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(71) Applicant: **Daikin Industries, Ltd.**
Osaka 530-8323 (JP)

(72) Inventor: **SETOGUCHI, Takayuki**
Sakai-shi
Osaka 591-8511 (JP)

(74) Representative: **HOFFMANN EITLE**
Patent- und Rechtsanwälte
Arabellastraße 4
81925 München (DE)

(54) AIR CONDITIONING APPARATUS

(57) It is an object of this invention to provide an air conditioning apparatus using supercritical refrigerant for easily regulating the circulation amount of refrigerant. A refrigeration apparatus (1b) uses refrigerant operating in the supercritical zone. The refrigeration apparatus (1b) includes a compressor (21), a first heat exchanger (23), a first expansion mechanism (V2), a subcooling heat exchanger (24), a second expansion mechanism (V3), a second heat exchanger (31) and a control section (5). The compressor is configured to compress the refrigerant. The first heat exchanger is configured to cool the high-pressure refrigerant compressed by the compressor. The first expansion mechanism is configured to decompress the refrigerant to critical pressure or less. The subcooling heat exchanger is configured to subcool the refrigerant decompressed by the first expansion mechanism. The second expansion mechanism is configured to decompress the refrigerant cooled by the subcooling heat exchanger to low pressure. The second heat exchanger is configured to heat the refrigerant decompressed by the second expansion mechanism. The control section is configured to conduct first control to regulate the first and second expansion mechanisms for storing the refrigerant of a liquid state in the subcooling heat exchanger.

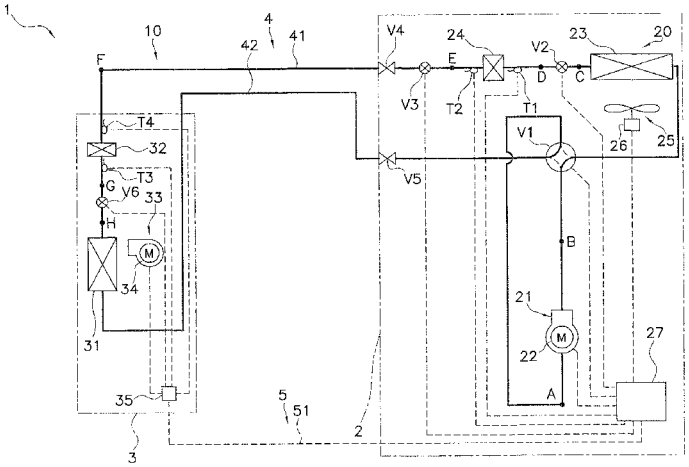

FIG. 1

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Description

TECHNICAL FIELD

[0001] The present invention relates to an air conditioning apparatus using supercritical refrigerant operating in the supercritical zone, and in particular to an air conditioning apparatus for easily regulating refrigeration performance.

BACKGROUND ART

[0002] A conventionally known refrigeration apparatus is configured to execute a vapor-compression refrigeration cycle by means of refrigerant circulation. The refrigeration apparatus of this type has been widely used as an air conditioning apparatus and the like. For example, Patent Document 1 exemplifies a refrigeration apparatus of this type. The refrigeration apparatus is configured to execute a so-called supercritical refrigeration cycle. In the supercritical refrigeration cycle, carbon dioxide (CO_2) is used as refrigerant, and the high pressure of CO_2 in the refrigeration cycle is set to be equal to or greater than the critical pressure of CO_2.

<Patent Document 1>
Japanese Laid-open Patent Application No. JP-A-H10-54617

DISCLOSURE OF THE INVENTION

<Technical Problem>

[0003] According to the refrigeration apparatus using supercritical refrigerant (e.g., CO_2 refrigerant), however, refrigerant is not in a liquid state but in a supercritical state under the high pressure. This makes it difficult to store the refrigerant even if the refrigeration apparatus is provided with a receiver. Accordingly, a function for regulating the evaporation amount of refrigerant does not work well, and performance control and COP optimum control do not appropriately function.

[0004] It is an object of the present invention to provide an air conditioning apparatus using supercritical refrigerant for easily regulating the circulation amount of refrigerant.

<Solution to Problem>

[0005] A refrigeration apparatus of a first aspect of the present invention is a refrigeration apparatus using refrigerant operating in the supercritical zone. The refrigeration apparatus includes a compressor, a first heat exchanger, a first expansion mechanism, a subcooling heat exchanger, a second expansion mechanism, a second heat exchanger and a control section. The compressor is configured to compress the refrigerant. The first heat exchanger is configured to cool the high-pressure refrigerant compressed by the compressor. The first expansion mechanism is configured to decompress the refrigerant to critical pressure or less. The subcooling heat exchanger is configured to subcool the refrigerant decompressed by the first expansion mechanism. The second expansion mechanism is configured to decompress the refrigerant cooled by the subcooling heat exchanger to low pressure. The second heat exchanger is configured to heat the refrigerant decompressed by the second expansion mechanism. The control section is configured to execute first control to regulate the first and second expansion mechanisms for storing the refrigerant of a liquid state in the subcooling heat exchanger.

[0006] According to the first aspect of the present invention, the subcooling heat exchanger is further provided in the outlet side of the first heat exchanger functioning as a gas cooler. Moreover, the first expansion mechanism for decompressing the refrigerant to the critical pressure or less is provided between the first heat exchanger and the subcooling heat exchanger.

[0007] With the structure, the refrigeration apparatus is capable of controlling degree of opening of the first expansion mechanism and regulating intermediate pressure of the refrigerant. Accordingly, the refrigeration apparatus is capable of storing the liquid refrigerant in the subcooling heat exchanger and regulating the amount of the refrigerant. Consequently, the refrigeration apparatus is capable of optimally controlling the high pressure of the refrigerant and executing an efficient operation.

[0008] A refrigeration apparatus of a second aspect of the present invention is the refrigeration apparatus of the first aspect of the present invention, wherein the refrigeration apparatus further includes subcooling information obtaining means. The subcooling information obtaining means is capable of obtaining subcooling information used for calculating degree of subcooling of the refrigerant in the subcooling heat exchanger. Furthermore, the control section is configured to calculate the degree of subcooling based on the subcooling information. The first control is conducted based on the degree of subcooling.

[0009] According to the second aspect of the present invention, the refrigeration apparatus further includes the subcooling information obtaining means capable of obtaining the subcooling information, and the control section is configured to execute the first control based on the degree of subcooling calculated based on the subcooling information. Accordingly, the refrigeration apparatus is capable of controlling the first and second expansion mechanisms for both setting the refrigerant to be in a subcooling state in the subcooling heat exchanger and setting the refrigerant to be in a liquid state in the subcooling heat exchanger. Consequently, the refrigeration apparatus is capable of regulating the amount of the refrigerant.

[0010] A refrigeration apparatus of a third aspect of the present invention is the refrigeration apparatus of the second aspect of the present invention, wherein the subcooling information obtaining means is composed of an

inlet temperature sensor and an outlet temperature sensor. The inlet temperature sensor is capable of detecting refrigerant inlet temperature in the subcooling heat exchanger. The outlet temperature sensor is capable of detecting refrigerant outlet temperature in the subcooling heat exchanger.

[0011] According to the third aspect of the present invention, the inlet temperature sensor detects the inlet temperature of the subcooling heat exchanger whereas the outlet temperature sensor detects the outlet temperature of the subcooling heat exchanger. Temperature detected by the inlet temperature sensor is equal to the saturated liquid temperature because the refrigerant is in a gas-liquid two-phase state. Accordingly, the refrigeration apparatus is capable of calculating the degree of subcooling based on the obtained saturated liquid temperature and the obtained outlet temperature.

[0012] A refrigeration apparatus of a fourth aspect of the present invention is the refrigeration apparatus of the second aspect of the present invention, wherein the subcooling information obtaining means is composed of an inlet pressure sensor and an outlet temperature sensor. The inlet pressure sensor is capable of detecting refrigerant inlet pressure of the subcooling heat exchanger. The outlet temperature sensor is capable of detecting refrigerant outlet temperature of the subcooling heat exchanger.

[0013] According to the fourth aspect of the present invention, the inlet pressure sensor detects the inlet pressure of the subcooling heat exchanger whereas the outlet temperature sensor detects the outlet temperature of the subcooling heat exchanger. Accordingly, the refrigeration apparatus is capable of calculating the saturated liquid temperature based on the detected inlet pressure, and is capable of calculating the degree of subcooling based on the saturated liquid temperature and the outlet temperature.

[0014] A refrigeration apparatus of a fifth aspect of the present invention is a refrigeration apparatus using refrigerant operating in the supercritical zone, wherein the refrigeration apparatus includes a compressor, a first heat exchanger, a first expansion mechanism, a subcooling heat exchanger, a second expansion mechanism, a second heat exchanger, a switch mechanism and a control section. The compressor is configured to compress the refrigerant. The first heat exchanger is configured to conduct heat exchange of the refrigerant. The first expansion mechanism is configured to decompress the refrigerant. The subcooling heat exchanger is configured to subcool the refrigerant. The second expansion mechanism is configured to decompress the refrigerant. The second heat exchanger is configured to conduct heat exchange of the refrigerant. The switch mechanism is capable of switching between a first condition and a second condition. The first condition is a condition for causing the refrigerant evaporated in the second heat exchanger to flow into the compressor and for causing the refrigerant compressed in the compressor to flow into the first heat exchanger. The second condition is a condition for causing the refrigerant evaporated in the first heat exchanger to flow into the compressor and for causing the refrigerant compressed in the compressor to flow into the second heat exchanger. The control section is configured to conduct first control and second control. The first control is control configured to cause the first expansion mechanism to decompress the refrigerant from high pressure to intermediate pressure equal to or less than the supercritical pressure and cause the second expansion mechanism to decompress the intermediate-pressure refrigerant subcooled by the subcooling heat exchanger to low pressure for storing the refrigerant of a liquid state in the subcooling heat exchanger in the first condition switched by the switch mechanism. The second control is control configured to cause the second expansion mechanism to decompress the refrigerant from high pressure to the intermediate pressure equal to or less than the supercritical pressure and cause the first expansion mechanism to decompress the intermediate-pressure refrigerant subcooled by the subcooling heat exchanger to low pressure for storing the refrigerant of a liquid state in the subcooling heat exchanger in the second condition switched by the switch mechanism.

[0015] According to the fifth aspect of the present invention, the refrigeration apparatus is provided with the switch mechanism capable of switching between the first condition for causing the first heat exchanger to function as a gas cooler and for causing the second heat exchanger to function as an evaporator and the second condition for causing the first heat exchanger to function as an evaporator and for causing the second heat exchanger to function as a gas cooler. When the first heat exchanger functions as a gas cooler, the subcooling heat exchanger is further provided in the refrigerant outlet side of the first heat exchanger. Additionally, the first expansion mechanism for decompressing the refrigerant to the critical pressure or less is further provided between the first heat exchanger and the subcooling heat exchanger. On the other hand, when the second heat exchanger functions as a gas cooler, the subcooling heat exchanger is connected to the refrigerant outlet side of the second heat exchanger. Additionally, the second expansion mechanism for decompressing the refrigerant to the critical pressure or less is further provided between the second heat exchanger and the subcooling heat exchanger.

[0016] With the structure, for instance, the refrigeration apparatus is capable of regulating the intermediate pressure of the refrigerant by controlling the degree of opening of the first expansion mechanism in the cooling operation whereas it is capable of regulating the intermediate pressure of the refrigerant by controlling the degree of opening of the third expansion mechanism in the heating operation. Accordingly, the refrigeration apparatus is capable of regulating the amount of the refrigerant by storing the liquid refrigerant into the outdoor subcooling heat exchanger (e.g., in the cooling operation) or the indoor subcooling heat exchanger (e.g., in the heating op-

eration). Consequently, the refrigeration apparatus is capable of optimally controlling the high pressure of the refrigerant.

[0017] A refrigeration apparatus of a sixth aspect of the present invention is the refrigeration apparatus of the fifth aspect of the present invention, wherein the refrigeration apparatus further includes subcooling information obtaining means. The subcooling information obtaining means is capable of obtaining subcooling information used for calculating the degree of subcooling of the refrigerant in the subcooling heat exchanger. The control section is configured to calculate the degree of subcooling based on the subcooling information. The first control or the second control is conducted based on the degree of subcooling.

