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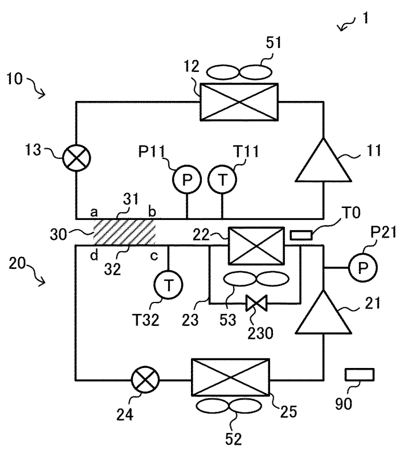
(54) **REFRIGERATION CYCLE DEVICE**

(57) A refrigeration cycle apparatus includes a high-stage circuit in which a high-stage compressor, a high-stage condenser, a high-stage expansion valve, and, a high-stage flow passage of a cascade heat exchanger are connected annularly by pipes and in which high-stage refrigerant circulates, a low-stage circuit in which a low-stage compressor, an intermediate cooler, a low-stage flow passage of the cascade heat exchanger, a low-stage expansion valve, and, a low-stage evaporator are connected annularly by pipes and in which low-stage refrigerant circulates, and a controller configured to control operation of the high-stage circuit and the low-stage circuit. The controller is configured to, when determining that the refrigerant in a liquid state flows into the high-stage compressor, allow high temperature low-stage refrigerant, being the low-stage refrigerant having a high temperature and discharged from the low-stage compressor, to flow into the low-stage flow passage of the cascade heat exchanger.

FIG. 1



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Description

Technical Field

[0001] The present disclosure relates to refrigeration cycle apparatuses and more particularly relates to a refrigeration cycle apparatus including a high-stage circuit and a low-stage circuit.

Background Art

[0002] Two-stage refrigeration cycles including a high-stage circuit in which high-stage refrigerant circulates and a low-stage circuit in which low-stage refrigerant circulates are known for refrigeration cycle apparatuses. In the two-stage refrigeration cycles, heat is exchanged between the high-stage refrigerant flowing in the high-stage circuit, which functions as a high-stage evaporator, and the low-stage refrigerant flowing in the low-stage circuit, which functions as a low-stage condenser, by means of a cascade heat exchanger including a high-stage circuit connected to the high-stage circuit described above and a low-stage circuit connected to the low-stage circuit described above.

[0003] For example, Patent Literature 1 discloses a refrigeration cycle apparatus using a two-stage refrigeration cycle in which an intermediate cooler is provided upstream from a low-stage condenser. With the configuration in Patent Literature 1, the intermediate cooler cools gas discharged from a low-stage compressor connected in a low-stage circuit. This decreases the amount of cooling by a high-stage evaporator and reduces the amount of power with which a high-stage compressor operates.

Citation List

Patent Literature

[0004] Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2012-107805

Summary of Invention

Technical Problem

[0005] With the configuration in Patent Literature 1, low-stage refrigerant is cooled to a lower temperature by the intermediate cooler, and the low-stage refrigerant flows into a low-stage flow passage functioning as the low-stage condenser in a cascade heat exchanger; high-stage refrigerant in a high-stage flow passage functioning as the high-stage evaporator in the cascade heat exchanger exchanges heat with the low-stage refrigerant, so that the high-stage refrigerant evaporates and changes into gas refrigerant. At this time, if heat exchanged with low-stage refrigerant fails to superheat high-stage refrigerant, this causes liquid backflow, which is inflow of refrigerant in a liquid state into the high-stage compressor. As a result, the high-stage compressor can be damaged, or the capacity of the high-stage compressor can be degraded.

[0006] The present disclosure has been made to address the problem described above, and an object thereof is to provide a refrigeration cycle apparatus with a reduced likelihood of damage to a high-stage compressor or degradation of the capacity of the high-stage compressor.

Solution to Problem

[0007] A refrigeration cycle apparatus according to an embodiment of the present disclosure includes a high-stage circuit in which a high-stage compressor, a high-stage condenser, a high-stage expansion valve, and, a high-stage flow passage of a cascade heat exchanger are connected annularly by pipes and in which high-stage refrigerant circulates, a low-stage circuit in which a low-stage compressor, an intermediate cooler, a low-stage flow passage of the cascade heat exchanger, a low-stage expansion valve, and, a low-stage evaporator are connected annularly by pipes and in which low-stage refrigerant circulates, and a controller configured to control operation of the high-stage circuit and the low-stage circuit. The controller is configured to, when determining that the refrigerant in a liquid state flows into the high-stage compressor, allow high temperature low-stage refrigerant, being the low-stage refrigerant having a high temperature and discharged from the low-stage compressor, to flow into the low-stage flow passage of the cascade heat exchanger.

