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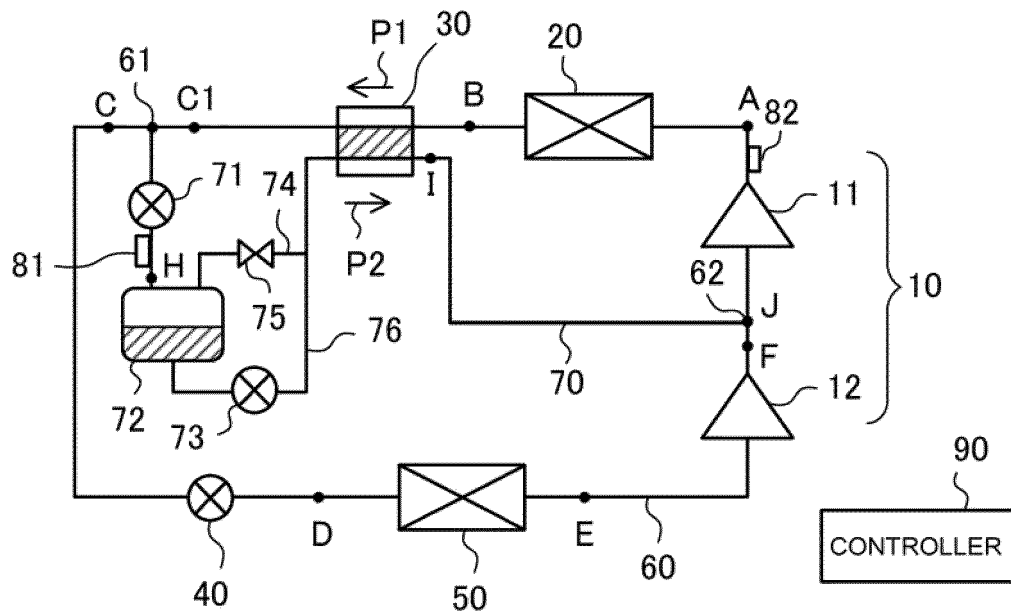
(54) **REFRIGERATION CYCLE DEVICE**

(57) A refrigeration cycle apparatus includes a controller, a low-stage compressor configured to compress refrigerant from a first pressure to an intermediate pressure that is higher than the first pressure, a high-stage compressor configured to compress the refrigerant having the intermediate pressure from the intermediate pressure to a second pressure that is higher than the intermediate pressure, a condenser through which the refrigerant having the second pressure exchanges heat with air, an INJ branch unit through which the refrigerant flowing out from the condenser is divided into first refrigerant and second refrigerant, an expansion valve configured to expand the first refrigerant divided through the INJ branch unit to decompress the first refrigerant to the first pressure, an evaporator through which the first refrigerant flowing out from the expansion valve exchanges heat with air and from which the first refrigerant having the first pressure flows out toward the low-stage compressor, an INJ junction unit located between a discharge port of the low-stage compressor and a suction port of the

high-stage compressor, and an injection circuit located between the INJ branch unit and the INJ junction unit and through which the second refrigerant divided through the INJ branch unit is sucked into the high-stage compressor. The injection circuit includes an INJ expansion valve configured to expand the second refrigerant and a receiver configured to divide the second refrigerant expanded by the INJ expansion valve into liquid refrigerant and gas refrigerant and store the liquid refrigerant and the gas refrigerant. The stored liquid refrigerant flows out from the receiver toward the INJ junction unit. The controller is configured to control a ratio of a displacement of the high-stage compressor to a displacement of the low-stage compressor. The displacement of the low-stage compressor is a value obtained by multiplying a volume of the low-stage compressor and a rotating speed of the low-stage compressor. The displacement of the high-stage compressor is a value obtained by multiplying a volume of the high-stage compressor and a rotating speed of the high-stage compressor.

EP 4 350 247 A1

FIG. 1



Description

Technical Field

5 **[0001]** The present disclosure relates to a refrigeration cycle apparatus including an injection circuit.

Background Art

10 **[0002]** Some multistage-compression refrigeration cycle apparatus has been known that includes a low-stage compressor and a high-stage compressor and compresses refrigerant in two stages (see, for example, Patent Literature 1).

[0003] In the refrigeration cycle apparatus described in Patent Literature 1, the low-stage compressor, the high-stage compressor, a radiator, a heat inter changer, a first expansion valve, and an evaporator are connected by refrigerant pipes.

15 **[0004]** In the refrigeration cycle apparatus described in Patent Literature 1, an injection circuit is provided as a bypass for refrigerant having an intermediate pressure. One end of the injection circuit is connected between the radiator and the heat inter changer. The other end of the injection circuit is connected between a discharge port of the low-stage compressor and a suction port of the high-stage compressor. The injection circuit is provided with a second expansion valve. The heat inter changer described above is located downstream of the second expansion valve.

20 **[0005]** The low-stage compressor compresses sucked refrigerant from a low pressure to an intermediate pressure. The high-stage compressor compresses the refrigerant discharged from the low-stage compressor and having an intermediate pressure to a high pressure. The refrigerant discharged from the high-stage compressor flows into the radiator. Through the radiator, the refrigerant exchanges heat with air, and is thus condensed. In the heat inter changer, subcooling is provided to the refrigerant condensed through the radiator. Hereinafter, this refrigerant to which subcooling has been provided is referred to as "first refrigerant."

25 **[0006]** Meanwhile, the refrigerant condensed through the radiator is partially divided into the injection circuit. In the injection circuit, this refrigerant is decompressed by the second expansion valve and thereafter flows into the heat inter changer. In the heat inter changer, this refrigerant provides subcooling to the first refrigerant. Hereinafter, the refrigerant having provided subcooling to the first refrigerant is referred to as "second refrigerant." Thereafter, the second refrigerant is guided to the discharge side of the low-stage compressor that is the suction side of the high-stage compressor.

30 **[0007]** Meanwhile, the first refrigerant to which subcooling has been provided in the heat inter changer is guided to the first expansion valve. The first refrigerant expanded to a low pressure by the first expansion valve flows into the evaporator. Through the evaporator, the first refrigerant exchanges heat with air, and thus evaporates. The first refrigerant having evaporated through the evaporator is sucked into the low-stage compressor.

35 **[0008]** At the start-up of the refrigeration cycle apparatus described in Patent Literature 1, this refrigeration cycle apparatus causes the low-stage compressor and the high-stage compressor to start operating at individual rotating speeds that are lower than their respective maximum possible rotating speeds at which the low-stage compressor and the high-stage compressor exhibit maximum possible performance, and to increase the individual rotating speeds in stages.

Citation List

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Patent Literature

[0009] Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2012-247154

45 Summary of Invention

Technical Problem

50 **[0010]** If the refrigeration cycle apparatus described in Patent Literature 1 controls the value of intermediate pressure, this refrigeration cycle apparatus is supposed to, for example, increase or decrease the rotating speed of the high-stage compressor, thereby to control this value. When the rotating speed of the high-stage compressor is simply increased to reduce the intermediate pressure, a condensation load in the radiator increases. There is thus a possibility that a discharge pressure (that is, a high pressure) of the high-stage compressor may excessively increase.

55 **[0011]** The present disclosure has been made to solve the above problems, and it is an object of the present disclosure to provide a refrigeration cycle apparatus in which it is possible to reduce or eliminate an excessive increase in high pressure, while reducing an intermediate pressure.