[0018] According to the sixth aspect of the present invention, the refrigeration apparatus further includes the subcooling information obtaining means capable of obtaining the subcooling information, and the control section is configured to conduct the first control or the second control based on the degree of subcooling calculated based on the subcooling information. Accordingly, the refrigeration apparatus is capable of controlling the first and second expansion mechanisms for setting the refrigerant to be in a subcooling state in the subcooling heat exchanger and for setting the refrigerant to be in a liquid state in the subcooling heat exchanger. Consequently, the refrigeration apparatus is capable of regulating the amount of the refrigerant.

[0019] A refrigeration apparatus of a seventh aspect of the present invention is a refrigeration apparatus using refrigerant operating in the supercritical zone, wherein the refrigeration apparatus includes a heat source unit, a utilization unit and a control section. The heat source unit includes a compressor, a heat source side heat exchanger, a first expansion mechanism, a heat source side auxiliary heat exchanger, a second expansion mechanism and a switch mechanism. The compressor is configured to compress the refrigerant. The heat source side heat exchanger is configured to conduct heat exchange between the refrigerant and first fluid. The first expansion mechanism is capable of decompressing the refrigerant. The heat source side auxiliary heat exchanger is configured to conduct heat exchange of the refrigerant. The second expansion mechanism is capable of decompressing the refrigerant. The switch mechanism is capable of switching between a first condition and a second condition. The first condition is a condition for causing the refrigerant to flow into the compressor after the utilization side heat exchanger conducts the heat exchange of the refrigerant and for causing the refrigerant compressed by the compressor to flow into the heat source side heat exchanger. The second condition is a condition for causing the refrigerant to flow into the compressor after the heat source side heat exchanger conducts the heat exchange of the refrigerant and for causing the refrigerant compressed by the compressor to flow into the utilization side heat exchanger. The utilization unit includes a utilization side heat exchanger, a third expansion mechanism and a utilization side auxiliary heat exchanger. The utilization side heat exchanger is configured to conduct heat exchange of the refrigerant. The third expansion mechanism is capable of decompressing the refrigerant. The utilization side auxiliary heat exchanger is configured to conduct heat exchange of the refrigerant. The control section is configured to conduct first control, second control and third control. The first control is control configured to cause the heat source side auxiliary heat exchanger to function as a subcooler and regulate the first and second expansion mechanisms for storing the refrigerant of a liquid state in the heat source side auxiliary heat exchanger when temperature of the first fluid is less than the critical temperature of the refrigerant in the first condition switched by the switch mechanism. The second control is control configured to cause the utilization side auxiliary heat exchanger to function as a subcooler and regulate the second and third expansion mechanisms for storing the refrigerant of a liquid state in the utilization side auxiliary heat exchanger when temperature of the first fluid is equal to or greater than the critical temperature of the refrigerant in the first condition switched by the switch mechanism. The third control is control configured to cause the utilization side auxiliary heat exchanger to function as a subcooler and regulate the second and third expansion mechanisms for storing the refrigerant of a liquid state in the utilization side auxiliary heat exchanger in the second condition switched by the switch mechanism.

[0020] According to the seventh aspect of the present invention, the heat source unit further includes a switch mechanism (e.g., a four-way switch valve) capable of switching between a first condition and a second condition. Furthermore, the control section is configured to control the first and second expansion mechanisms in the first condition switched by the switch mechanism (e.g., in the cooling operation). On the other hand, the control section is configured to control the second and third expansion mechanisms in the second condition switched by the switch mechanism (e.g., in the heating operation). The control section is configured to conduct the third control for controlling the second and third expansion mechanisms for storing the liquid refrigerant in the utilization side subcooling heat exchanger not in the heat source side subcooling heat exchanger, for example, when the external temperature is equal to or greater than the critical temperature of the refrigerant in the cooling operation.

[0021] With the structure, the control section is capable of regulating the intermediate pressure of the refrigerant by controlling the first expansion mechanism in the cooling operation whereas it is capable of regulating the intermediate pressure of the refrigerant by controlling the third expansion mechanism in the heating operation. Furthermore, the control section is capable of regulating the amount of the liquid refrigerant in the heat source side subcooling heat exchanger in the cooling operation by

controlling the second expansion mechanism whereas it is capable of regulating the amount of the liquid refrigerant in the utilization side subcooling heat exchanger in the heating operation by controlling the second expansion mechanism. When the refrigerant exceeds the critical point, it enters a supercritical state and thus control of the amount of the refrigerant will be difficult. Thus, it is difficult to store the refrigerant in the heat source side subcooling heat exchanger when temperature of the first fluid is equal to or greater than the critical temperature. On the other hand, the utilization side heat exchanger functions as an evaporator. Accordingly, temperature of the second fluid is often equal to or less than the critical temperature. It is therefore possible to store the liquid refrigerant in the utilization side subcooling heat exchanger by the control section conducting the third control for controlling the second and third expansion mechanisms.

[0022] A refrigeration apparatus of an eighth aspect of the present invention is the refrigeration apparatus of the seventh aspect of the present invention, wherein the heat source unit further includes heat source side subcooling information obtaining means. The heat source side subcooling information obtaining means is capable of detecting first subcooling degree of the heat source side auxiliary heat exchanger. The utilization unit further includes utilization side subcooling information obtaining means. The utilization side subcooling information obtaining means is capable of detecting second subcooling degree of the utilization side auxiliary heat exchanger. The first control is conducted based on the first subcooling degree. The second and third controls are conducted based on the second subcooling degree.

[0023] According to the eighth aspect of the present invention, the heat source unit further includes second inlet pressure detection means and second outlet temperature detection means in the refrigerant inlet and the refrigerant outlet of the heat source side subcooling heat exchanger, respectively, for detecting the degree of subcooling. With the both detection means, it is possible to obtain second inlet pressure (i.e., intermediate pressure) and second outlet temperature.

[0024] With the structure, the control section is capable of calculating the degree of subcooling based on the second inlet pressure and the second outlet temperature. Consequently, the control section is capable of regulating the amount of the refrigerant by storing the liquid refrigerant in the first subcooling heat exchanger based on the degree of subcooling.

[0025] A refrigeration apparatus of a ninth aspect of the present invention is the refrigeration apparatus of the eighth aspect of the present invention, wherein the heat source side subcooling information obtaining means is composed of a first inlet temperature sensor and a first outlet temperature sensor. The first inlet temperature sensor is capable of detecting refrigerant inlet temperature of the heat source side auxiliary heat exchanger. On the other hand, the first outlet temperature sensor is capable of detecting refrigerant outlet temperature of the heat source side auxiliary heat exchanger.

[0026] According to the ninth aspect of the present invention, the first inlet temperature sensor and the first outlet temperature sensor are used in the refrigerant inlet and the refrigerant outlet of the heat source side auxiliary heat exchanger, respectively, as the heat source side subcooling information obtaining means. With the structure, the first inlet temperature sensor is capable of detecting the saturated liquid temperature of the refrigerant. Furthermore, it is possible to calculate the first subcooling degree based on the saturated liquid temperature and the refrigerant outlet temperature detected by the first outlet temperature sensor.

[0027] A refrigeration apparatus of a tenth aspect of the present invention is the refrigeration apparatus of the eighth aspect or the ninth aspect of the present invention, wherein the utilization side subcooling information obtaining means is composed of a second inlet temperature sensor and a second outlet temperature sensor. The second inlet temperature sensor is capable of detecting refrigerant inlet temperature of the utilization side auxiliary heat exchanger. The second outlet temperature sensor is capable of detecting refrigerant outlet temperature of the utilization side auxiliary heat exchanger.

[0028] According to the tenth aspect of the present invention, the second inlet temperature sensor and the second outlet temperature sensor are used in the refrigerant inlet and the refrigerant outlet of the utilization side auxiliary heat exchanger, respectively, as the utilization side subcooling information obtaining means. With the structure, the second inlet temperature sensor is capable of detecting the saturated liquid temperature of the refrigerant. Furthermore, it is possible to calculate the second subcooling degree based on the saturated liquid temperature and the refrigerant outlet temperature detected by the second outlet temperature sensor.

[0029] A refrigeration apparatus of an eleventh aspect of the present invention is the refrigeration apparatus of any of the first to tenth aspects of the present invention, wherein the refrigerant is carbon dioxide (CO_2) refrigerant.

[0030] According to the eleventh aspect of the present invention, the CO_2 refrigerant is used as refrigerant. The global warming potential (GWP) value of the CO_2 refrigerant equals to "1". This is much smaller than the GWP value of the conventional refrigerant. For example, the GWP value of the fluorocarbon refrigerant is approximately hundreds to ten thousand.

[0031] Therefore, use of the CO_2 refrigerant less burdening the environment makes it possible to inhibit worsening of the global environment.

<Advantageous Effects of Invention>

[0032] According to the refrigeration apparatus of the first aspect of the present invention, it is possible to control the degree of opening of the first expansion mecha-

nism and regulate the intermediate pressure of the refrigerant. Accordingly, the refrigeration apparatus is capable of storing the liquid refrigerant in the subcooling heat exchanger, and is capable of regulating the amount of the refrigerant. Consequently, the refrigeration apparatus is capable of optimally controlling the high pressure of the refrigerant, and is capable of conducting an efficient operation.

[0033] According to the refrigeration apparatus of the second aspect of the present invention, it is possible to control the first and second expansion mechanisms for setting the refrigerant to be in a subcooling state in the subcooling heat exchanger and for setting the refrigerant to be in a liquid state in the subcooling heat exchanger. Therefore, the refrigeration apparatus is capable of regulating the amount of the refrigerant.

[0034] According to the refrigeration apparatus of the third aspect of the present invention, it is possible to calculate the subcooling degree based on the obtained saturated liquid temperature and the obtained outlet temperature.

[0035] According to the refrigeration apparatus of the fourth aspect of the present invention, it is possible to calculate the saturated liquid temperature based on the detected inlet pressure. Furthermore, it is possible to calculate degree of subcooling based on the saturated liquid temperature and the outlet temperature.

[0036] According to the refrigeration apparatus of the fifth aspect of the present invention, for instance, it is possible to regulate the intermediate pressure of the refrigerant by controlling the degree of opening of the first expansion mechanism in the cooling operation whereas it is possible to regulate the intermediate pressure of the refrigerant by controlling the degree of opening of the third expansion mechanism in the heating operation. Accordingly, the refrigeration apparatus is capable of regulating the amount of the refrigerant by storing the liquid refrigerant in the outdoor subcooling heat exchanger (e.g., in the cooling operation) or the indoor subcooling heat exchanger (e.g., in the heating operation). Consequently, the refrigeration apparatus is capable of optimally controlling the high pressure of the refrigerant.

[0037] According to the refrigeration apparatus of the sixth aspect of the present invention, it is possible to control the first and second expansion mechanisms for setting the refrigerant to be in a subcooling state in the subcooling heat exchanger and for setting the refrigerant to be in a liquid state in the subcooling heat exchanger. Accordingly, the refrigeration apparatus is capable of regulating the amount of the refrigerant.

[0038] According to the refrigeration apparatus of the seventh aspect of the present invention, the control section is capable of regulating the intermediate pressure of the refrigerant by controlling the first expansion mechanism in the cooling operation whereas it is capable of regulating the intermediate pressure of the refrigerant by controlling the third expansion mechanism in the heating operation. Furthermore, the control section is capable of regulating the amount of the liquid refrigerant of the heat source side subcooling heat exchanger in the cooling operation by controlling the second expansion mechanism whereas it is capable of regulating the amount of the liquid refrigerant of the utilization side subcooling heat exchanger in the heating operation by controlling the second expansion mechanism. When the refrigerant exceeds the critical point, it enters a supercritical state and control of the amount of the refrigerant will be difficult. Accordingly, when temperature of the first fluid is equal to or greater than the critical temperature, it is difficult to store the refrigerant in the heat source side subcooling heat exchanger. On the other hand, temperature of the second fluid is often equal to or less than the critical temperature because the utilization side heat exchanger functions as an evaporator. Therefore, the third control of the second and third expansion mechanisms by the control section makes it possible to store the liquid refrigerant in the utilization side subcooling heat exchanger.