Advantageous Effects of Invention

[0008] With the refrigeration cycle apparatus according to an embodiment of the present disclosure, when it is determined that the refrigerant in a liquid state is to be transferred to the high-stage side compressor, the low-stage refrigerant at a high temperature flows into the cascade heat exchanger, and the high-stage refrigerant is superheated. As a result, liquid backflow is inhibited, and it is thus possible to reduce the likelihood of damage to the high-stage compressor or degradation of the capacity of the high-stage compressor.

Brief Description of Drawings

[0009]

[Fig. 1] Fig. 1 schematically illustrates a configuration of a refrigerant circuit of a refrigeration cycle apparatus according to Embodiment 1.

[Fig. 2] Fig. 2 is a flowchart of control by a controller of the refrigeration cycle apparatus according to Embodiment 1.

[Fig. 3] Fig. 3 is a pressure-enthalpy (ph) diagram of a high-stage circuit of the refrigeration cycle apparatus according to Embodiment 1.

[Fig. 4] Fig. 4 is a ph diagram of a low-stage circuit of the refrigeration cycle apparatus according to Embodiment 1.

[Fig. 5] Fig. 5 is a graph plotting temperature of refrigerants in a cascade heat exchanger of the refrigeration cycle apparatus according to Embodiment 1.

[Fig. 6] Fig. 6 is a ph diagram of the high-stage circuit of the refrigeration cycle apparatus according to Embodiment 1 in a liquid backflow mitigation operation.

[Fig. 7] Fig. 7 is a ph diagram of the low-stage circuit of the refrigeration cycle apparatus according to Embodiment 1 in the liquid backflow mitigation operation.

[Fig. 8] Fig. 8 is a graph plotting temperature of the refrigerants in the cascade heat exchanger of the refrigeration cycle apparatus according to Embodiment 1.

[Fig. 9] Fig. 9 illustrates a refrigerant circuit of a refrigeration cycle apparatus according to Embodiment 2.

Description of Embodiments

[0010] Hereinafter, a refrigeration cycle apparatus 1 according to embodiments will be described with reference to the drawings. The relative dimensions of the constituent members, the shapes of the constituent members, and other specifics in the drawings can be different from actual ones. In the drawings, elements assigned like reference characters are identical to or correspond to each other; the same applies to the entire specification. Alphabets after numerals in the reference numerals in the drawings are sometimes omitted in descriptions. For ease of understanding, terms indicating directions, such as "upper", "lower", "right", "left", "front", or "back", are used when appropriate. The terms indicating directions are used merely for ease of description and should not be interpreted as limiting the disposition and orientation of an apparatus or component.

Embodiment 1

[0011] Fig. 1 schematically illustrates a configuration of a refrigerant circuit of the refrigeration cycle apparatus 1 according to Embodiment 1. As illustrated in Fig. 1, the refrigeration cycle apparatus 1 according to Embodiment 1 includes a high-stage circuit 10 and a low-stage circuit 20. The high-stage circuit 10 and the low-stage circuit 20 are coupled by a cascade heat exchanger 30. As high-stage refrigerant that flows in the high-stage circuit 10, for example, R410A, R32, R404A, HFO-1234yf, propane, isobutane, carbon dioxide, or ammonia may be used. As low-stage refrigerant that flows in the low-stage circuit 20, for example, carbon dioxide, that is, CO_2, which has smaller effects on global warming when leaking out as refrigerant, may be used. The low-stage circuit may also be referred to as a primary-side circuit, the high-stage circuit as a secondary-side circuit, the low-stage refrigerant as primary-side refrigerant, and the high-stage refrigerant as secondary-side refrigerant.

[0012] The cascade heat exchanger 30 is a refrigerant-to-refrigerant heat exchanger for causing the high-stage refrigerant flowing through a high-stage flow passage 31 and the low-stage refrigerant flowing through a low-stage flow passage 32 to exchange heat. The high-stage flow passage 31 forms a portion of the high-stage circuit 10. The low-stage flow passage 32 forms a portion of the low-stage circuit 20. In the cascade heat exchanger 30, the high-stage flow passage 31 and the low-stage flow passage 32 provide countercurrent flows. Specifically, one end side of the cascade heat exchanger 30 is the entry side of the high-stage flow passage 31 and also the exit side of the low-stage flow passage 32. At the one end side, heat is exchanged between the high-stage refrigerant flowing in the high-stage flow passage 31 and the low-stage refrigerant flowing out of the low-stage flow passage 32. The other end side of the cascade heat exchanger 30 is the exit side of the high-stage flow passage 31 and also the entry side of the low-stage flow passage 32. At the other end side, heat is exchanged between the high-stage refrigerant flowing out of the high-stage flow passage 31 and the low-stage refrigerant flowing in the low-stage flow passage 32.