Solution to Problem

[0012] A refrigeration cycle apparatus according to an embodiment of the present disclosure includes a controller, a low-stage compressor configured to compress refrigerant from a first pressure to an intermediate pressure that is higher than the first pressure, a high-stage compressor configured to compress the refrigerant having the intermediate pressure from the intermediate pressure to a second pressure that is higher than the intermediate pressure, a condenser through which the refrigerant having the second pressure exchanges heat with air, an INJ branch unit through which the refrigerant flowing out from the condenser is divided into first refrigerant and second refrigerant, an expansion valve configured to expand the first refrigerant divided through the INJ branch unit to decompress the first refrigerant to the first pressure, an evaporator through which the first refrigerant flowing out from the expansion valve exchanges heat with air and from which the first refrigerant having the first pressure flows out toward the low-stage compressor, an INJ junction unit located between a discharge port of the low-stage compressor and a suction port of the high-stage compressor, and an injection circuit located between the INJ branch unit and the INJ junction unit and through which the second refrigerant divided through the INJ branch unit is sucked into the high-stage compressor. The injection circuit includes an INJ expansion valve configured to expand the second refrigerant and a receiver configured to divide the second refrigerant expanded by the INJ expansion valve into liquid refrigerant and gas refrigerant and store the liquid refrigerant and the gas refrigerant. The stored liquid refrigerant flows out from the receiver toward the INJ junction unit. The controller is configured to control a ratio of a displacement of the high-stage compressor to a displacement of the low-stage compressor. The displacement of the low-stage compressor is a value obtained by multiplying a volume of the low-stage compressor and a rotating speed of the low-stage compressor. The displacement of the high-stage compressor is a value obtained by multiplying a volume of the high-stage compressor and a rotating speed of the high-stage compressor.

Advantageous Effects of Invention

[0013] In the refrigeration cycle apparatus according to an embodiment of the present disclosure, the injection circuit is provided with the receiver to control the ratio of the displacement of the high-stage compressor to the displacement of the low-stage compressor, and thereby control the intermediate pressure that is an internal pressure in the receiver. Therefore, the refrigeration cycle apparatus can reduce or eliminate an excessive increase in the high pressure that is a discharge pressure of the high-stage compressor, while reducing the intermediate pressure.

Brief Description of Drawings

[0014]

[Fig. 1] Fig. 1 is a refrigerant circuit diagram illustrating the configuration of a refrigeration cycle apparatus according to Embodiment 1.

[Fig. 2] Fig. 2 is a perspective view illustrating an example of the configuration of a heat inter changer (HIC) provided in the refrigeration cycle apparatus according to Embodiment 1.

[Fig. 3] Fig. 3 is a p-h diagram illustrating a refrigeration cycle when a refrigeration cycle apparatus described in Patent Literature 1 uses a high-pressure supercritical refrigerant such as CO₂.

[Fig. 4] Fig. 4 is a flowchart illustrating a processing flow of a control method (M1) in the refrigeration cycle apparatus according to Embodiment 1.

[Fig. 5] Fig. 5 is a flowchart illustrating a processing flow of a control method (M2) in the refrigeration cycle apparatus according to Embodiment 1.

[Fig. 6] Fig. 6 is a p-h diagram illustrating a refrigeration cycle of the refrigeration cycle apparatus according to Embodiment 1.

Description of Embodiments

[0015] Hereinafter, an embodiment of a refrigeration cycle apparatus according to the present disclosure will be described with reference to the drawings. The present disclosure is not limited to the embodiment described below, and can be variously modified without departing from the scope of the present disclosure. In addition, the present disclosure includes all combinations of configurations that can be combined among the configurations shown in the embodiment described below and its modification. In the drawings below, the same reference signs denote the same or equivalent components, which are common throughout the entire specification. Note that the relative relationship of sizes of the constituent components, the shapes of the constituent components, and other features in the drawings may differ from those of actual ones.

Embodiment 1

[0016] Fig. 1 is a refrigerant circuit diagram illustrating the configuration of a refrigeration cycle apparatus according to Embodiment 1. As shown in Fig. 1, the refrigeration cycle apparatus includes a refrigerant circuit as a main circuit in which a compressor 10, a condenser 20, a heat inter changer (HIC) 30, an expansion valve 40, and an evaporator 50 are connected by a refrigerant pipe 60. The compressor 10 includes a high-stage compressor 11 and a low-stage compressor 12.

[0017] As shown in Fig. 1, the refrigerant pipe 60 is provided with an INJ branch unit 61 and an INJ junction unit 62. The INJ branch unit 61 is located between the heat inter changer (HIC) 30 and the expansion valve 40. The INJ junction unit 62 is located between a discharge port of the low-stage compressor 12 and a suction port of the high-stage compressor 11.

[0018] As shown in Fig. 1, the refrigeration cycle apparatus includes an injection circuit 70. The injection circuit 70 is an intermediate-pressure refrigerant bypass circuit through which refrigerant having an intermediate pressure P_M flows. The intermediate pressure P_M will be described later. One end of the injection circuit 70 is connected to the INJ branch unit 61, while the other end of the injection circuit 70 is connected to the INJ junction unit 62.

[0019] The injection circuit 70 is formed in which an INJ expansion valve 71, a receiver 72, and a flow control valve 73 are connected by an injection pipe 76. The injection circuit 70 may be provided with a gas vent pipe 74. The gas vent pipe 74 is a bypass pipe connected to the receiver 72 and the injection pipe 76. The gas vent pipe 74 may be provided with an on-off valve 75.

[0020] In the main circuit, refrigerant flows inside the refrigerant pipe 60 through the low-stage compressor 12, the INJ junction unit 62, the high-stage compressor 11, the condenser 20, the heat inter changer (HIC) 30, the INJ branch unit 61, the expansion valve 40, and the evaporator 50 in this order.

[0021] In the injection circuit 70, refrigerant flows inside the injection pipe 76 through the INJ branch unit 61, the INJ expansion valve 71, the receiver 72, the flow control valve 73, the heat inter changer (HIC) 30, and the INJ junction unit 62 in this order.

[0022] The configurations of the devices that form the refrigeration cycle apparatus shown in Fig. 1 are described below.

[0023] The low-stage compressor 12 compresses sucked refrigerant from a low pressure P_L to the intermediate pressure P_M , and discharges the compressed refrigerant. The low-stage compressor 12 is, for example, an inverter compressor. In a case where the low-stage compressor 12 is an inverter compressor, the rotating speed may be optionally changed by use of a drive circuit such as an inverter circuit to change the refrigerant delivery capacity of the low-stage compressor 12 per unit time. In this case, the drive circuit is controlled by a controller 90. Note that the low pressure P_L is a first pressure, which is set in advance.

[0024] The high-stage compressor 11 compresses, to a high pressure P_H , the refrigerant discharged from the low-stage compressor 12 and having the intermediate pressure P_M , and the refrigerant flowing in from the injection circuit 70 and having the intermediate pressure P_M . The refrigerant discharged from the high-stage compressor 11 flows into the condenser 20. The high-stage compressor 11 is, for example, an inverter compressor. In a case where the high-stage compressor 11 is an inverter compressor, the rotating speed may be optionally changed by use of a drive circuit such as an inverter circuit to change the refrigerant delivery capacity of the high-stage compressor 11 per unit time. In this case, the drive circuit is controlled by the controller 90. Note that the high pressure P_H is a second pressure, which is set in advance. The second pressure is higher than the first pressure. The intermediate pressure P_M is higher than the first pressure and lower than the second pressure.

[0025] The condenser 20 is located, for example, outdoors. The condenser 20 is a heat exchanger through which refrigerant flowing inside the heat exchanger exchanges heat with air. The condenser 20 is, for example, a fin-and-tube heat exchanger. Refrigerant condensed into liquid through the condenser 20 flows into the heat inter changer (HIC) 30.