[0039] According to the refrigeration apparatus of the eighth aspect of the present invention, the control section is capable of calculating degree of subcooling based on the second inlet pressure and the second outlet temperature. Therefore, the control section is capable of regulating the amount of the refrigerant by storing the liquid refrigerant in the first subcooling heat exchanger based on degree of subcooling.

[0040] According to the refrigeration apparatus of the ninth aspect of the present invention, the first inlet temperature sensor is capable of detecting the saturated liquid temperature of the refrigerant. Furthermore, it is possible to calculate the first subcooling degree based on the saturated liquid temperature and the refrigerant outlet temperature detected by the first outlet temperature sensor.

[0041] According to the refrigeration apparatus of the tenth aspect of the present invention, the second inlet temperature sensor is capable of detecting the saturated liquid temperature of the refrigerant. Furthermore, it is possible to calculate the second subcooling degree based on the saturated liquid temperature and the refrigerant outlet temperature detected by the second outlet temperature sensor.

[0042] According to the refrigeration apparatus of the eleventh aspect of the present invention, use of the CO_2 refrigerant less burdening the environment makes it possible to inhibit worsening of the global environment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0043]

Fig. 1 is a diagram illustrating a refrigerant circuit of an air conditioning apparatus according to an embodiment of the present invention.

Fig. 2 is a P-H chart for showing a two-stage expansion refrigeration cycle with CO_2 refrigerant in the air

conditioning apparatus of the present invention.
Fig. 3 is a refrigerant circuit diagram of an air conditioning apparatus according to Modification (1).
Fig. 4 is a refrigerant circuit diagram of an air conditioning apparatus exclusively used for a cooling operation according to Modification (5).
Fig. 5 is a refrigerant circuit diagram of an air conditioning apparatus exclusively used for a heating operation according to Modification (5).
Fig. 6 is a refrigerant circuit diagram of an air conditioning apparatus according to Modification (6).

EXPLANATION OF THE REFERENCE NUMERALS

[0044]

1, 1a-1d	air conditioning apparatus
2, 2a, 2b	outdoor unit (heat source unit)
3, 3a-3c, 3d	indoor unit (utilization unit)
21	compressor
23	outdoor heat exchanger (first heat exchanger, heat source side heat exchanger)
24	outdoor subcooling heat exchanger (subcooling heat exchanger, heat source side auxiliary heat exchanger)
31, 31a-31c	indoor heat exchanger (second heat exchanger, utilization side heat exchanger)
32, 32a-32c	indoor subcooling heat exchanger (utilization side auxiliary heat exchanger)
T1	first outdoor subcooling temperature sensor (first inlet temperature sensor)
T2	second outdoor subcooling temperature sensor (first outlet temperature sensor)
T1	first indoor subcooling temperature sensor (second inlet temperature sensor, second outlet temperature sensor)
T2	second indoor subcooling temperature sensor (second inlet temperature sensor, second outlet temperature sensor)
V1	four-way switch valve (switch mechanism)
V2	first outdoor expansion valve (first expansion mechanism)
V3	second outdoor expansion valve (second expansion mechanism)
V6, V6a-V6c	indoor expansion valve (third expansion mechanism)

BEST MODE FOR CARRYING OUT THE INVENTION

[0045] An air conditioning apparatus according to an embodiment of the present invention will be hereinafter explained with reference to the attached drawings.

<Structure of Air Conditioning Apparatus>

[0046] Fig. 1 is a schematic configuration diagram of an air conditioning apparatus 1 according to an embodiment of the present invention. The air conditioning apparatus 1 is an apparatus used for cooling and heating the indoor space of a building and the like by conducting a two-stage expansion refrigeration cycle operation. In the present invention, carbon dioxide (CO_2) refrigerant (i.e., supercritical refrigerant) is used. The air conditioning apparatus 1 mainly includes an outdoor unit 2, an indoor unit 3 and a refrigerant communication pipe 4. The outdoor unit 2 functions as a heat source unit. The indoor unit 3 is connected to the outdoor unit 2, and functions as a utilization unit. The refrigerant communication pipe 4 connects the outdoor unit 2 and the indoor unit 3. The refrigerant communication pipe 4 is composed of a liquid refrigerant communication pipe 41 and a gas refrigerant communication pipe 42. In other words, a refrigerant circuit 10 of the air conditioning apparatus 1 according to the present embodiment is formed by the interconnection among the outdoor unit 2, the indoor unit 3 and the refrigerant communication pipe 4.

(1) Outdoor Unit

[0047] The outdoor unit 2 is disposed outside a building and the like. The outdoor unit 2 is connected to the indoor unit 3 through the refrigerant communication pipe 4. The outdoor unit 2 forms a part of the refrigerant circuit 10.

[0048] Next, structure of the outdoor unit 2 will be explained. The outdoor unit 2 mainly includes an outdoor side refrigerant circuit 20. The outdoor side refrigerant circuit 20 forms a part of the refrigerant circuit 10. The outdoor side refrigerant circuit 20 mainly includes a compressor 21, a four-way switch valve V1, an outdoor heat exchanger 23 functioning as a heat source side heat exchanger, a first outdoor expansion valve V2 functioning as an expansion mechanism, an outdoor subcooling heat exchanger 24 functioning as a heat source side subcooling heat exchanger, a second outdoor expansion valve V3 functioning as an expansion mechanism, a liquid side stop valve V4 and a gas side stop valve V5.

[0049] The compressor 21 is a compressor capable of changing its operation capacity. In the present embodiment, the compressor 21 is a positive-displacement compressor to be driven by a motor 22. Here, rotation speed Rm of the motor 22 is controlled by an inverter. Note that only single compressor 21 is provided in the present embodiment. However, the number of the compressor 21 is not limited to this. For example, two or more compressors may be parallel-connected depending on the number of indoor units to be connected to the outdoor unit 2 or the like.

[0050] The four-way switch valve V1 is a valve provided for causing the outdoor heat exchanger 23 to function as a gas cooler and an evaporator. The four-way switch valve V 1 is connected to the outdoor heat exchanger

23, the suction side of the compressor 21, the discharge side of the compressor 21 and the gas refrigerant communication pipe 42. When the outdoor heat exchanger 23 is caused to function as a gas cooler, the four-way switch valve V1 is configured to connect the discharge side of the compressor 21 and the outdoor heat exchanger 23, and is also configured to connect the suction side of the compressor 21 and the gas refrigerant communication pipe 42 (see a solid-line condition in Fig. 1). On the other hand, when the outdoor heat exchanger 23 is caused to function as an evaporator, the four-way switch valve V1 is configured to connect the outdoor heat exchanger 23 and the suction side of the compressor 21, and is also configured to connect the discharge side of the compressor 21 and the gas refrigerant communication pipe 42 (see a dashed-line condition in Fig. 1).

[0051] The outdoor heat exchanger 23 is a heat exchanger allowed to function as a gas cooler and an evaporator. In the present embodiment, the outdoor heat exchanger 23 is a cross-fin typed fin-and-tube heat exchanger for conducting heat exchange between the refrigerant and air functioning as a heat source. One end of the outdoor heat exchanger 23 is connected to the four-way switch valve V1 while the other end thereof is connected to the outdoor subcooling heat exchanger 24 via the first outdoor expansion valve V2.

[0052] The first outdoor expansion valve V2 is an electric expansion valve for regulating the pressure, the flow rate and the like of refrigerant flowing through the outdoor side refrigerant circuit 20. The first outdoor expansion valve V2 is connected between the outdoor heat exchanger 23 and the outdoor subcooling heat exchanger 24. In a cooling operation, the first outdoor expansion valve V2 is configured to function as a first-stage expansion mechanism in the two-stage expansion refrigeration cycle. On the other hand, in a heating operation, the first outdoor expansion valve V2 is fully opened and causes the refrigerant to flow into the outdoor heat exchanger 23 so as not to change pressure of the refrigerant. When the first outdoor expansion valve V2 functions as the first-stage expansion mechanism, it decompresses the refrigerant from high pressure Ph to intermediate pressure Pm. Here, the intermediate pressure Pm is equal to or less than critical pressure Pk of the refrigerant. However, when the external temperature is equal to or greater than 31 degrees Celsius (i.e., the critical temperature of the CO_2 refrigerant) in the cooling operation, the first outdoor expansion valve V2 is configured to be fully opened.

[0053] The outdoor subcooling heat exchanger 24 is a heat exchanger allowed to function as a subcooler and an evaporator. In the present embodiment, the outdoor subcooling heat exchanger 24 is a cross-fin typed fin-and-tube heat exchanger for conducting heat exchange between the refrigerant and air functioning as a heat source. One end of the outdoor subcooling heat exchanger 24 is connected to the outdoor heat exchanger 23 via the first outdoor expansion valve V2 while the other end thereof is connected to the liquid refrigerant communication pipe 41 via the second outdoor expansion valve V3. However, when the external temperature is equal to or greater than 31 degrees Celsius (i.e., critical temperature of the CO_2 refrigerant) in the cooling operation, the outdoor subcooling heat exchanger 24 is configured to function as a gas cooler. In this regard, the outdoor subscooling heat exchanger 24 is similar to the aforementioned outdoor heat exchanger 23.

[0054] The second outdoor expansion valve V3 is an electric expansion valve for regulating the pressure, the flow rate and the like of the refrigerant flowing through the outdoor side refrigerant circuit 20. The second outdoor expansion valve V3 is connected to the liquid side of the outdoor subcooling heat exchanger 24. In both the cooling and heating operations, the first outdoor expansion valve V2 is configured to function as a second-stage expansion mechanism of the two-stage expansion refrigeration cycle, and is configured to decompress the refrigerant from the intermediate pressure Pm to low pressure Pl. However, when the external temperature is equal to or greater than 31 degrees Celsius (i.e., the critical temperature of the CO_2 refrigerant) in the cooling operation, the second outdoor expansion valve V3 is configured to function as the first-stage expansion mechanism of the two-stage expansion refrigeration cycle, and is configured to decompress the refrigerant from the high pressure Ph to the intermediate pressure Pm equal to or less than the critical pressure Pk of the refrigerant.

[0055] Furthermore, the outdoor unit 2 includes an outdoor fan 25. The outdoor fan 25 functions as a ventilation fan for sucking outdoor air into the outdoor unit 2 and then discharging the air to the outside after the outdoor heat exchanger 23 conducts heat exchange between the sucked air and the refrigerant. The outdoor fan 25 is a fan capable of changing the flow rate of air to be supplied to the outdoor heat exchanger 23. In the present embodiment, the outdoor fan 25 is a propeller fan to be driven by a motor 26, for instance. Here, the motor 26 is composed of a DC fan motor.

[0056] Additionally, the outdoor unit 2 is provided with various sensors. A first outdoor subcooling temperature sensor T1 is provided between the outdoor subcooling heat exchanger 24 and the first outdoor expansion valve V2. The first outdoor subcooling temperature sensor T1 is configured to detect temperature of the refrigerant. Additionally, a second outdoor subcooling temperature sensor T2 is provided between the outdoor subcooling heat exchanger 24 and the second outdoor expansion valve V3. The second outdoor subcooling temperature sensor T2 is configured to detect temperature of the refrigerant. In the present embodiment, each of the first and second outdoor subcooling temperature sensors T1 and T2 is composed of a thermistor.

[0057] Moreover, the outdoor unit 2 includes an outdoor side control section 27. The outdoor side control section 27 is configured to control operations of each of the elements forming the outdoor unit 2. The outdoor side control section 27 includes a microcomputer, a memory,

an inverter circuit and the like. The microcomputer is provided for controlling the outdoor unit 2. The inverter circuit is configured to control the motor 22 and the like. The outdoor side control section 27 is capable of transmitting/receiving a control signal and the like to/from an aftermentioned indoor side control section 35 of the indoor unit 3 through a transmission line 51. In other words, the outdoor side control section 27, the indoor side control section 35 and the transmission line 51 connecting each of the control sections form a control section 5 for controlling the entire operation of the air conditioning apparatus 1.