[0013] The high-stage circuit 10 includes a high-stage compressor 11, a high-stage condenser 12, a high-stage expansion valve 13, and the high-stage flow passage 31 of the cascade heat exchanger 30 that are connected annularly by pipes in the order presented.

[0014] The high-stage compressor 11 is operable to suck the high-stage refrigerant released from the high-stage flow passage 31 of the cascade heat exchanger 30, compress the high-stage refrigerant to a high temperature and high pressure, and discharge the high-stage refrigerant at the high temperature and pressure. The high-stage compressor 11 is, for example, an inverter compressor. When the high-stage compressor 11 is an inverter compressor, the rotation speed may be changed by a drive circuit such as an inverter circuit to change the amount of refrigerant per unit time to be discharged from the high-stage compressor 11. In this case, the controller 90 controls the drive circuit. The discharge side of the high-stage compressor 11 is connected to the entry side of the high-stage condenser 12.

[0015] The high-stage condenser 12 is a heat exchanger for causing the high-stage refrigerant flowing in the high-stage condenser 12 to exchange heat with a heat medium surrounding the high-stage condenser 12. The high-stage condenser 12 is, for example, an air-cooled heat exchanger. When the high-stage condenser 12 is of an air-cooled type, a first fan 51 can be provided near the high-stage condenser 12. In this case, the controller 90 controls drive of the first fan 51. The exit side of the high-stage condenser 12 is connected to the high-stage expansion valve 13.

[0016] The high-stage expansion valve 13 is operable to expand the high-stage refrigerant to decrease pressure. As the high-stage expansion valve 13, for example, a thermostatic expansion valve or linear electronic expansion valve may be used. When the high-stage expansion valve 13 is implemented by an electronic expansion valve, the controller 90 controls the opening degree. The exit side of the high-stage expansion valve 13 is connected to the entry side of the high-stage flow passage 31 of the cascade heat exchanger 30.

[0017] The high-stage flow passage 31 of the cascade heat exchanger 30 functions as an evaporator in which the high-stage refrigerant evaporates as the result of heat exchange. The exit side of the high-stage flow passage 31 is connected to the suction side of the high-stage compressor 11.

[0018] The low-stage circuit 20 includes a low-stage compressor 21, an intermediate cooler 22, the low-stage flow passage 32 of the cascade heat exchanger 30, a low-stage expansion valve 24, and a low-stage evaporator 25 that are connected annularly by pipes. The low-stage circuit 20 includes a bypass 23 for bypassing the intermediate cooler 22.

[0019] The low-stage compressor 21 is operable to suck the low-stage refrigerant, compress the low-stage refrigerant into high temperature and high pressure refrigerant, and discharge the low-stage refrigerant. The low-stage compressor 21 is, for example, an inverter compressor. When the low-stage compressor 21 is an inverter compressor, the rotation speed may be changed by a drive circuit such as an inverter circuit to change the amount of refrigerant per unit time to be discharged from the low-stage compressor 21. In this case, the controller 90 controls the drive circuit. The discharge side of the low-stage compressor 21 is connected to the entry side of the intermediate cooler 22.

[0020] The intermediate cooler 22 is a heat exchanger for causing the low-stage refrigerant compressed by the low-stage compressor 21 to a high temperature, flowing in the intermediate cooler 22, to exchange heat with a heat medium surrounding the intermediate cooler 22. The intermediate cooler 22 is, for example, an air-cooled heat exchanger. When the intermediate cooler 22 is an air-cooled heat exchanger, a third fan 53 can be provided near the intermediate cooler 22. In this case, the controller 90 controls drive of the third fan 53. The exit side of the intermediate cooler 22 is connected to the entry side of the low-stage flow passage 32 of the cascade heat exchanger 30.

[0021] One end of the bypass 23 is connected between the discharge side of the low-stage compressor 21 and the entry side of the intermediate cooler 22, and the other end of the bypass 23 is connected between the exit side of the intermediate cooler 22 and the entry side of the low-stage flow passage 32 of the cascade heat exchanger 30. A bypass valve 230 is connected in the bypass 23. The bypass valve 230 is operable to close or open the bypass 23. When the bypass valve 230 is opened, the bypass 23 changes to the open state, and the low-stage refrigerant flows through the bypass 23 while bypassing the intermediate cooler 22. The controller 90 controls the bypass valve 230 to open or close. The bypass valve 230 may be implemented by, for example, a solenoid valve that is able to open or close the bypass 23.

[0022] The low-stage flow passage 32 of the cascade heat exchanger 30 functions as a condenser in which the low-stage refrigerant condenses as the result of heat exchange. The exit side of the low-stage flow passage 32 is connected to the entry side of the low-stage expansion valve 24.

