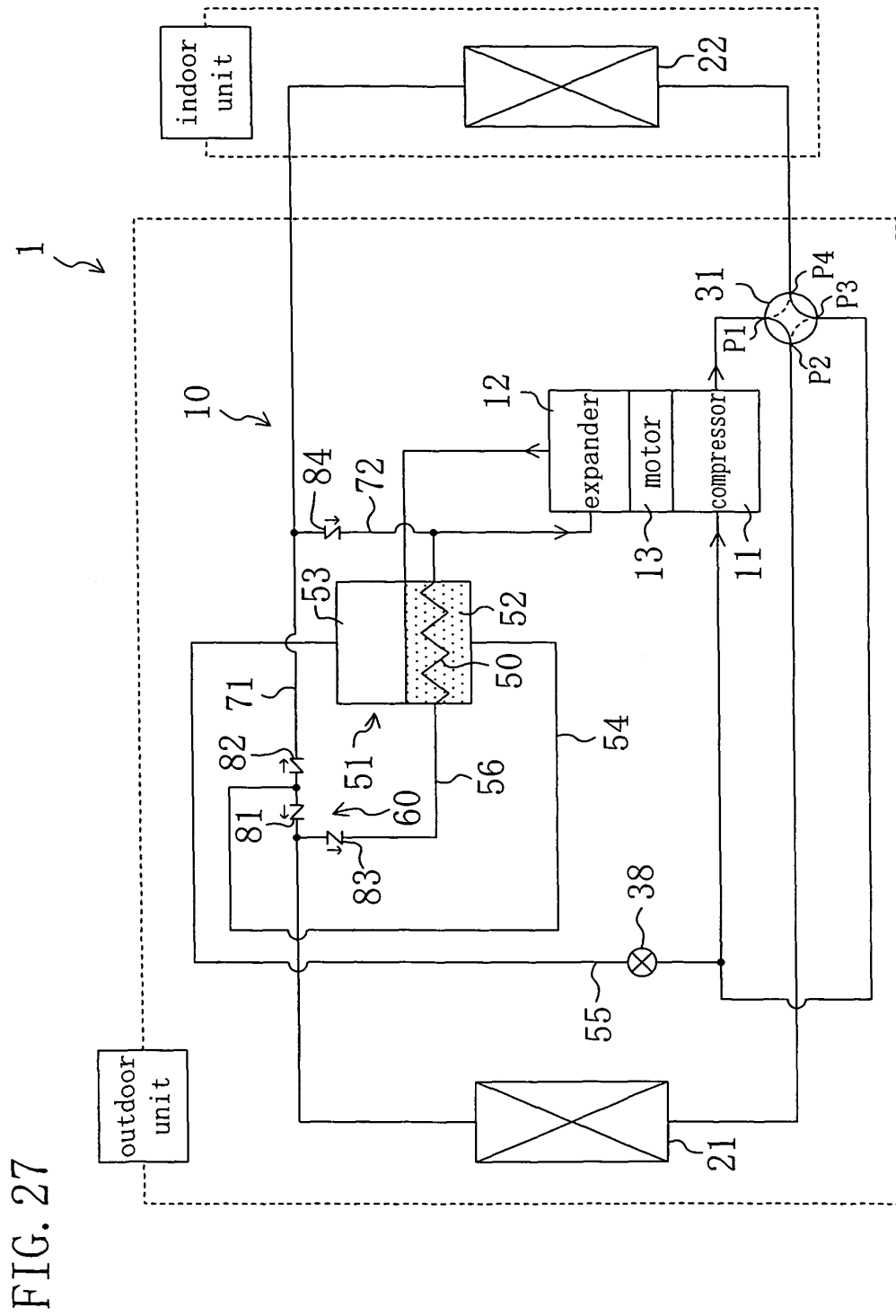


FIG. 28