[0058] The elements of the control section 5 are connected for receiving detection signals from a variety of sensors (not illustrated in the figure) and for controlling the various devices 21, 25 and 33 and valves V1, V2, V3 and V6, respectively, based on the detection signals and the like.

(2) Indoor Unit

[0059] The indoor unit 3 is installed by being embedded in or hanged down or the like from the ceiling of the indoor space of a building and the like, or by being hanged down on the wall thereof or the like. The indoor unit 3 is connected to the outdoor unit 2 through the refrigerant communication pipe 4. The indoor unit 3 forms a part of the refrigerant circuit 10.

[0060] Next, structure of the indoor unit 3 will be explained. The indoor unit 3 mainly includes an indoor side refrigerant circuit 30. The indoor side refrigerant circuit 30 forms a part of the refrigerant circuit 10. The indoor side refrigerant circuit 30 mainly includes an indoor heat exchanger 31, an indoor expansion valve V6 and an indoor subcooling heat exchanger 32. The indoor heat exchanger 31 functions as a utilization side heat exchanger. The indoor expansion valve V6 functions as an expansion mechanism. The indoor subcooling heat exchanger 32 functions as a utilization side subcooler.

[0061] The indoor heat exchanger 31 is a cross-fin typed fin-and-tube heat exchanger formed by a heat transmission tube and a plurality of fins. The indoor heat exchanger 31 is configured to function as an evaporator of the refrigerant for cooling the indoor air in the cooling operation. On the other hand, the indoor heat exchanger 31 is configured to function as a gas cooler of the refrigerant for heating the indoor air in the heating operation.

[0062] The indoor expansion valve V6 is an electric expansion valve for regulating the pressure, the flow rate and the like of the refrigerant flowing through the indoor side refrigerant circuit 30. The indoor expansion valve V6 is connected to the liquid side of the indoor heat exchanger 31. In this regard, the indoor expansion valve V6 is similar to the aforementioned first outdoor expansion valve V2. In the cooling operation, the indoor expansion valve V6 is configured to be fully opened and causes the refrigerant to flow into the indoor heat exchanger 31 so as not to change pressure of the refrigerant. On the other hand, in the heating operation, the indoor expansion valve V6 is configured to function as the first-stage expansion mechanism of the two-stage expansion refrigeration cycle. When the indoor expansion valve V6 functions as the first-stage expansion mechanism, it is configured to decompress the refrigerant from the high pressure Ph to the intermediate pressure Pm. In this regard, the indoor expansion valve V6 is also similar to the first outdoor expansion valve V2. However, when the external temperature is equal to or greater than 31 degrees Celsius (i.e., the critical temperature of the CO_2 refrigerant) in the cooling operation, the indoor expansion valve V6 is configured to function as the second-stage expansion mechanism of the two-stage expansion refrigeration cycle, and is configured to decompress the refrigerant from the intermediate pressure Pm to the low pressure Pl.

[0063] The indoor subcooling heat exchanger 32 is a heat exchanger allowed to function as a subcooler and an evaporator. In the present embodiment, the indoor subcooling heat exchanger 32 is a cross-fin typed fin-and-tube heat exchanger for conducting heat exchange between the refrigerant and air functioning as a heat source. One end of the indoor subcooling heat exchanger 32 is connected to the indoor heat exchanger 31 via the indoor expansion valve V6 whereas the other end thereof is connected to the liquid refrigerant communication pipe 41. However, when the external temperature is equal to or greater than 31 degrees Celsius (i.e., the critical temperature of the CO_2 refrigerant) in the cooling operation, the indoor subcooling heat exchanger 32 is configured to function as an evaporator. In this regard, the indoor subcooling heat exchanger 32 is similar to the indoor heat exchanger 31.

[0064] Furthermore, the indoor unit 3 includes an indoor fan 33. The indoor fan 33 functions as a ventilation fan for sucking the indoor air into the indoor unit 3 and subsequently causing the sucked air to exchange heat with the refrigerant in the indoor heat exchanger 31 and thereafter supplying same to the indoor space as the supply air. The indoor fan 33 is a fan capable of changing the flow rate of air to be supplied to the indoor heat exchanger 31. In the present embodiment, the indoor fan 33 may be a centrifugal fan, a multi-blade fan and the like to be driven by a motor 34. Here, the motor 34 is composed of a DC fan motor.

[0065] Additionally, the indoor unit 3 is provided with various sensors. A first indoor subcooling temperature sensor T3 is provided between the indoor subcooling heat exchanger 32 and the indoor expansion valve V6. The first indoor subcooling temperature sensor T3 is configured to detect temperature of the refrigerant. Additionally, a second indoor subcooling temperature sensor T4 is provided on the liquid refrigerant communication pipe 41 side of the indoor subcooling heat exchanger 32. The second indoor subcooling temperature sensor T4 is configured to detect temperature of the refrigerant. In the present embodiment, each of the first and second indoor subcooling temperature sensors T3 and T4 is composed

of a thermistor.

[0066] Moreover, the indoor unit 3 is provided with the indoor side control section 35 for controlling operations of each of the elements forming the indoor unit 3. The indoor side control section 35 includes a microcomputer, a memory and the like provided for controlling the indoor unit 3. The indoor side control section 35 is capable of transmitting/receiving a control signal and the like to/from a remote controller (not illustrated in the figure) for independently operating a corresponding indoor unit 3 from other units. Additionally, the indoor side control section 35 is capable of transmitting/receiving, etc. a control signal and the like to/from the outdoor unit 2 through the transmission line 51.

(3) Refrigerant Communication Pipe

[0067] When the air conditioning apparatus 1 is installed in an installation place of a building and the like, the refrigerant communication pipe 4 is attached to the air conditioning apparatus 1 in the installation site. Any suitable refrigerant communication pipes 4 of a variety of lengths and diameters may be used depending on an installation condition (e.g., an installation site and a combination of the outdoor unit 2 and the indoor unit 3).

<Operation of Air Conditioning Apparatus>

[0068] Next, operations of the air conditioning apparatus 1 of the present embodiment will be explained.

[0069] The air conditioning apparatus 1 of the present embodiment is configured to be operated in two operation modes depending on operation loads of the indoor unit 3 necessary for cooling/heating the indoor space. One of the operation modes is a cooling operation for causing the indoor unit 3 to cool the indoor space while the other of the operation modes is a heating operation for causing the indoor unit 3 to heat the indoor space.

[0070] Operations of the air conditioning apparatus 1 in each of the operation modes will be hereinafter explained.

(1) Cooling Operation

[0071] First, the cooling operation will be explained with reference to Figs. 1 and 2. In the cooling operation, the four-way switch valve V1 in the outdoor side refrigerant circuit 20 of the outdoor unit 2 is switched to the solid-line condition illustrated in Fig. 1. Accordingly, the outdoor heat exchanger 23 is configured to function as a gas cooler, and the indoor heat exchanger 31 is configured to function as an evaporator.

[0072] When the compressor 21, the outdoor fan 25 and the indoor fan 33 are activated under the condition of the refrigerant circuit 10, gas refrigerant of the low pressure Pl is inhaled into the compressor 21 and is compressed to the high pressure Ph therein. The compressed gas refrigerant of the high pressure Ph flows into the outdoor heat exchanger 23. The outdoor heat exchanger 23 herein functions as a gas cooler. The outdoor heat exchanger 23 releases heat into the outdoor air supplied by the outdoor fan 25 for cooling the refrigerant. Subsequently, the first outdoor expansion valve V2 decompresses the gas refrigerant from the high pressure Ph to the intermediate pressure Pm equal to or less than the critical pressure Pk of the refrigerant. When the refrigerant is decompressed to the intermediate pressure Pm, it enters a gas-liquid two-phase state and flows into the outdoor subcooling heat exchanger 24. The refrigerant is further cooled in the outdoor subcooling heat exchanger 24 and changes into liquid refrigerant. Thus the refrigerant enters a subcooling state. The outdoor subcooling heat exchanger 24 stores the liquid refrigerant, and the second outdoor expansion valve V3 controls the amount of the liquid refrigerant stored in the outdoor subcooling heat exchanger 24. The amount of the liquid refrigerant stored in the outdoor subcooling heat exchanger 24 is controlled based on degree of subcooling of the refrigerant. The degree of subcooling of refrigerant is calculated based on temperatures detected by the first and second outdoor subcooling temperature sensors T1 and T2. The second outdoor expansion valve V3 herein decompresses the subcooling-state refrigerant to approximately the sucking pressure of the compressor 21. Thus the decompressed refrigerant changes into gas-liquid two-phase state refrigerant of the low pressure Pl.

[0073] Subsequently, the refrigerant of the low pressure Pl is transported to the indoor unit 3 through the liquid side stop valve V4 and the liquid refrigerant communication pipe 41. In the indoor unit 3, the indoor subcooling heat exchanger 32 and the indoor heat exchanger 31 conduct heat exchange between the indoor air and the transported liquid refrigerant of the low pressure Pl. Then, the liquid refrigerant of the low pressure Pl evaporates and changes into gas refrigerant of the low pressure Pl. At this time, the indoor expansion valve V6 is fully opened. The gas refrigerant of the low pressure Pl is transported to the outdoor unit 2 through the gas refrigerant communication pipe 42. Then, it is again inhaled into the compressor 21 through the gas side stop valve V5.

[0074] When the external temperature is 31 degrees Celsius or more (i.e., the critical temperature of the CO_2 refrigerant), another control, which is different from the aforementioned control, will be executed. The following is an explanation thereof. First, the first outdoor expansion valve V2 is fully opened, and the outdoor heat exchanger 23 and the outdoor subcooling heat exchanger 24 are caused to function as gas coolers. Next, the second outdoor expansion valve V3 decompresses the refrigerant of the high pressure Ph cooled by the outdoor heat exchanger 23 and the outdoor subcooling heat exchanger 24 to the intermediate pressure Pm equal to or less than the critical pressure Pk of the refrigerant. After the refrigerant is decompressed to the intermediate pressure Pm, it is transported to the indoor unit 3. The refrig-

erant is herein further cooled by the indoor subcooling heat exchanger 32 and changes into liquid refrigerant. Thus it enters a subcooling state. The indoor subcooling heat exchanger 32 stores the liquid refrigerant, and the indoor expansion valve V6 controls the amount of the liquid refrigerant stored in the indoor subcooling heat exchanger 32. The amount of the liquid refrigerant stored in the indoor subcooling heat exchanger 32 is controlled based on degree of subcooling of the refrigerant. The degree of subcooling of the refrigerant is calculated based on temperatures detected by the first and second indoor subcooling temperature sensors T3 and T4. The indoor expansion valve V6 decompresses the subcooling-state refrigerant to approximately the sucking pressure of the compressor 21. Accordingly, it changes into gas-liquid two-phase state refrigerant of the low pressure Pl. Then, the indoor heat exchanger 31 conducts heat exchange between the indoor air and the refrigerant of the low pressure Pl. The refrigerant evaporates and changes into gas refrigerant of the low pressure Pl. The gas refrigerant of the low pressure Pl is transported to the outdoor unit 2 through the gas refrigerant communication pipe 42. Then, the gas refrigerant is again inhaled into the compressor 21 through the gas side stop valve V5.

(2) Heating Operation

[0075] In the heating operation, the four-way switch valve V1 of the outdoor side refrigerant circuit 20 of the outdoor unit 2 is switched to the dashed-line condition in Fig. 1. Accordingly, the outdoor heat exchanger 23 is configured to function as an evaporator whereas the indoor heat exchanger 31 is configured to function as a gas cooler.

[0076] When the compressor 21, the outdoor fan 25 and the indoor fan 33 are activated under the condition of the refrigerant circuit 10, gas refrigerant of the low pressure Pl is inhaled into the compressor 21 and is compressed therein. The gas refrigerant of the low pressure Pl accordingly changes into gas refrigerant of the high pressure Ph, and is transported to the gas refrigerant communication pipe 42 through the four-way switch valve V1 and the gas side stop valve V5.