[0026] The heat inter changer (HIC) 30 is configured to perform inter-refrigerant heat exchange to cool one refrigerant by the other refrigerant. As shown in Fig. 2, the heat inter changer (HIC) 30 is formed by, for example, a double pipe. Fig. 2 is a perspective view illustrating an example of the configuration of the heat inter changer (HIC) 30 provided in the refrigeration cycle apparatus according to Embodiment 1. For convenience of description, Fig. 2 illustrates a portion of the configuration of the heat inter changer (HIC) 30 in a transparent manner by use of dotted lines. In the example in Fig. 2, the heat inter changer (HIC) 30 is formed by an outer pipe 31 located on the outside, and an inner pipe 32 located inside the outer pipe 31. Refrigerant flowing out from the condenser 20 in the direction of arrows P1 in Fig. 2 flows through the outer pipe 31. Refrigerant flowing through the injection pipe 76 in the direction of an arrow P2 in Fig. 2 flows inside the inner pipe 32. As shown by the arrows in Fig. 2, a flow direction of refrigerant flowing through the outer pipe 31 (the direction of the arrows P1) is opposite to a flow direction of refrigerant flowing through the inner pipe 32 (the direction of the arrow P2). These refrigerant flows face each other. Note that the heat inter changer (HIC) 30 is not limited to the example in Fig. 2. For example, refrigerant flowing through the injection pipe 76 may flow through the outer pipe 31, while refrigerant flowing out from the condenser 20 may flow through the inner pipe 32. The heat inter changer (HIC) 30 may have a configuration other than the configuration shown in Fig. 2.

[0027] In the heat inter changer (HIC) 30, refrigerant (second refrigerant, which will be described later) flowing out from the receiver 72 and flowing through the injection pipe 76 cools refrigerant flowing out from the condenser 20 to provide subcooling to this refrigerant flowing out from the condenser 20. Thereafter, the refrigerant (the second refrigerant) having provided subcooling still flows through the injection pipe 76 and is guided to the INJ junction unit 62. As described above, the INJ junction unit 62 is located on the discharge side of the low-stage compressor 12 that is the suction side of the high-stage compressor 11.

[0028] In contrast, refrigerant to which subcooling has been provided in the heat inter changer (HIC) 30 is divided into the first refrigerant and the second refrigerant through the INJ branch unit 61. The first refrigerant divided through the INJ branch unit 61 flows through the refrigerant pipe 60 and is guided to the expansion valve 40. The expansion valve 40 expands and decompresses the first refrigerant. The first refrigerant expanded to the low pressure P_L flows into the evaporator 50. The expansion valve 40 is, for example, an electronic expansion valve. In a case where the expansion valve 40 is formed by an electronic expansion valve, the opening degree of the expansion valve 40 is controlled and adjusted by the controller 90.

[0029] The evaporator 50 is located in, for example, a room space. The evaporator 50 is a heat exchanger through which refrigerant flowing inside the heat exchanger exchanges heat with air. The evaporator 50 is, for example, a fin-and-tube heat exchanger. Through the evaporator 50, the first refrigerant exchanges heat with air, and thus evaporates. The first refrigerant having evaporated into gas through the evaporator 50 is sucked into the low-stage compressor 12. The low-stage compressor 12 sucks refrigerant flowing out from the evaporator 50 and having the low pressure P_L , then compresses this refrigerant to the intermediate pressure P_M , and discharges the compressed refrigerant.

[0030] In contrast, the second refrigerant divided through the INJ branch unit 61 flows through the injection pipe 76 and then flows into the INJ expansion valve 71.

[0031] The INJ expansion valve 71 expands and decompresses the second refrigerant. The second refrigerant expanded to the intermediate pressure P_M flows into the receiver 72. The INJ expansion valve 71 is, for example, an electronic expansion valve. In a case where the INJ expansion valve 71 is formed by an electronic expansion valve, the opening degree of the INJ expansion valve 71 is controlled and adjusted by the controller 90.

[0032] The receiver 72 stores the second refrigerant expanded to the intermediate pressure P_M by the INJ expansion valve 71. In the receiver 72, the second refrigerant is divided into liquid refrigerant and gas refrigerant. The liquid refrigerant obtained by dividing the second refrigerant by the receiver 72 flows into the inner pipe 32 of the heat inter changer (HIC) 30 through the injection pipe 76. The second refrigerant flowing through the inner pipe 32 exchanges heat with refrigerant flowing through the outer pipe 31, and thereafter is guided to the INJ junction unit 62. At this time, the second refrigerant cools the refrigerant flowing through the outer pipe 31 in the heat inter changer (HIC) 30 to provide subcooling to this refrigerant flowing through the outer pipe 31. Note that the heat inter changer (HIC) 30 is not necessarily provided, but may be provided only when needed.

[0033] The flow control valve 73 is provided in the injection pipe 76 and between the receiver 72 and the heat inter changer (HIC) 30. The flow rate of the second refrigerant (liquid refrigerant) flowing out from the receiver 72 is adjusted by the opening degree of the flow control valve 73. The flow control valve 73 is, for example, an electronic adjusting valve. In this case, the opening degree of the flow control valve 73 is controlled by the controller 90.

[0034] At the INJ junction unit 62, the second refrigerant flowing through the injection pipe 76 and having the intermediate pressure P_M , and the first refrigerant discharged from the low-stage compressor 12 and having the intermediate pressure P_M join together. The refrigerant having joined together at the INJ junction unit 62 is sucked into the high-stage compressor 11. The high-stage compressor 11 compresses the sucked refrigerant having the intermediate pressure P_M to the high pressure P_H , and discharges the compressed refrigerant.

[0035] The gas vent pipe 74 is a bypass pipe connected between the receiver 72 and the injection pipe 76. One end of the gas vent pipe 74 is connected to an upper portion of the receiver 72, while the other end of the gas vent pipe 74 is connected to the injection pipe 76 at a location between the flow control valve 73 and the heat inter changer (HIC) 30. The gas vent pipe 74 allows gas refrigerant in the receiver 72 to flow out to the injection pipe 76 when the on-off valve 75 is in an open state, and stops the outflow of the gas refrigerant in the receiver 72 when the on-off valve 75 is in a closed state. With this configuration, composition of the refrigerant flowing in the injection circuit 70, that is, a gas density of this refrigerant can be finely adjusted. However, the gas vent pipe 74 is not necessarily provided, but may be provided only when needed.

[0036] The controller 90 is formed by a processing circuit. The processing circuit is formed by dedicated hardware or a processor. Examples of the dedicated hardware include an application specific integrated circuit (ASIC) and a field programmable gate array (FPGA). The processor executes programs stored in a memory. Storage circuitry (not shown) provided in the controller 90 is formed by the memory. The memory is a nonvolatile or volatile semiconductor memory such as a random access memory (RAM), a read only memory (ROM), a flash memory, and an erasable programmable ROM (EPROM), or a disk such as a magnetic disk, a flexible disk, and an optical disk.

[0037] As shown in Fig. 1, in Embodiment 1, a first pressure sensor 81 configured to measure the intermediate pressure P_M is installed between the INJ expansion valve 71 and the receiver 72. Information on the intermediate pressure P_M

detected by the first pressure sensor 81 is transmitted to the controller 90. The intermediate pressure P_M is an internal pressure in the receiver 72.