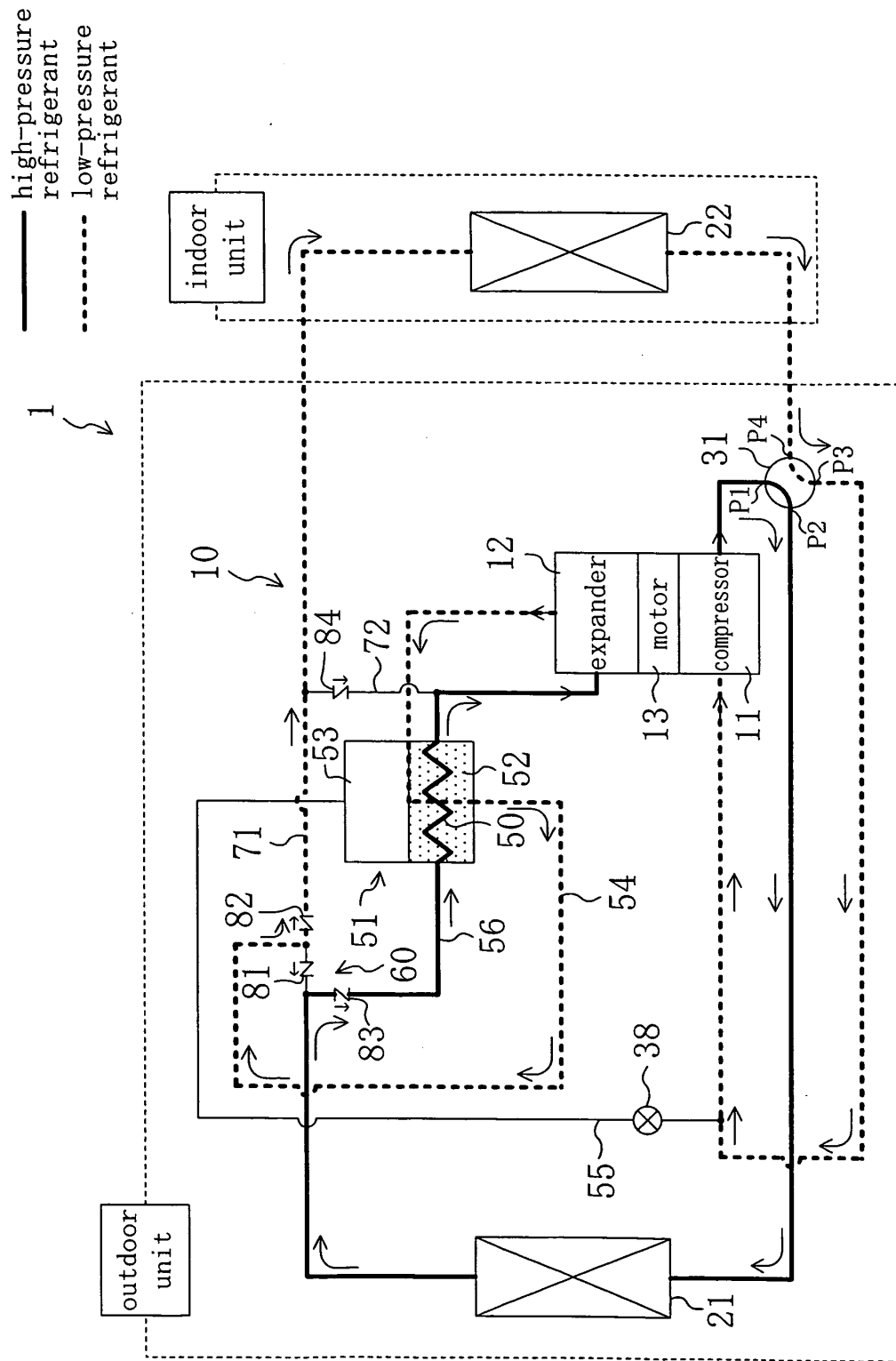


FIG. 29

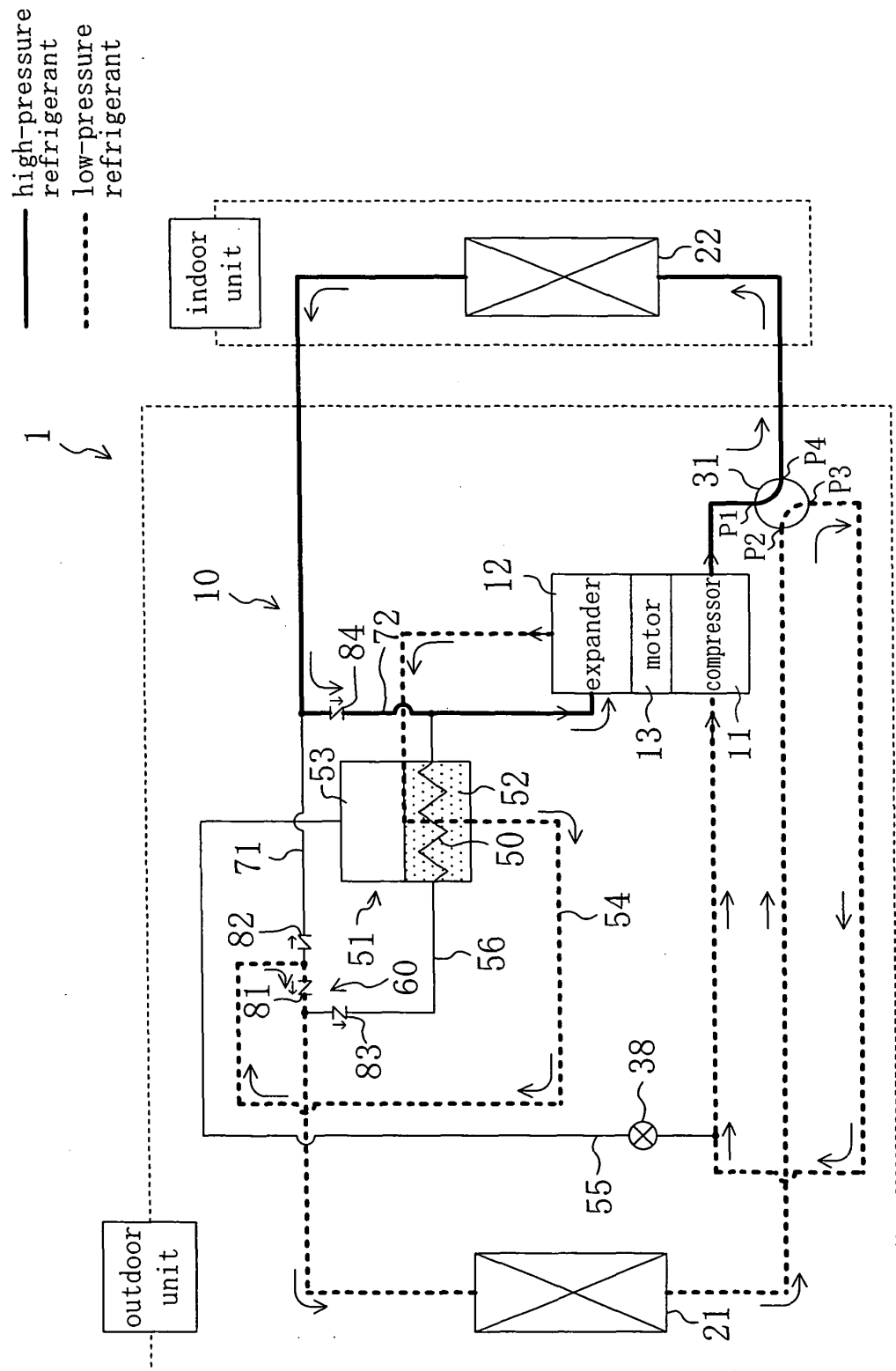