[0077] After the gas refrigerant of the high pressure Ph is transported to the gas refrigerant communication pipe 42, it is transported to the indoor unit 3. Subsequently, the gas refrigerant of the high pressure Ph transported to the indoor unit 3 is further transported to the indoor heat exchanger 31. The indoor heat exchanger 31 conducts heat exchange between the indoor air and the refrigerant for cooling the refrigerant. Accordingly, the refrigerant changes into liquid refrigerant of the high pressure Ph. Subsequently, when the liquid refrigerant passes through the indoor expansion valve V6, it is decompressed to the intermediate pressure Pm in accordance with degree of opening of the indoor expansion valve V6. When the refrigerant is decompressed to the intermediate pressure Pm, it changes into gas-liquid two-phase state refrigerant, and flows into the indoor subcooling heat exchanger 32. The indoor subcooling heat exchanger 32 further cools the refrigerant. The refrigerant thus changes into subcooling-state liquid refrigerant. The indoor subcooling heat exchanger 32 stores the liquid refrigerant, and the second outdoor expansion valve V3 controls the amount of the liquid refrigerant stored in the indoor subcooling heat exchanger 32. The amount of the liquid refrigerant stored in the indoor subcooling heat exchanger 32 is controlled based on degree of subcooling of the refrigerant. The degree of subcooling of the refrigerant is calculated based on temperatures detected by the first and second indoor subcooling temperature sensors T3 and T4.

[0078] The subcooling-state refrigerant is subsequently transported to the outdoor unit 2 through the liquid refrigerant communication pipe 41. The refrigerant is transported to the second outdoor expansion valve V3 through the liquid side stop valve V4. The second outdoor expansion valve V3 decompresses the refrigerant to approximately the sucking pressure of the compressor 21. The refrigerant thus changes into gas-liquid two-phase state refrigerant of the low pressure Pl. The outdoor subcooling heat exchanger 24 and the outdoor heat exchanger 23 conduct heat exchange between the external air and the decompressed refrigerant of the low pressure Pl. Accordingly the refrigerant evaporates and changes into gas refrigerant of the low pressure Pl. At this time, the first outdoor expansion valve V2 is fully opened. The gas refrigerant of the low pressure Pl is again inhaled into the compressor 21 through the four-way switch valve V1.

<Two-stage Expansion Refrigeration Cycle>

[0079] Fig. 2 illustrates the refrigeration cycle under the supercritical condition with a P-H chart (Mollier diagram). In the present invention, the CO_2 refrigerant (i.e., the supercritical refrigerant) is used as refrigerant. Moreover, the present invention adopts the two-stage expansion refrigeration cycle configured to expand the refrigerant in two stages with two expansion mechanisms. As described above, the refrigerant circuit 10 is mainly composed of the compressor 21, the outdoor heat exchanger 23, the first outdoor expansion valve V2, the outdoor subcooling heat exchanger 24, the second outdoor expansion valve V3, the indoor subcooling heat exchanger 32, the indoor expansion valve V6 and the indoor heat exchanger 31. Points A, B, C, D, E and F in Fig. 2 illustrate states of refrigerant at the corresponding points in Fig. 1 in the cooling operation. On the other hand, points (A), (B), (E), (F), (G) and (H) in Fig. 2 illustrate states of refrigerant at the corresponding points of Fig. 1 in the heating operation. Note that the two-stage expansion cycle in the cooling operation (i.e., when the external temperature is equal to or less than the critical temperature of the CO_2 refrigerant) will be hereinafter explained with reference to Figs. 1 and 2. Note it is possible to explain

the two-stage expansion cycle in the heating operation by replacing the points C, D, E and F with the points H, G, F and E, respectively.

[0080] In the refrigerant circuit 10, the compressor 21 compresses the refrigerant and the compressed refrigerant changes into high-temperature refrigerant of the high pressure Ph (A → B). At this time, the gas refrigerant, CO_2, enters a supercritical state. Note the term "supercritical state" means a state of material under temperature and pressure equal to or greater than the critical point K. Supercritical-state material has both gas diffusivity and liquid solubility. In Fig. 2, the supercritical state of the refrigerant is shown in the area positioned rightward of a critical temperature isothermal curve Tk at the critical pressure Pk or greater. When the refrigerant (material) enters a supercritical state, there is no distinction between gas phase and liquid phase. Additionally, the term "gas phase" is a state of the refrigerant shown by the area positioned rightward of a saturated vapor curve Sv at the critical pressure Pk or less. On the other hand, the term "liquid phase" is a state of the refrigerant shown by the area positioned leftward of both a saturated liquid curve Sl and the critical temperature isothermal curve Tk. After the refrigerant enters a supercritical state of high temperature and high pressure by the compression of the compressor 21, the outdoor heat exchanger 23 functioning as a gas cooler releases heat of the supercritical-state refrigerant. Accordingly, the refrigerant changes into low-temperature refrigerant of the high pressure Ph (B → C). At this time, the refrigerant is in a supercritical state. Therefore, the refrigerant operates with sensible heat change (i.e., temperature change) in the interior of the outdoor hear exchanger 23. After the outdoor heat exchanger 23 releases heat of the refrigerant, the refrigerant expands in conjunction with opening of the first outdoor expansion valve V2. Accordingly, the refrigerant of the high pressure Ph is decompressed to the intermediate pressure Pm (C → D). Subsequently, the refrigerant decompressed by the first outdoor expansion valve V2 to the intermediate pressure Pm flows into the outdoor subcooling heat exchanger 24 without changing its pressure. The outdoor subcooling heat exchanger 24 further cools the refrigerant. Accordingly, the refrigerant enters a subcooling state (D → E). Moreover, the second outdoor expansion valve V3 further expands the subcooling-state refrigerant. Thus the refrigerant changes into refrigerant of the low pressure Pl (E → F). The refrigerant of the low pressure Pl passes through the liquid refrigerant communication pipe 41, absorbs heat and evaporates in the indoor subcooling heat exchanger 32 and the indoor heat exchanger 31. Furthermore, the evaporated refrigerant passes through the gas refrigerant communication pipe 42, and returns to the compressor 21 (F → A).

<Characteristics>

(1)

[0081] In the present invention, the outdoor unit 2 further includes the four-way switch valve V1 capable of switching the operation modes between the cooling operation and the heating operation. Moreover, the control section 5 is configured to control the first and second outdoor expansion valves V2 and V3 when the four-way switch valve V1 is switched into the solid-line condition in Fig. 1 (i.e., the cooling operation). On the other hand, the control section 5 is configured to control the second outdoor expansion valve V3 and the indoor expansion valve V6 when the four-way switch valve V1 is switched into the dashed-line condition in Fig. 1 (i.e., the heating operation). When the external temperature is equal to or greater than the critical temperature of the refrigerant in the cooling operation, the control section 5 is configured to control the second outdoor expansion valve V3 and the indoor expansion valve V6 for storing the liquid refrigerant in the indoor subcooling heat exchanger 32 without storing it in the outdoor subcooling heat exchanger 24.

[0082] Therefore, the control section 5 is capable of regulating the intermediate pressure of the refrigerant by controlling the first outdoor expansion valve V2 in the cooling operation. On the other hand, the control section 5 is capable of regulating the intermediate pressure of the refrigerant by controlling the indoor expansion valve V6 in the heating operation. Moreover, the control section 5 is capable of regulating the amount of the liquid refrigerant in the outdoor subcooling heat exchanger 24 by controlling the second outdoor expansion valve V3 in the cooling operation. On the other hand, the control section 5 is capable of regulating the amount of the liquid refrigerant in the indoor subcooling heat exchanger 32 in the heating operation. When the refrigerant exceeds the critical point, it enters a supercritical state. It is thus difficult to control the amount of the refrigerant in this condition. By the same token, it is difficult to store the refrigerant in the outdoor subcooling heat exchanger 24 when the external temperature is equal to or greater than 31 degrees Celsius (i.e., the critical temperature of the refrigerant). Furthermore, temperature of the indoor air is often equal to or less than 31 degrees Celsius (i.e., the critical temperature of the CO_2 refrigerant) because the indoor heat exchanger 31 functions as an evaporator. Therefore, it is possible to store the liquid refrigerant in the indoor subcooling heat exchanger 32 by the control section 5 controlling both the second outdoor expansion valve V3 and the indoor expansion valve V6.

(2)

[0083] In the present invention, the outdoor unit 2 includes the first and second outdoor subcooling temperature sensors T1 and T2 at the refrigerant inlet and the

refrigerant outlet of the outdoor subcooling heat exchanger 24 for detecting degree of subcooling. It is possible to obtain the intermediate pressure Pm and the outlet temperature of the outdoor subcooling heat exchanger 24 with the temperature sensors T1 and T2 when the external temperature is less than 31 degrees Celsius in the cooling operation. Moreover, the indoor unit 3 includes the first and second indoor subcooling temperature sensors T3 and T4 at the refrigerant inlet and the refrigerant outlet of the indoor subcooling heat exchanger 32 for detecting degree of subcooling. It is possible to obtain the intermediate pressure Pm and the outlet temperature of the indoor subcooling heat exchanger 32 with the temperature sensors T3 and T4 both in the heating operation and in the cooling operation when the external temperature is equal to or greater than 31 degrees Celsius.

[0084] Therefore, the control section 5 is capable of calculating degree of subcooling based on the intermediate pressure Pm and the outlet temperature of the outdoor subcooling heat exchanger 24 or that of the indoor subcooling heat exchanger 32. Consequently, the control section 5 is capable of storing the liquid refrigerant in the outdoor subcooling heat exchanger 24 or the indoor subcooling heat exchanger 32 functioning as a subcooling heat exchanger based on degree of subcooling of the refrigerant, and is capable of regulating the amount of the refrigerant.

(3)

[0085] In the present invention, the CO_2 refrigerant is used as refrigerant. The global warming potential (GWP) value of the CO_2 refrigerant equals to 1. The value is much lower than conventional refrigerant such as fluorocarbon refrigerant having the GWP value of approximately hundreds to ten thousand.

[0086] Therefore, use of the CO_2 refrigerant less burdening the environment makes it possible to inhibit worsening of the global environment.

<Modifications>

(1)

[0087] The air conditioning apparatus 1 of the present embodiment is a so-called pair-type air conditioning device, and single indoor unit 3 is connected to single outdoor unit 2. However, the air conditioning apparatus 1 is not limited to the structure. For example, the air conditioning apparatus of the present invention may be a multi-type air conditioning apparatus 1a, and a plurality of indoor units may be connected to single outdoor unit. As illustrated in Fig. 3, for instance, three indoor units 3a, 3b and 3c may be parallel-connected to single outdoor unit 2. Elements of the indoor units 3a, 3b and 3c in Fig. 3 correspond to those of the indoor unit 3 explained in the present embodiment, respectively. Additionally, "a", "b" and "c" are added at the end of reference numerals of the elements of the indoor units 3a, 3b and 3c. For example, the indoor fan 33 of the indoor unit 3 corresponds to the indoor fans 33a, 33b and 33c of the indoor units 3a, 3b and 3c, respectively. The indoor unit 3 has the same structure as the indoor units 3a, 3b and 3c. In the example of Fig. 3, three indoor units 3a to 3c are connected to the outdoor unit 2. However, the number of the indoor units is not limited to this. For example, any suitable number (e.g., two, four or five) of the indoor units may be connected to the outdoor unit 2.

[0088] The air conditioning apparatus 1a of the present modification is provided with a plurality of the indoor units 3a to 3c. Accordingly, when different operation loads are applied to the indoor units 3a to 3c in their installation places, the air conditioning apparatus 1a allows the indoor units 3a to 3c to independently operate for coping with the respective operational loads. Therefore, when operational loads vary in places, the air conditioning apparatus 1a is capable of more efficiently operating compared to an air conditioning apparatus with single indoor unit.

(2)

[0089] In the air conditioning apparatus of the present embodiment, the outdoor unit 2 is provided with the first outdoor expansion valve V2 as an expansion mechanism while the indoor unit 3 is provided with the indoor expansion valve V6 as an expansion mechanism. However, the expansion mechanisms are not limited to the expansion valves. For example, expansion devices may be used as the expansion mechanisms.