[0038] As shown in Fig. 1, in Embodiment 1, a second pressure sensor 82 configured to measure the high pressure P_H is further installed between the discharge port of the high-stage compressor 11 and the condenser 20. Information on the high pressure P_H detected by the second pressure sensor 82 is transmitted to the controller 90. The high pressure P_H is a discharge pressure of the high-stage compressor 11.

[0039] The refrigeration cycle apparatus described in Patent Literature 1 mentioned above is not supposed to use a high-pressure supercritical refrigerant such as CO_2 (carbon dioxide) as refrigerant. In contrast, in the refrigeration cycle apparatus according to Embodiment 1, it is possible to use a high-pressure supercritical refrigerant such as CO_2 . If the refrigeration cycle apparatus described in Patent Literature 1 uses the high-pressure supercritical refrigerant such as CO_2 , the intermediate pressure may exceed a critical pressure.

[0040] Fig. 3 is a p-h diagram illustrating a refrigeration cycle when the refrigeration cycle apparatus described in Patent Literature 1 uses the high-pressure supercritical refrigerant such as CO_2 . In Fig. 3, the horizontal axis represents a specific enthalpy, while the vertical axis represents a pressure of refrigerant. A solid line 100 shows a saturated vapor line. A solid line 101 shows a saturated liquid line. The intersection of the saturated vapor line 100 and the saturated liquid line 101 is represented as K showing a critical point. A critical pressure that is a pressure at the critical point K is represented as P_K .

[0041] In Fig. 3, T1 shows a compression process performed by the high-stage compressor, T2 shows a condensation process performed by the radiator, and T3 shows a heat exchange process performed by the heat inter changer. T4 shows an expansion process performed by the first expansion valve. T5 shows an evaporation process performed by the evaporator. T6 shows a compression process performed by the low-stage compressor. T7 shows an expansion process performed by the second expansion valve. T8 shows a heat exchange process performed by the heat inter changer.

[0042] When the refrigeration cycle apparatus described in Patent Literature 1 mentioned above controls the intermediate pressure P_M , this refrigeration cycle apparatus is supposed to, for example, increase or decrease the rotating speed of the high-stage compressor, thereby to control the intermediate pressure P_M . At this time, when the rotating speed of the high-stage compressor is simply increased to reduce the intermediate pressure P_M , this results in an increase in condensation load in the radiator located downstream of the high-stage compressor. As a consequence, there is a possibility that the high pressure P_H that is a discharge pressure of the high-stage compressor may excessively increase. In this case, the intermediate pressure P_M may possibly exceed the critical pressure P_K as shown in Fig. 3.

[0043] In view of the above, in the refrigeration cycle apparatus according to Embodiment 1, the injection circuit 70 is provided with the receiver 72 and the flow control valve 73 as shown in Fig. 1. Further, in the refrigeration cycle apparatus according to Embodiment 1, the controller 90 controls the intermediate pressure P_M that is an internal pressure in the receiver 72 such that the intermediate pressure P_M is reduced to the critical pressure P_K or lower. During the control, when the high pressure P_H increases excessively, the controller 90 decreases the opening degree of the flow control valve 73 to allow liquid refrigerant to be stored in the receiver 72, thereby to decrease the high pressure P_H . Specifically, a control method (M1) described below is used to control the intermediate pressure P_M . In addition, a control method (M2) described below is used to control the high pressure P_H . Note that the control by use of the control method (M2) is exercised only when necessary.

[0044] Control method (M1): The intermediate pressure P_M is controlled to become lower than or equal to the critical pressure P_K . Specifically, the intermediate pressure P_M is reduced by increasing the ratio of a displacement of the high-stage compressor 11 to a displacement of the low-stage compressor 12.

[0045] Control method (M2): The high pressure P_H is controlled not to exceed a design pressure of the high-stage compressor 11. Specifically, the high pressure P_H is decreased by reducing the outflow amount of liquid refrigerant that flows out from the receiver 72 to store the liquid refrigerant in the receiver 72.

[Control method (M1)]

[0046] First, the control method (M1) is explained. Fig. 4 is a flowchart illustrating a processing flow of the control method (M1) in the refrigeration cycle apparatus according to Embodiment 1. In Fig. 4, the intermediate pressure P_M is controlled to become lower than or equal to a first threshold.

[0047] As shown in Fig. 4, in step S1, the controller 90 obtains a detection value of the intermediate pressure P_M from the first pressure sensor 81.

[0048] Next, in step S2, the controller 90 compares the intermediate pressure P_M with the first threshold. When a result of the comparison shows that the intermediate pressure P_M is higher than the first threshold, the process proceeds to step S3. In contrast, when a result of the comparison shows that the intermediate pressure P_M is lower than or equal to the first threshold, the processing of flow in Fig. 4 is terminated with no further processing.

[0049] In step S3, the controller 90 performs first processing, which is set in advance, on the intermediate pressure

P_M such that the intermediate pressure P_M becomes lower than or equal to the first threshold. The first processing will be described below. With this first processing, the intermediate pressure P_M is decreased.

[0050] The first threshold is, for example, the critical pressure P_K . Since Embodiment 1 is supposed to use CO_2 (carbon dioxide) as refrigerant, the first threshold is, for example, the critical pressure P_K of CO_2 . CO_2 is known to have a critical temperature of 31.1 degrees C and a critical pressure P_K of 7.1 MPa. Therefore, the first threshold is, for example, 7.1 MPa. As described above, CO_2 is a refrigerant that can be brought into a supercritical state under relatively mild conditions such as the critical temperature of 31.1 degrees C and the critical pressure P_K of 7.1 MPa.

[0051] As an example of the first processing, the following processing is performed.

[Control by means of displacement]

[0052] As the first processing, the controller 90 increases the ratio of a displacement of the high-stage compressor 11 to a displacement of the low-stage compressor 12. That is, the controller 90 increases the ratio of the displacement of the high-stage compressor 11 to the displacement of the low-stage compressor 12. The displacements of the low-stage compressor 12 and the high-stage compressor 11 are calculated by Expression (2) below. That is, not only the ratio of rotating speed between the low-stage compressor 12 and the high-stage compressor 11 is considered, but the ratio of volume between the low-stage compressor 12 and the high-stage compressor 11 is also considered.

$$\text{Displacement of low-stage compressor} = \text{volume of low-stage compressor} \times \text{rotating speed of low-stage compressor}$$

$$\text{Displacement of high-stage compressor} = \text{volume of high-stage compressor} \times \text{rotating speed of high-stage compressor}$$

(1)

[0053] The controller 90 may increase the ratio of displacement by a given amount that is set in advance. However, instead, the controller 90 may increase the ratio of displacement by an amount according to the value of intermediate pressure P_M . In this case, in the storage circuitry of the controller 90, a data table is stored in advance. In the data table, the amounts of increase in the ratio of displacement are associated with the values of intermediate pressure P_M . When the volume of the low-stage compressor 12 and the high-stage compressor 11 is considered constant, the ratio of the rotating speed of the high-stage compressor 11 to the rotating speed of the low-stage compressor 12 may be increased. Specifically, at least one of the rotating speed of the low-stage compressor 12 and the rotating speed of the high-stage compressor 11 is controlled

[0054] In the manner as described above, in step S3, the controller 90 performs the first processing, which is set in advance. With this first processing, the intermediate pressure P_M is decreased. The controller 90 repeats the processing of flow in Fig. 4 at given intervals. With this repetitive processing, the controller 90 can control the intermediate pressure P_M such that intermediate pressure P_M becomes lower than or equal to the critical pressure P_K . The intermediate pressure P_M is controlled to be constantly lower than or equal to the critical pressure P_K in the manner as described above. Consequently, this can ensure that liquid refrigerant is stored at the critical pressure P_K or lower in the receiver 72.