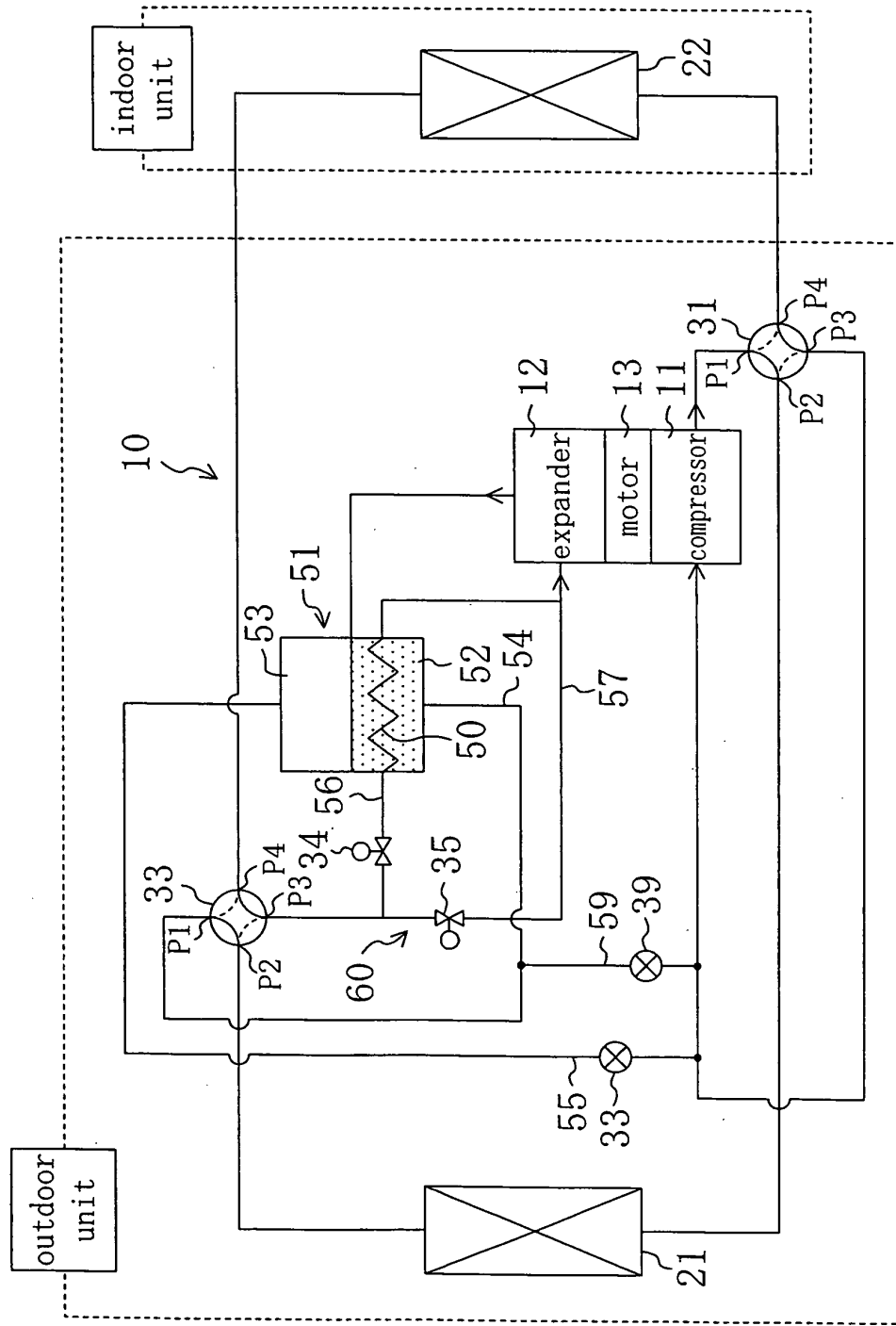