(3)

[0090] In the air conditioning apparatus of the present embodiment, temperature sensors are respectively provided at the inlet and the outlet of the outdoor subcooling heat exchanger 24 and at the inlet and the outlet of the indoor subcooling heat exchanger 32 for calculating degree of subcooling of the refrigerant. However, the sensors provided at the refrigerant inlet side of the subcooling heat exchangers 24 and 32 are not limited to the temperature sensors. For example, pressure sensors may be provided therein. Specifically, pressure sensors may be used instead of the first outdoor subcooling temperature sensor T1 disposed in the refrigerant flow directional inlet side of the outdoor subcooling heat exchanger 24 functioning as a subcooler in the cooling operation and the first indoor subcooling temperature sensor T3 disposed in the refrigerant flow directional inlet side of the indoor subcooling heat exchanger 32 functioning as a subcooler in the heating operation. However, when the external temperature is equal to or greater than 31 degrees Celsius in the cooling operation, not the outdoor subcooling heat exchanger 24 but the indoor subcooling heat exchanger 32 functions as a subcooler. Therefore, the sensor disposed at the refrigerant flow directional out-

let side of the indoor subcooling heat exchanger 32 (i.e., the first indoor subcooling temperature sensor T3) has to be a temperature sensor in this case. In the present embodiment, it is thus possible to only replace the first outdoor subcooling temperature sensor T1 with a pressure sensor.

[0091] Moreover, pressure sensors may be further provided at the refrigerant flow directional inlet sides of the subcooling heat exchangers 24 and 32, respectively, in addition to temperature sensors.

(4)

[0092] In the air conditioning apparatus 1 of the present embodiment, the outdoor air is used as a heat source. However, the heat source is not limited to the outdoor air. For example, water and the like may be used as a heat source.

(5)

[0093] The air conditioning apparatus of the present embodiment includes the four-way switch valve V1 in the outdoor unit 2, and is capable of executing both the cooling and heating operations. However, the air conditioning apparatus of the present invention is not limited to the structure. For example, as illustrated in Figs 4 and 5, the air conditioning apparatus of the present invention may be an air conditioning apparatus 1b exclusively used for the cooling operation without any four-way switch valves or an air conditioning apparatus 1c exclusively used for the heating operation without any four-way switch valves.

[0094] Specifically, the air conditioning apparatus 1b exclusively used for the cooling operation in Fig. 4 is configured to control the first and second outdoor expansion valves V2 and V3 for storing the liquid refrigerant in the outdoor subcooling heat exchanger 24. On the other hand, the air conditioning apparatus 1c exclusively used for the heating operation in Fig. 5 is configured to control the first and second outdoor expansion valves V2 and V3 for storing the liquid refrigerant in the outdoor subcooling heat exchanger 24. In this regard, the air conditioning apparatus 1c in Fig. 5 is similar to the air conditioning apparatus 1b in Fig. 4.

(6)

[0095] In the air conditioning apparatus of the present embodiment, the outdoor unit 2 is provided with the outdoor subcooling heat exchanger 24 whereas the indoor unit 3 is provided with the indoor subcooling heat exchanger 32. Furthermore, the refrigerant circuit 10 is provided with two devices functioning as subcooling heat exchangers. However, structure of the air conditioning apparatus is not limited to this. As illustrated in Fig. 6, for instance, an air conditioning apparatus 1d may be provided with single device configured to function as a subcooling heat exchanger.

[0096] Specifically, in the air conditioning apparatus 1d of Fig. 6, only an outdoor unit 2 is provided with an outdoor subcooling heat exchanger 24. The outdoor unit 2 is further provided with first and second outdoor expansion valves V2 and V3 so as to sandwich the outdoor subcooling heat exchanger 24 therebetween. In both the cooling and heating operations, the air conditioning apparatus 1d is configured to control the first and second outdoor expansion valves V2 and V3 for storing the liquid refrigerant in the outdoor subcooling heat exchanger 24.

INDUSTRIAL APPLICABILITY

[0097] The air conditioning apparatus of the present invention is capable of optimally controlling high pressure of refrigerant by regulating the circulation amount of refrigerant. Additionally, the air conditioning apparatus is useful as an air conditioning apparatus and the like using supercritical refrigerant operating in the supercritical zone for easily regulating the circulation amount of supercritical refrigerant.

Claims

1. A refrigeration apparatus (1b) using refrigerant operating in the supercritical zone, comprising:

   a compressor (21) configured to compress the refrigerant;
   a first heat exchanger (23) configured to cool the high pressure refrigerant compressed by the compressor;
   a first expansion mechanism (V2) configured to decompress the refrigerant to critical pressure or less;
   a subcooling heat exchanger (24) configured to subcool the refrigerant decompressed by the first expansion mechanism;
   a second expansion mechanism (V3) configured to decompress the refrigerant cooled by the subcooling heat exchanger to low pressure;
   a second heat exchanger (31) configured to heat the refrigerant decompressed by the second expansion mechanism; and
   a control section (5) configured to conduct first control to regulate the first and second expansion mechanisms for storing the refrigerant of a liquid state in the subcooling heat exchanger.

2. The refrigeration apparatus (1b) according to claim 1,
   further comprising subcooling information obtaining means configured to obtain subcooling information used for calculating degree of subcooling of the refrigerant in the subcooling heat exchanger, and
   wherein the control section is configured to calculate the degree of subcooling based on the subcooling

information, and
the first control is conducted based on the degree of subcooling.

3. The refrigeration apparatus (1b) according to claim 2, wherein the subcooling information obtaining means is composed of an inlet temperature sensor (T1) capable of detecting refrigerant inlet temperature of the subcooling heat exchanger and an outlet temperature sensor (T2) capable of detecting refrigerant outlet temperature of the subcooling heat exchanger.

4. The refrigeration apparatus according to claim 2, wherein the subcooling information obtaining means is composed of an inlet pressure sensor capable of detecting refrigerant inlet pressure of the subcooling heat exchanger and an outlet temperature sensor capable of detecting refrigerant outlet temperature of the subcooling heat exchanger.

5. A refrigeration apparatus (1d) using refrigerant operating in the supercritical zone, comprising:

a compressor (21) configured to compress the refrigerant;
a first heat exchanger (23) configured to conduct heat exchange of the refrigerant;
a first expansion mechanism (V2) configured to decompress the refrigerant;
a subcooling heat exchanger (24) configured to subcool the refrigerant;
a second expansion mechanism (V3) configured to decompress the refrigerant;
a second heat exchanger (31) configured to conduct heat exchange of the refrigerant;
a switch mechanism (V1) configured to be capable of switching between a first condition and a second condition,
the first condition causing the refrigerant evaporated in the second heat exchanger to flow into the compressor and causing the refrigerant compressed in the compressor to flow into the first heat exchanger,
the second condition causing the refrigerant evaporated in the first heat exchanger to flow into the compressor and causing the refrigerant compressed in the compressor to flow into the second heat exchanger; and
a control section (5) configured to conduct first control and second control,
the first control being configured to cause the first expansion mechanism to decompress the refrigerant from high pressure to intermediate pressure equal to or less than the supercritical pressure and cause the second expansion mechanism to decompress the intermediate pressure refrigerant subcooled by the subcooling heat exchanger to low pressure for storing the refrigerant of a liquid state in the subcooling heat exchanger in the first condition switched by the switch mechanism, and
the second control being configured to cause the second expansion mechanism to decompress the refrigerant from high pressure to the intermediate pressure equal to or less than the supercritical pressure and cause the first expansion mechanism to decompress the intermediate pressure refrigerant subcooled by the subcooling heat exchanger to low pressure for storing the refrigerant of a liquid state in the subcooling heat exchanger in the second condition switched by the switch mechanism.

6. The refrigeration apparatus (1d) according to claim 5,
further comprising subcooling information obtaining means configured to obtain subcooling information used for calculating degree of subcooling of the refrigerant in the subcooling heat exchanger, and
wherein the control section is configured to calculate the degree of subcooling based on the subcooling information, and
the first control or the second control is conducted based on the degree of subcooling.

7. A refrigeration apparatus (1) using refrigerant operating in the supercritical zone, comprising:

a heat source unit (2) including;
a compressor (21) configured to compress the refrigerant;
a heat source side heat exchanger (23) configured to conduct heat exchange between the refrigerant and first fluid;
a first expansion mechanism (V2) capable of decompressing the refrigerant;
a heat source side auxiliary heat exchanger (24) configured to conduct heat exchange of the refrigerant;
a second expansion mechanism (V3) capable of decompressing the refrigerant; and
a switch mechanism (V1) capable of switching between a first condition and a second condition,
the first condition causing the refrigerant to flow into the compressor after a utilization side heat exchanger conducts the heat exchange of the refrigerant and causing the refrigerant compressed by the compressor to flow into the heat source side heat exchanger,
the second condition causing the refrigerant to flow into the compressor after the heat source side heat exchanger conducts the heat exchange of the refrigerant and causing the refrigerant compressed by the compressor to flow into the utilization side heat exchanger;

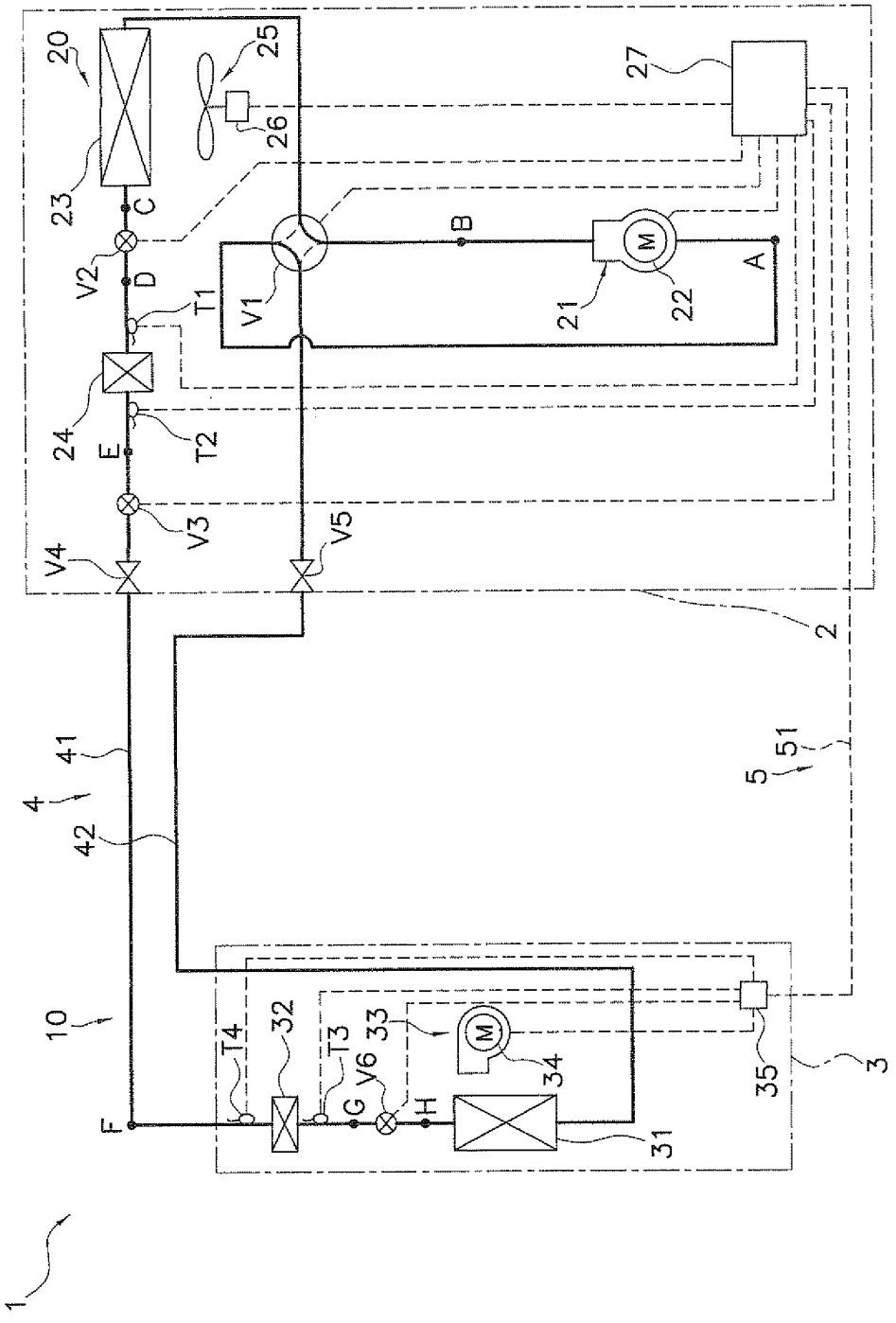
a utilization unit (3) including the utilization side heat exchanger (31) configured to conduct heat exchange of the refrigerant, a third expansion mechanism (V6) capable of decompressing the refrigerant, and a utilization side auxiliary heat exchanger (32) configured to conduct heat exchange of the refrigerant; and
a control section (5) configured to conduct first control, second control and third control,
the first control being configured to cause the heat source side auxiliary heat exchanger to function as a subcooler and regulate the first and second expansion mechanisms for storing the refrigerant of a liquid state in the heat source side auxiliary heat exchanger when temperature of the first fluid is less than the critical temperature of the refrigerant in the first condition switched by the switch mechanism,
the second control being configured to cause the utilization side auxiliary heat exchanger to function as a subcooler and regulate the second and third expansion mechanisms for storing the refrigerant of a liquid state in the utilization side auxiliary heat exchanger when temperature of the first fluid is equal to or greater than the critical temperature of the refrigerant in the first condition switched by the switch mechanism, and
the third control being configured to cause the utilization side auxiliary heat exchanger to function as a subcooler and regulate the second and third expansion mechanisms for storing the refrigerant of a liquid state in the utilization side auxiliary heat exchanger in the second condition switched by the switch mechanism.