[0055] In step S3, as the first processing, the ratio of the displacement of the high-stage compressor 11 to the displacement of the low-stage compressor 12 is increased, instead of simply increasing the displacement of the high-stage compressor 11. When the displacement of the high-stage compressor 11 is simply increased, a condensation load in the condenser 20 increases, and there is a possibility that the high pressure P_H may excessively increase. In view of that, in Embodiment 1, the ratio of the displacement of the high-stage compressor 11 to the displacement of the low-stage compressor 12 is increased. This can prevent an increase in the condensation load in the condenser 20, and accordingly can reduce or eliminate an excessive increase in the high pressure P_H . Since an increase in the condensation load in the condenser 20 can be prevented, the condenser 20 can be decreased in size (in other words, downsized), and manufacturing costs of the refrigeration cycle apparatus can be reduced accordingly.

[0056] Next, the control method (M2) is explained. Fig. 5 is a flowchart illustrating a processing flow of the control method (M2) in the refrigeration cycle apparatus according to Embodiment 1. In Fig. 5, the high pressure P_H is controlled not to exceed a design pressure P_{comp} of the high-stage compressor 11.

[0057] In general, a design pressure P_{comp} and a proof pressure P_{max} are set for a compressor. The design pressure P_{comp} refers to a reference pressure value used for design calculation for a strength of a compressor. The design pressure P_{comp} is set to a value greater than or equal to the maximum possible value of internal pressure P in a

compressor, which can be generated during normal operation of the compressor. The design pressure P_{comp} is obtained by multiplying the maximum possible value of internal pressure P , which can be generated during normal operation of the compressor, by a coefficient larger than or equal to 1 (for example, 1.1). Alternatively, the design pressure P_{comp} is obtained by adding a certain value (for example, 0.1 Mpa) to the maximum possible value of internal pressure P , which can be generated during normal operation of the compressor.

[0058] The proof pressure P_{max} of the compressor is a legally-specified value based on the design pressure P_{comp} of the compressor. The proof pressure P_{max} is set at a value greater than the design pressure P_{comp} of the compressor in accordance with the law.

[0059] A value of breaking pressure P_{br} at which the compressor can possibly be broken has a tolerance on the higher-pressure side from the proof pressure P_{max} . That is, the value of breaking pressure P_{br} is larger than the value of proof pressure P_{max} . When the internal pressure in the compressor exceeds the breaking pressure P_{br} , a pressure vessel that forms a housing of the compressor may possibly be broken. Note that the breaking pressure P_{br} is obtained by durability experiments on the compressor or other experiments.

[0060] In the manner as described above, a compressor is designed to ensure the proof pressure P_{max} , which is legally specified according to the design pressure P_{comp} . Therefore, the high pressure P_H is controlled not to exceed the design pressure P_{comp} of the high-stage compressor 11, and the high-stage compressor 11 is thus surely prevented from being broken.

[0061] As shown in Fig. 5, in step S11, the controller 90 obtains a detection value of the high pressure P_H from the second pressure sensor 82.

[0062] Next, in step S12, the controller 90 compares the high pressure P_H with the second threshold. When a result of the comparison shows that the high pressure P_H is higher than the second threshold, the process proceeds to step S13. In contrast, when a result of the comparison shows that the high pressure P_H is lower than or equal to the second threshold, the processing of flow in Fig. 5 is terminated with no further processing.

[0063] In step S13, the controller 90 performs second processing, which is set in advance, on the high pressure P_H such that the high pressure P_H becomes lower than or equal to the second threshold. The second processing will be described below. With this second processing, the high pressure P_H is decreased.

[0064] The second threshold is, for example, the design pressure P_{comp} of the high-stage compressor 11. The design pressure P_{comp} is obtained by multiplying the maximum possible value of internal pressure P , which can be generated during normal operation of the high-stage compressor 11, by a coefficient larger than or equal to 1 (for example, 1.1). Alternatively, the design pressure P_{comp} is obtained by adding a certain value (for example, 0.1 Mpa) to the maximum possible value of internal pressure P , which can be generated during normal operation of the high-stage compressor 11.

[0065] As an example of the second processing, the following processing is performed.

[Control by means of flow control valve]

[0066] The controller 90 decreases the opening degree of the flow control valve 73 as the second processing.

[0067] The controller 90 may decrease the opening degree of the flow control valve 73 by a given amount that is set in advance. However, instead, the controller 90 may increase the opening degree of the flow control valve 73 by an amount according to the value of high pressure P_H . In this case, in the storage circuitry of the controller 90, a data table is stored in advance. In the data table, the amounts of decrease in the opening degree of the flow control valve 73 are associated with the values of high pressure P_H .

[0068] In the manner as described above, in step S13, the controller 90 performs the second processing, which is set in advance. With this second processing, the high pressure P_H is decreased. The controller 90 repeats the processing of flow in Fig. 5 at given intervals in parallel with the processing of flow in Fig. 4. However, it is desirable to delay the timing at which the processing of flow in Fig. 5 starts, compared to the timing at which the processing of flow in Fig. 4 starts, by a length of time, which is set in advance. Specifically, for example, the processing of flow in Fig. 4 and the processing of flow in Fig. 5 are performed alternately. By performing the processing in Fig. 5, the controller 90 can control the high pressure P_H to prevent the high pressure P_H from exceeding the design pressure P_{comp} of the high-stage compressor 11. That is, the controller 90 can control the high pressure P_H such that the high pressure P_H constantly satisfies the following relationship: the high pressure $P_H >$ the second threshold. In this manner, the controller 90 controls the high pressure P_H such that the high pressure P_H is constantly lower than or equal to the second threshold. This makes it possible to use flat tubes as heat transfer tubes of the condenser 20. The flat tubes are smaller in internal volume of the flow passage through which refrigerant flows (that is, cross-sectional area of the flow passage) than circular tubes. For this reason, when the high pressure P_H is a high-pressure-side pressure, it is difficult to use flat tubes whose flow passages have a relatively small cross-sectional area. In Embodiment 1, liquid refrigerant is stored in the receiver 72, which can increase the amount of surplus refrigerant in the receiver 72. This makes it possible to reduce the high pressure P_H . As a consequence, it is possible to use the flat tubes as the heat transfer tubes of the condenser 20. In Embodiment 1, the controller 90 controls the high pressure P_H such that the high pressure P_H is constantly lower than

or equal to the second threshold. Consequently, the flat tubes can be employed for the condenser 20, and accordingly the condenser 20 and thus the refrigeration cycle apparatus can both be decreased in size.

[0069] Fig. 6 is a p-h diagram illustrating a refrigeration cycle of the refrigeration cycle apparatus according to Embodiment 1. In Fig. 6, the horizontal axis represents a specific enthalpy, while the vertical axis represents a pressure of refrigerant. Note that the points A to J in Fig. 6 correspond to the points A to J shown on the refrigerant circuit diagram in Fig. 1. Actually, the point C and the point C1 are at the same position, however, in Fig. 6, these points C and C1 are shown slightly apart from each other for convenience of description.