FIG. 30



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2005/015862

A. CLASSIFICATION OF SUBJECT MATTER

F25B11/02 (2006.01), **F25B1/00** (2006.01)

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)

F25B11/02 (2006.01), **F25B1/00** (2006.01)

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	1996-2005
Kokai Jitsuyo Shinan Koho	1971-2005	Toroku Jitsuyo Shinan Koho	1994-2005

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 2003-279179 A (Mitsubishi Electric Corp.), 02 October, 2003 (02.10.03), (Family: none)	1-29
A	JP 2000-234814 A (Aisin Seiki Co., Ltd.), 29 August, 2000 (29.08.00), (Family: none)	1-29
A	JP 06-012202 B2 (Mitsui Engineering & Shipbuilding Co., Ltd.), 16 February, 1994 (16.02.94), (Family: none)	1-29

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

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"&" document member of the same patent family

Date of the actual completion of the international search
17 November, 2005 (17.11.05)Date of mailing of the international search report
29 November, 2005 (29.11.05)Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2005/015862

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 2000-081157 A (Denso Corp.), 21 March, 2000 (21.03.00), & US 6189326 B1 & EP 0971184 A2	1-29
A	JP 2003-121018 A (Daikin Industries, Ltd.), 23 April, 2003 (23.04.03), (Family: none)	1-29

Form PCT/ISA/210 (continuation of second sheet) (April 2005)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- JP 2001116371 A [0010]