8. The refrigeration apparatus (1) according to claim 7, wherein the heat source unit further includes heat source side subcooling information obtaining means capable of detecting first subcooling degree of the heat source side auxiliary heat exchanger,
the utilization unit further includes utilization side subcooling information obtaining means capable of detecting second subcooling degree of the utilization side auxiliary heat exchanger,
the first control is conducted based on the first subcooling degree, and
the second and third controls are conducted based on the second subcooling degree.

9. The refrigeration apparatus (1) according to claim 8, wherein the heat source side subcooling information obtaining means is composed of a first inlet temperature sensor (T1) capable of detecting refrigerant inlet temperature of the heat source side auxiliary heat exchanger and a first outlet temperature sensor (T2) capable of detecting refrigerant outlet temperature of the heat source side auxiliary heat exchanger.

10. The refrigeration apparatus (1) according to claim 8 or claim 9, wherein the utilization side subcooling information obtaining means is composed of a second inlet temperature sensor capable of detecting refrigerant inlet temperature of the utilization side auxiliary heat exchanger and a second outlet temperature sensor capable of detecting refrigerant outlet temperature of the utilization side auxiliary heat exchanger.

11. The refrigeration apparatus (1) according to any of claims 1 to 10, wherein the refrigerant is carbon dioxide (CO_2) refrigerant.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A
B
C
D
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F
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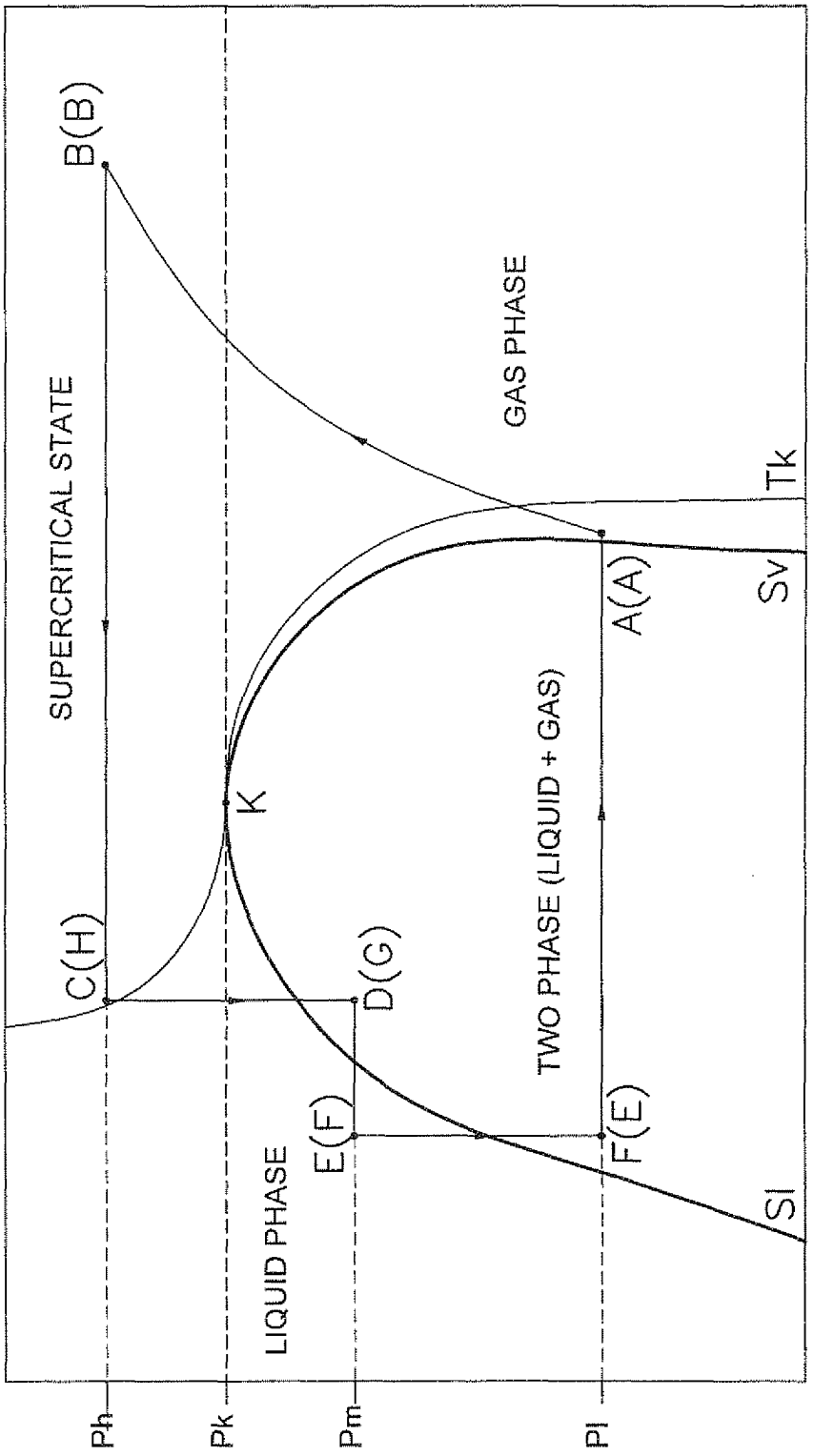
H
T1
T2
T3
T4
V1
V2
V3
V4
V5
V6
M

FIG. 1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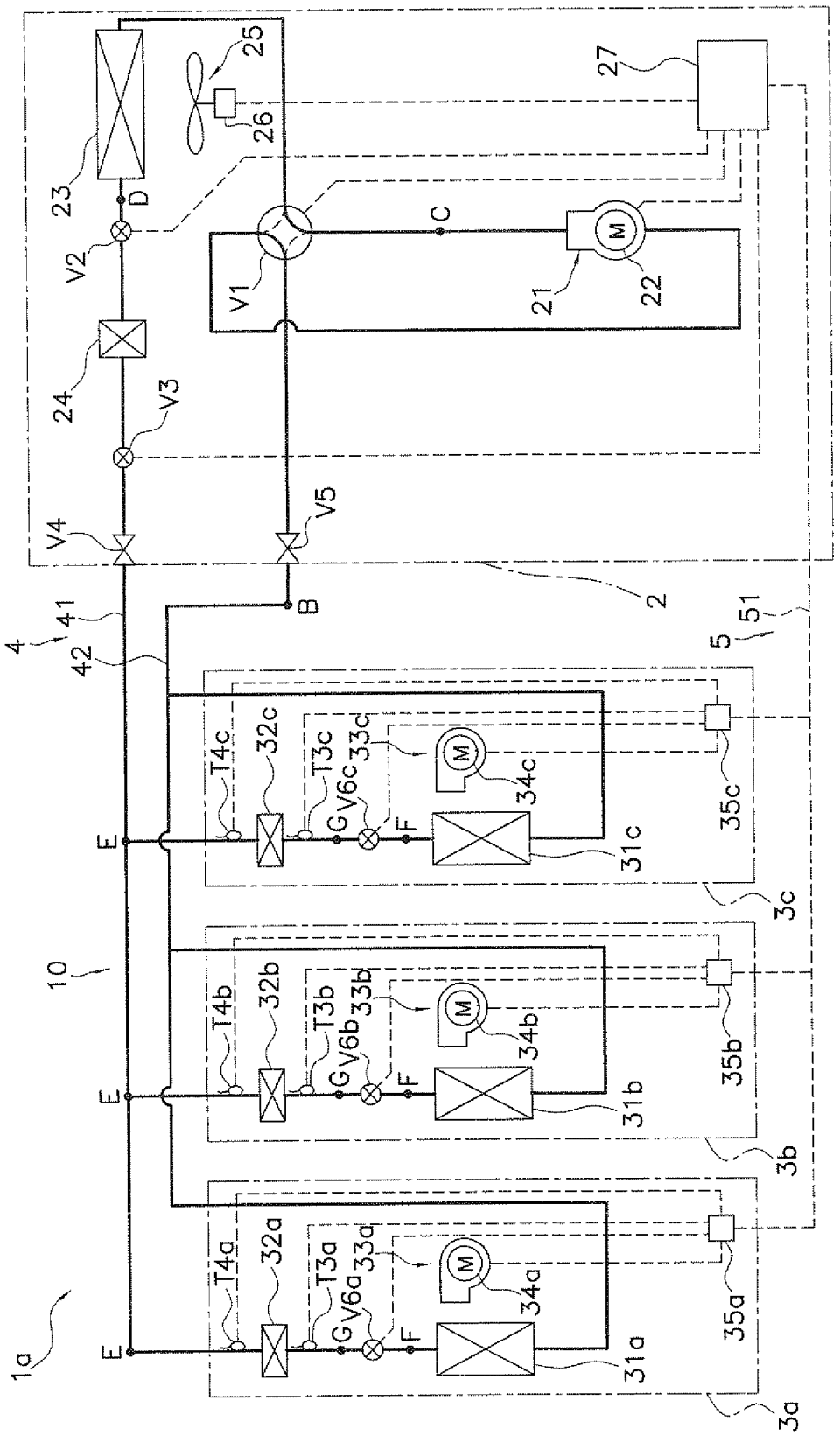
SUPERCRITICAL STATE
GAS PHASE
Tk
Sv
A(A)
K
C(H)
D(G)
TWO PHASE (LIQUID + GAS)
E(F)
F(E)
LIQUID PHASE
Sl
Ph
Pk
Pm
Pl
REFRIGERANT PRESSURE (P)
ENTHALPY (h)