[0070] First, the high-stage compressor 11 sucks refrigerant having the intermediate pressure P_M (at the point J) and compresses the refrigerant to the high pressure P_H (at the point A). High-temperature and high-pressure gas refrigerant discharged from the high-stage compressor 11 (at the point A) flows into the condenser 20. In the condenser 20, the high-temperature and high-pressure gas refrigerant transfers heat to air and is condensed to become refrigerant having the high pressure P_H (at the point B). The high-pressure refrigerant passes through the heat inter changer (HIC) 30 in the direction of the arrow P1 in Fig. 1, and is brought into a state in which the degree of subcooling is further increased (at the points C and C1). A portion of the refrigerant passing through the heat inter changer (HIC) 30 (at the point C1) flows into the INJ expansion valve 71 via the INJ branch unit 61. In the INJ expansion valve 71, the refrigerant having the high pressure P_H is decompressed to the intermediate pressure P_M , and flows into the receiver 72 to become two-phase gas-liquid refrigerant (at the point H). Thereafter, the liquid refrigerant flowing out from the receiver 72 passes through the heat inter changer (HIC) 30 in the direction of the arrow P2 that is opposite to the direction of the arrow P1 described above. This brings the liquid refrigerant into two-phase refrigerant having the intermediate pressure P_M with the increased temperature (at the point I).

[0071] In contrast, the remaining portion of the refrigerant passing through the heat inter changer (HIC) 30 (at the point C) flows into the expansion valve 40. In the expansion valve 40, the refrigerant having the high pressure P_H is decompressed to the low pressure P_L , and becomes two-phase gas-liquid refrigerant (at the point D). The two-phase refrigerant having the low pressure P_L (at the point D) flows into the evaporator 50. In the evaporator 50, the two-phase refrigerant having the low pressure P_L receives heat from air and thus evaporates to become gas refrigerant having the low pressure P_L (at the point E). This gas refrigerant having the low pressure P_L flows into the low-stage compressor 12. The low-stage compressor 12 sucks refrigerant having the low pressure P_L and compresses the refrigerant to the intermediate pressure P_M (at the point F). The gas refrigerant having the intermediate pressure P_M and discharged from the low-stage compressor 12 (at the point F) joins (at the point J) with the two-phase refrigerant having the intermediate pressure P_M and flowing out from the heat inter changer (HIC) 30 in the direction of the arrow P2 (at the point I). This refrigerant is sucked into the high-stage compressor 11, and the same cycle is repeated again.

[0072] As described above, the refrigeration cycle apparatus according to Embodiment 1 includes the injection circuit 70 including the receiver 72 and the flow control valve 73. The controller 90 controls the ratio of the displacement of the high-stage compressor 11 to the displacement of the low-stage compressor 12 such that, even when a high-pressure supercritical refrigerant such as CO_2 is used, the controller 90 can still control the intermediate pressure P_M to prevent it from exceeding the critical pressure P_K . With this control, the internal pressure in the receiver 72 can be maintained at the critical pressure P_K or lower. This makes it possible to always store liquid refrigerant in the receiver 72. In the manner as described above, Embodiment 1 can ensure that, even when a CO_2 refrigerant is used, at least a portion of the CO_2 refrigerant is stored as liquid refrigerant at the critical pressure P_K or lower in the receiver 72. As a consequence, the high pressure P_H that is a discharge pressure of the high-stage compressor 11 can be prevented from excessively increasing, and accordingly an increase in the condensation load in the condenser 20 can be reduced or eliminated.

[0073] In Embodiment 1, an increase in the condensation load in the condenser 20 can be reduced or eliminated in the manner as described above. It is thus possible to decrease the condenser 20 in size (downsize the condenser 20). As the condenser 20 is decreased in size, the manufacturing costs of the condenser 20 are reduced accordingly. This consequently leads to a reduction in the manufacturing costs of the refrigeration cycle apparatus in its entirety.

[0074] In Embodiment 1, the controller 90 controls the opening degree of the flow control valve 73 according to a detection value of high pressure P_H , such that the high pressure P_H does not exceed the design pressure P_{comp} of the high-stage compressor 11. With this control, the outflow amount of liquid refrigerant that flows out from the receiver 72 is reduced and the liquid refrigerant can thus be stored in the receiver 72. In this manner, the outflow amount of liquid refrigerant that flows out from the receiver 72 is reduced, and accordingly the amount of refrigerant to be sucked into the high-stage compressor 11 is decreased so that the high pressure P_H that is a discharge pressure of the high-stage compressor 11 can be decreased. In Embodiment 1, an increase in the high pressure P_H can be reduced or eliminated by storing liquid refrigerant in the receiver 72. It is thus possible for the condenser 20 provided downstream of the high-stage compressor 11 to use flat tubes whose flow passages have a relatively small internal volume.

[0075] Since CO_2 is a supercritical refrigerant, it is conceivable that the intermediate pressure P_M may exceed the critical pressure P_K . Therefore, the refrigeration cycle apparatus according to Embodiment 1, which is capable of controlling the intermediate pressure P_M to prevent it from exceeding the critical pressure P_K , is effective particularly when CO_2 is used as refrigerant.

[0076] In the refrigeration cycle apparatus according to Embodiment 1, the heat inter changer (HIC) 30 is provided and thus the degree of subcooling can be increased. Therefore, the performance of the refrigeration cycle apparatus can further be improved.

5 Reference Signs List

[0077] 10: compressor, 11: high-stage compressor, 12: low-stage compressor, 20: condenser, 31: outer pipe, 32: inner pipe, 40: expansion valve, 50: evaporator, 60: refrigerant pipe, 61: INJ branch unit, 62: INJ junction unit, 70: injection circuit, 71: INJ expansion valve, 72: receiver, 73: flow control valve, 74: gas vent pipe, 75: on-off valve, 76: injection pipe, 81: first pressure sensor, 82: second pressure sensor, 90: controller, 100: solid line (saturated vapor line), 101: solid line (saturated liquid line), K: critical point, P: internal pressure, P1: arrow, P2: arrow, P_H : high pressure, P_K : critical pressure, P_L : low pressure, P_M : intermediate pressure, Pbr: breaking pressure, Pcomp: design pressure, Pmax: proof pressure

15

Claims

1. A refrigeration cycle apparatus, comprising:

20 a controller;
 a low-stage compressor configured to compress refrigerant from a first pressure to an intermediate pressure that is higher than the first pressure;
 a high-stage compressor configured to compress the refrigerant having the intermediate pressure from the intermediate pressure to a second pressure that is higher than the intermediate pressure;
 25 a condenser through which the refrigerant having the second pressure exchanges heat with air;
 an INJ branch unit through which the refrigerant flowing out from the condenser is divided into first refrigerant and second refrigerant;
 an expansion valve configured to expand the first refrigerant divided through the INJ branch unit to decompress the first refrigerant to the first pressure;
 30 an evaporator through which the first refrigerant flowing out from the expansion valve exchanges heat with air and from which the first refrigerant having the first pressure flows out toward the low-stage compressor;
 an INJ junction unit located between a discharge port of the low-stage compressor and a suction port of the high-stage compressor; and
 an injection circuit located between the INJ branch unit and the INJ junction unit and through which the second refrigerant divided through the INJ branch unit is sucked into the high-stage compressor,
 35 the injection circuit including
 an INJ expansion valve configured to expand the second refrigerant, and
 a receiver configured to divide the second refrigerant expanded by the INJ expansion valve into liquid refrigerant and gas refrigerant and store the liquid refrigerant and the gas refrigerant, the stored liquid refrigerant flowing
 40 out from the receiver toward the INJ junction unit,
 the controller being configured to control a ratio of a displacement of the high-stage compressor to a displacement of the low-stage compressor,
 the displacement of the low-stage compressor being a value obtained by multiplying a volume of the low-stage compressor and a rotating speed of the low-stage compressor,
 45 the displacement of the high-stage compressor being a value obtained by multiplying a volume of the high-stage compressor and a rotating speed of the high-stage compressor.

2. The refrigeration cycle apparatus of claim 1, wherein the controller is configured to control the ratio of the displacement of the high-stage compressor to the displacement of the low-stage compressor, and thereby control the intermediate pressure that is an internal pressure in the receiver such that the intermediate pressure becomes lower than or equal to a first threshold.

3. The refrigeration cycle apparatus of claim 2, wherein the controller is configured to increase the ratio of the displacement of the high-stage compressor to the displacement of the low-stage compressor to decrease the intermediate pressure.

4. The refrigeration cycle apparatus of claim 2 or 3, wherein the first threshold is a critical pressure that is a pressure at a critical point of the refrigerant.

5. The refrigeration cycle apparatus of any one of claims 1 to 4, wherein the refrigerant is carbon dioxide.

6. The refrigeration cycle apparatus of any one of claims 1 to 5, wherein

the injection circuit includes
a flow control valve located between the receiver and the INJ junction unit, and configured to adjust an outflow
amount of the liquid refrigerant flowing out from the receiver, and
the controller is configured to control an opening degree of the flow control valve, and thereby control the second
pressure such that the second pressure becomes lower than or equal to a second threshold.

7. The refrigeration cycle apparatus of claim 6, wherein the controller is configured to decrease the opening degree
of the flow control valve to decrease the second pressure.

8. The refrigeration cycle apparatus of claim 6 or 7, wherein the second threshold is a design pressure of the high-
stage compressor.

9. The refrigeration cycle apparatus of any one of claims 1 to 8, comprising a heat inter changer located between the
condenser and the INJ branch unit, and configured to provide subcooling to the refrigerant flowing out from the
condenser, wherein

the refrigerant flowing out from the heat inter changer is divided through the INJ branch unit into the first refrigerant
and the second refrigerant, and
the liquid refrigerant flows out from the receiver toward the INJ junction unit through the heat inter changer.

10. The refrigeration cycle apparatus of claim 2 or any one of claims 3 to 9 as dependent on claim 2, comprising a first
pressure sensor located between the INJ expansion valve and the receiver, and configured to detect the intermediate
pressure that is an internal pressure in the receiver, wherein
the controller is configured to control the intermediate pressure according to the intermediate pressure detected by
the first pressure sensor such that the intermediate pressure becomes lower than or equal to the first threshold.

11. The refrigeration cycle apparatus of any one of claims 6 to 8, comprising a second pressure sensor located on a
discharge port side of the high-stage compressor, and configured to detect the second pressure that is a discharge
pressure of the high-stage compressor, wherein
the controller is configured to control the second pressure according to the second pressure detected by the second
pressure sensor such that the second pressure becomes lower than or equal to the second threshold.