FIG. 2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3a
3b
3c
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31c
32a
32b
32c
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34c
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35b
35c
A
B
C
D
E
F
G
M
T3a
T3b
T3c
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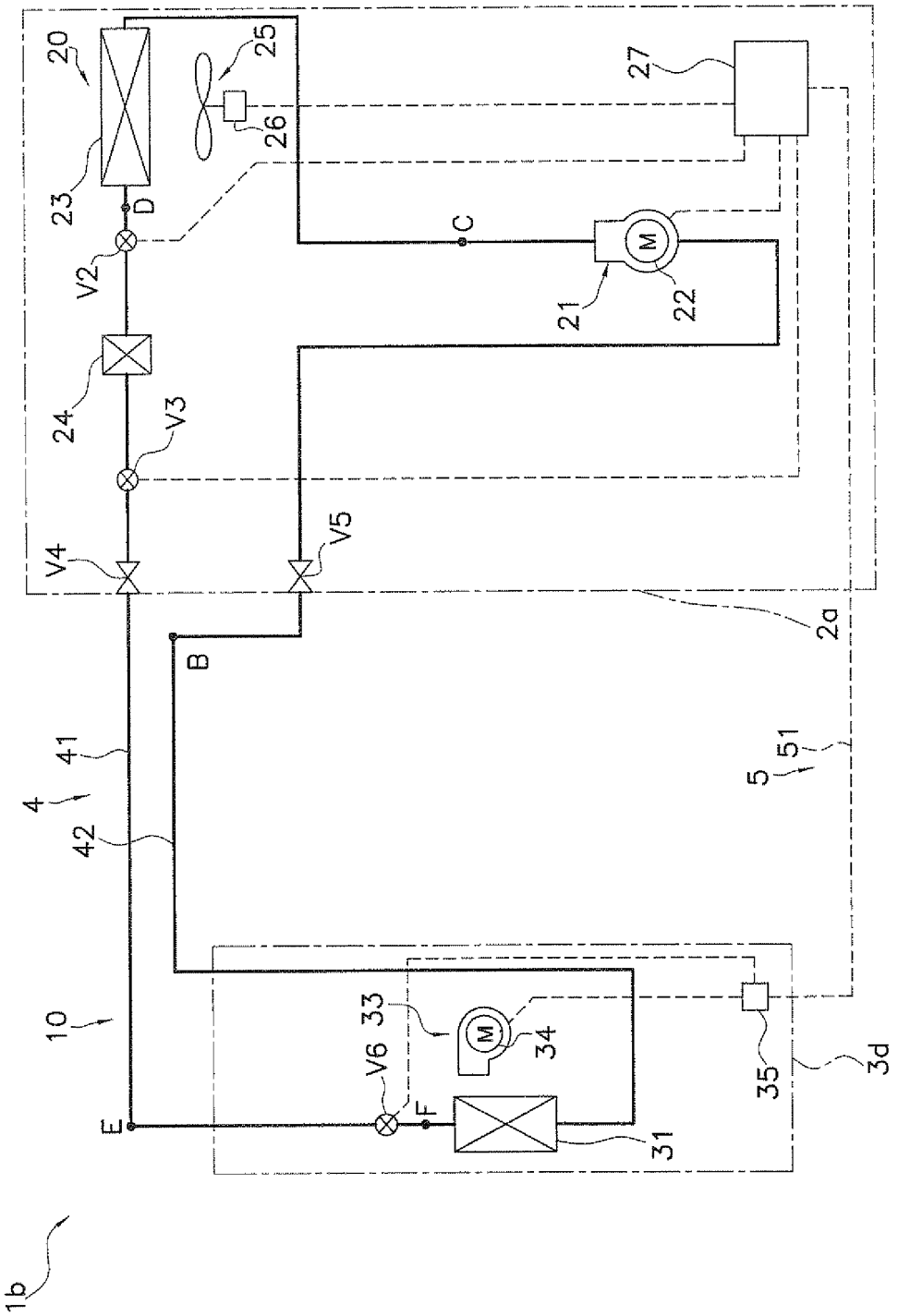
T4b
T4c
V1
V2
V3
V4
V5
V6a
V6b
V6c

FIG. 3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23
D
C
V2
M
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22
24
V3
V4
V5
2a
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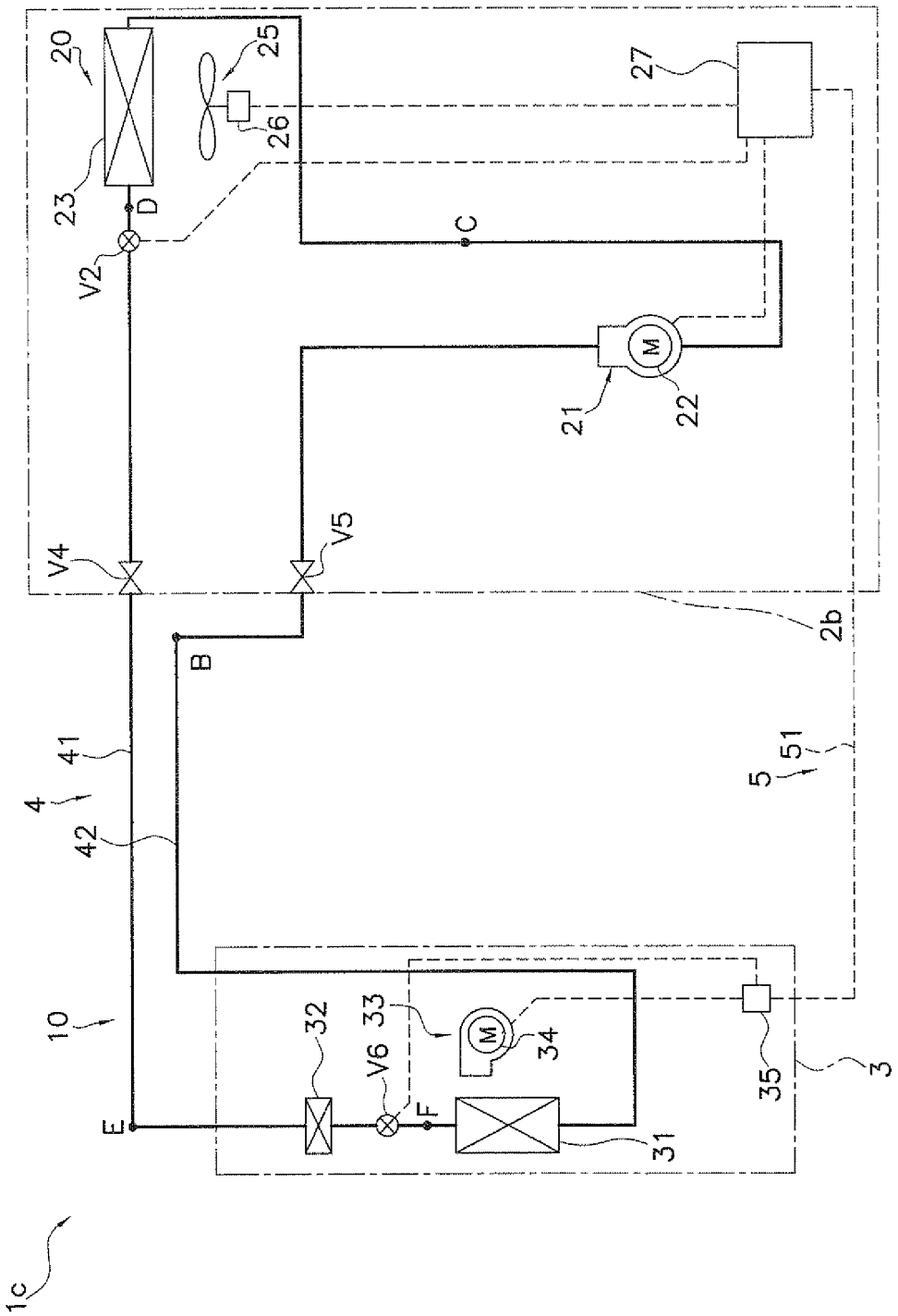
M
34
V6
F
35
3d
E
31
1b

FIG. 4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V6
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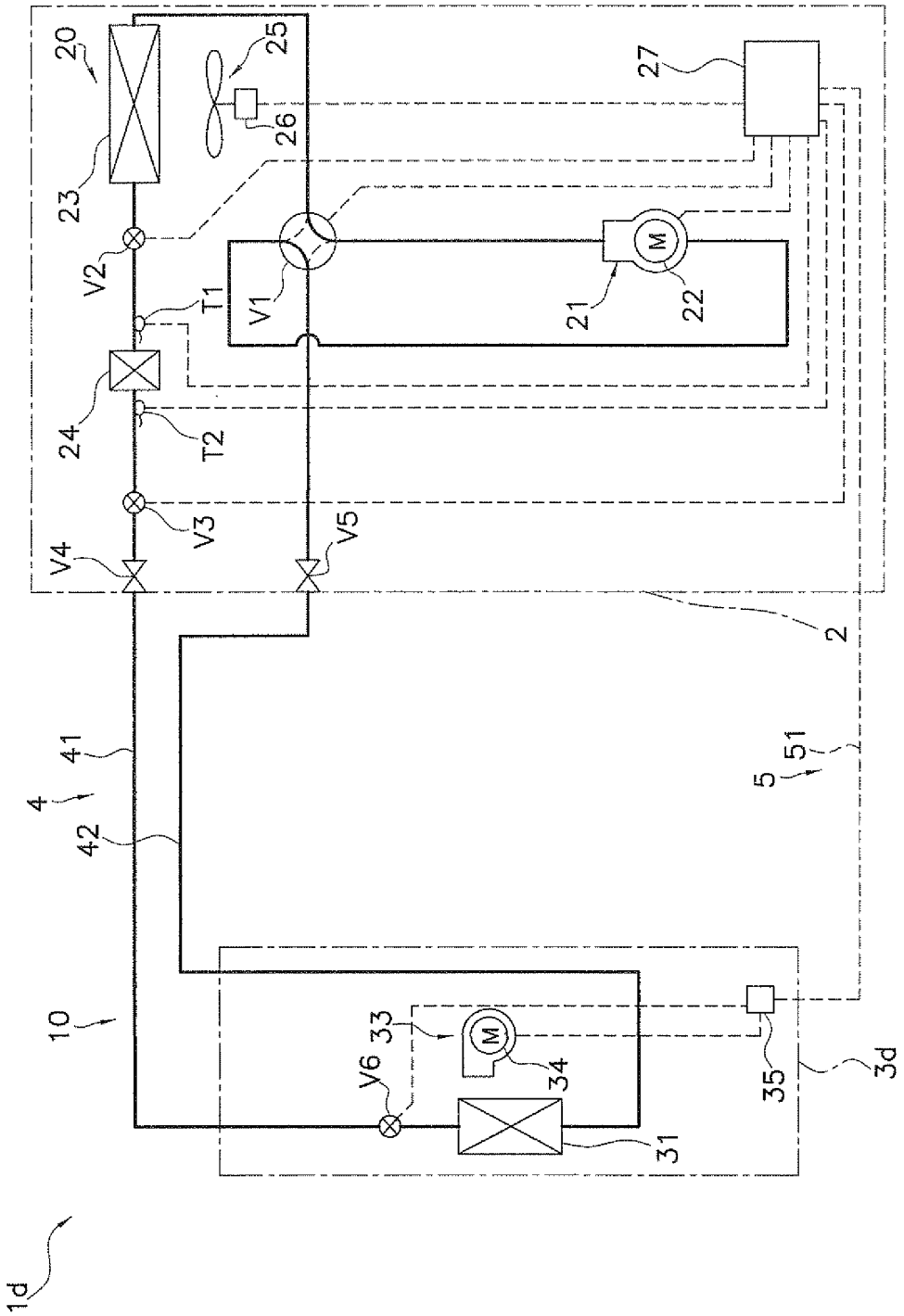
31
1c

FIG. 5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23
25
26
27
V2
T1
V1
21
22
24
T2
V3
V5
V4
2
41
4
42
5
51
V6
33
34
35
3d
31

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2007/071616

A. CLASSIFICATION OF SUBJECT MATTER
F25B1/00(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F25B1/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2008
Kokai Jitsuyo Shinan Koho 1971-2008 Toroku Jitsuyo Shinan Koho 1994-2008

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.
X A	JP 2002-168536 A (Mitsubishi Heavy Industries, Ltd.), 14 June, 2002 (14.06.02), Full text; Figs. 1 to 3 (Family: none)	1-6,11 7-10
A	JP 2005-226950 A (Mitsubishi Electric Corp.), 25 August, 2005 (25.08.05), Full text; Figs. 1 to 12 (Family: none)	1-11
A	JP 2004-100979 A (Matsushita Electric Industrial Co., Ltd.), 02 April, 2004 (02.04.04), Full text; Figs. 1 to 16 (Family: none)	1-11

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

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
01 February, 2008 (01.02.08)	12 February, 2008 (12.02.08)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (April 2007)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2007/071616

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 2000-205670 A (Sanden Corp.), 28 July, 2000 (28.07.00), Full text; Figs. 1 to 7 & EP 1026459 A1	1-11
A	JP 2001-4235 A (Sanden Corp.), 12 January, 2001 (12.01.01), Full text; Figs. 1 to 11 (Family: none)	1-11

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP H1054617 A **[0002]**