FIG. 1

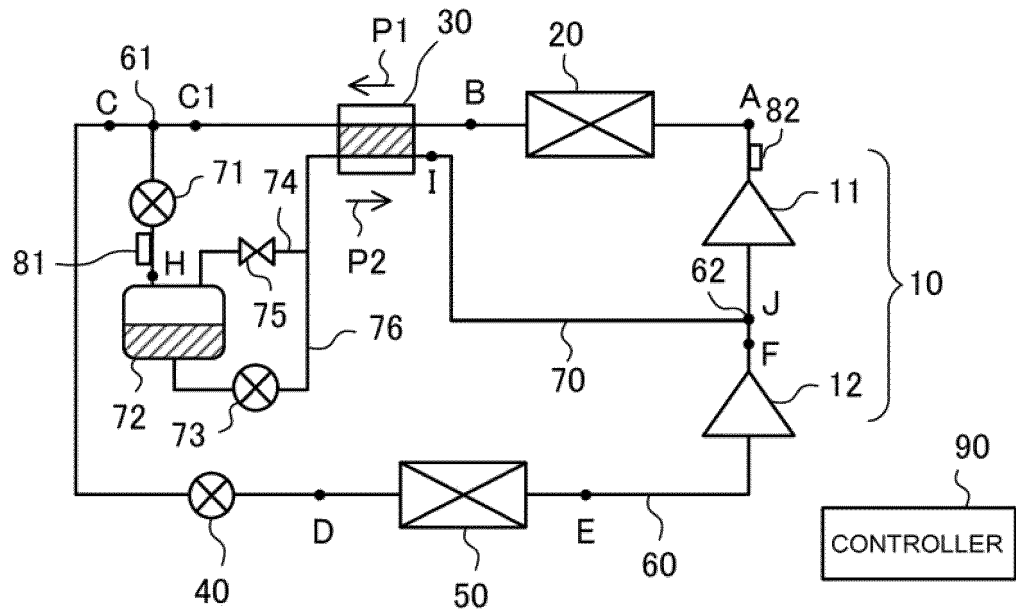


FIG. 2

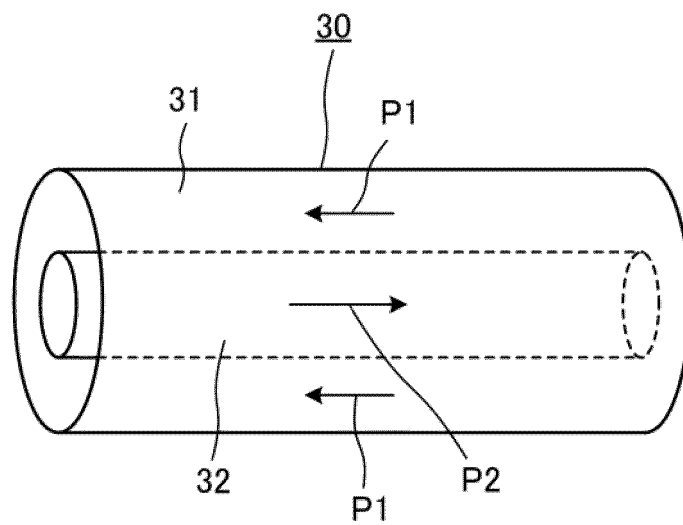


FIG. 3

Comparative Example

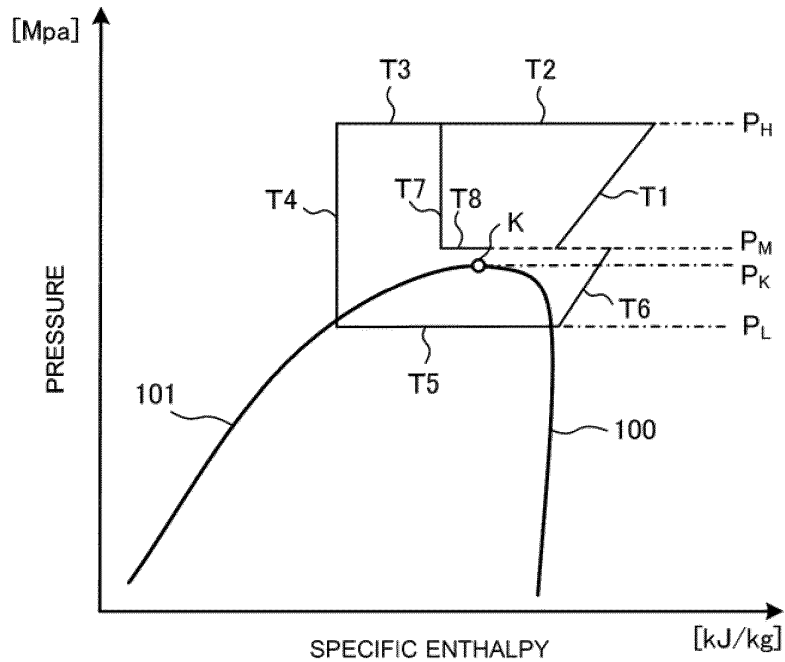


FIG. 4

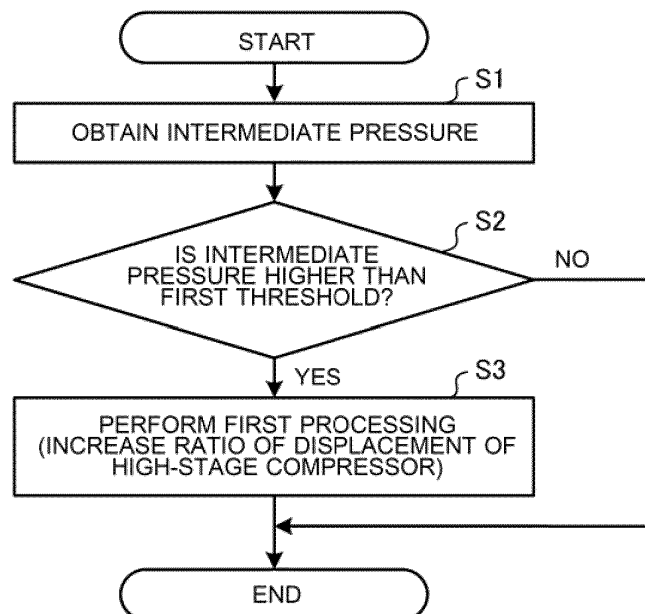


FIG. 5

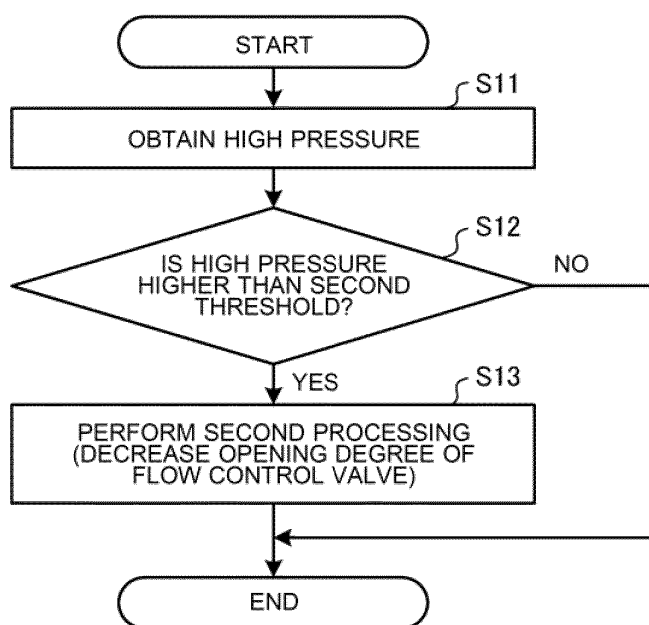
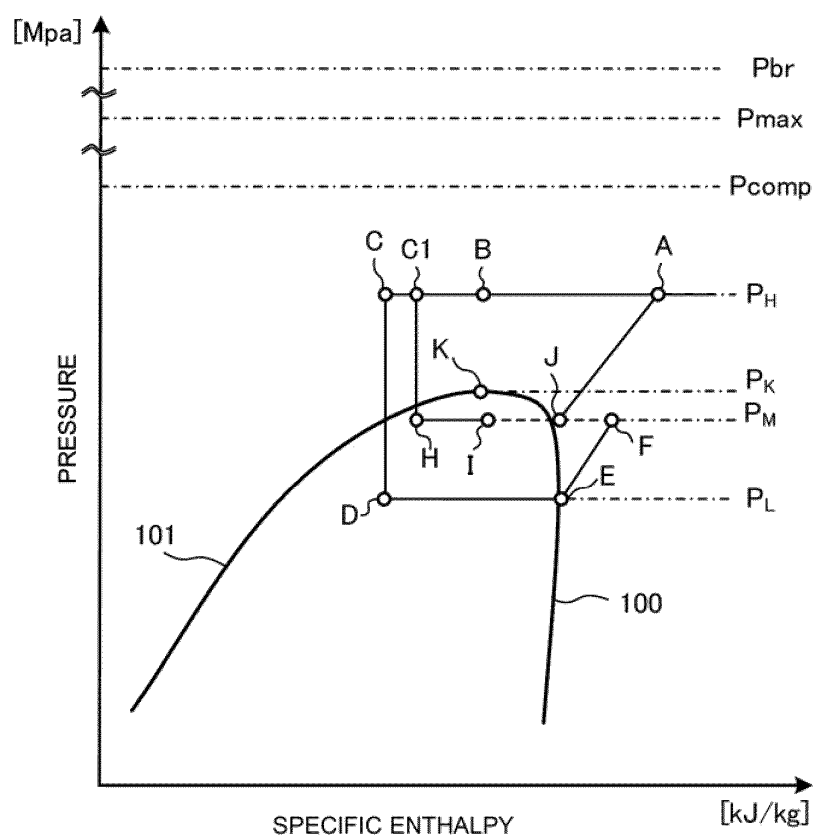


FIG. 6



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2021/019829

A. CLASSIFICATION OF SUBJECT MATTER <i>F25B 1/10</i> (2006.01)i FI: F25B1/10 E 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) F25B1/10 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Published examined utility model applications of Japan 1922-1996 Published unexamined utility model applications of Japan 1971-2021 Registered utility model specifications of Japan 1996-2021 Published registered utility model applications of Japan 1994-2021 Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)																		
C. DOCUMENTS CONSIDERED TO BE RELEVANT <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>A</td> <td>JP 2018-132223 A (PANASONIC IP MAN CORP) 23 August 2018 (2018-08-23) entire text, all drawings</td> <td>1-11</td> </tr> <tr> <td>A</td> <td>JP 2012-88040 A (DAIKIN INDUSTRIES LTD) 10 May 2012 (2012-05-10) entire text, all drawings</td> <td>1-11</td> </tr> <tr> <td>A</td> <td>WO 2021/048899 A1 (MITSUBISHI ELECTRIC CORP) 18 March 2021 (2021-03-18) entire text, all drawings</td> <td>1-11</td> </tr> <tr> <td>A</td> <td>WO 2020/208752 A1 (MITSUBISHI ELECTRIC CORP) 15 October 2020 (2020-10-15) entire text, all drawings</td> <td>1-11</td> </tr> <tr> <td>A</td> <td>JP 2012-247154 A (DENSO CORP) 13 December 2012 (2012-12-13) entire text, all drawings</td> <td>1-11</td> </tr> </tbody> </table>	Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	A	JP 2018-132223 A (PANASONIC IP MAN CORP) 23 August 2018 (2018-08-23) entire text, all drawings	1-11	A	JP 2012-88040 A (DAIKIN INDUSTRIES LTD) 10 May 2012 (2012-05-10) entire text, all drawings	1-11	A	WO 2021/048899 A1 (MITSUBISHI ELECTRIC CORP) 18 March 2021 (2021-03-18) entire text, all drawings	1-11	A	WO 2020/208752 A1 (MITSUBISHI ELECTRIC CORP) 15 October 2020 (2020-10-15) entire text, all drawings	1-11	A	JP 2012-247154 A (DENSO CORP) 13 December 2012 (2012-12-13) entire text, all drawings	1-11
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A	JP 2012-247154 A (DENSO CORP) 13 December 2012 (2012-12-13) entire text, all drawings	1-11																
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Date of the actual completion of the international search 22 June 2021	Date of mailing of the international search report 06 July 2021																	
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2021/019829

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				entire text, all drawings	

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