[0023] The low-stage expansion valve 24 is operable to expand the low-stage refrigerant to decrease pressure. As the low-stage expansion valve 24, for example, a thermostatic expansion valve or linear electronic expansion valve may be used. When the low-stage expansion valve 24 is implemented by an electronic expansion valve, the controller 90 controls the opening degree. The exit side of the low-stage expansion valve 24 is connected to the entry side of the low-stage evaporator 25.

[0024] The low-stage evaporator 25 is a heat exchanger for causing the low-stage refrigerant flowing in the low-stage evaporator 25 to exchange heat with a heat medium surrounding the low-stage evaporator 25. The low-stage evaporator 25 is, for example, an air-cooled heat exchanger. When the low-stage evaporator 25 is of an air-cooled type, a second fan 52 can be provided near the low-stage evaporator 25. In this case, the controller 90 controls drive of the second fan 52. The exit side of the low-stage evaporator 25 is connected to the suction side of the low-stage compressor 21.

[0025] The controller 90 includes a processing circuit. The processing circuit is implemented by a dedicated hardware device or processor. The dedicated hardware is, for example, an application specific integrated circuit (ASIC) or field programmable gate array (FPGA). The processor is operable to run programs stored in a memory. A storage unit provided in the controller 90, which is not illustrated in the drawings, is implemented by the memory. The memory is a non-volatile or volatile semiconductor memory such as a random-access memory (RAM), read-only memory (ROM), flash memory, or erasable programmable ROM (EPROM) or a disk such as a magnetic disk, flexible disk, or optical disc.

[0026] The controller 90 is operable to control operation of the high-stage circuit 10 and the low-stage circuit 20. The controller 90 receives detection values from different kinds of sensors provided in the high-stage circuit 10 or the low-stage circuit 20. The sensors include an air temperature sensor T0, a low-stage compressor discharge pressure sensor P21, a low-stage cascade entry temperature sensor T32, a high-stage compressor suction temperature sensor T11, and a high-stage compressor suction pressure sensor P11.

[0027] The air temperature sensor T0 is positioned in the same space as the intermediate cooler 22. The air temperature sensor T0 is operable to detect an air temperature of the space including the intermediate cooler 22. The air temperature sensor T0 detects, for example, the temperature of air taken in by the third fan 53. The low-stage compressor discharge pressure sensor P21 is positioned on the discharge side of the low-stage compressor 21. The low-stage compressor discharge pressure sensor P21 is operable to detect a discharge pressure of the low-stage compressor 21. The low-stage cascade entry temperature sensor T32 is positioned at the entry of the low-stage flow passage 32 of the cascade heat exchanger 30. The low-stage cascade entry temperature sensor T32 is operable to detect the temperature of the low-stage refrigerant at the entry of the low-stage flow passage 32 of the cascade heat exchanger 30. The high-stage compressor suction temperature sensor T11 is positioned on the suction side of the high-stage compressor 11. The high-stage compressor suction temperature sensor T11 is operable to detect the temperature of the high-stage refrigerant at the suction side of the high-stage compressor 11. The high-stage compressor suction pressure sensor P11 is positioned on the suction side of the high-stage compressor 11. The high-stage compressor suction pressure sensor P11 is operable to detect the pressure of the high-stage refrigerant at the suction side of the high-stage compressor 11.

[0028] As well as the sensors described above, the sensors may also include, for example, a low-stage compressor suction temperature sensor for detecting the temperature of the low-stage refrigerant on the suction side of the low-stage compressor 21 or low-stage compressor suction pressure sensor for detecting the pressure of the low-stage refrigerant, either of which can be positioned on the suction side of the low-stage compressor 21.

[0029] When the controller 90 determines, based on values transmitted from the sensors, that there is a high probability of liquid backflow to the high-stage compressor 11, the controller 90 performs a liquid backflow mitigation operation. In the liquid backflow mitigation operation, the low-stage refrigerant at a high temperature discharged from the low-stage compressor 21 is routed to the low-stage flow passage 32 of the cascade heat exchanger 30. In the liquid backflow mitigation operation, the controller 90 opens the bypass valve 230. As a result, the low-stage refrigerant flows in the bypass 23 to bypass the intermediate cooler 22. Without the intermediate cooler 22 cooling the low-stage refrigerant at a high temperature discharged from the low-stage compressor 21, the low-stage refrigerant at a high temperature directly flows into the low-stage flow passage 32 of the cascade heat exchanger 30.

[0030] Whether there is a high probability of liquid backflow is determinable using a first criterion, a second criterion, or a third criterion. The first criterion is when the air temperature in a space including the intermediate cooler 22 is smaller than the sum of the condensing temperature in the low-stage flow passage 32 of the cascade heat exchanger 30 and a first predetermined value. The first predetermined value is, for example, 5 K. The second criterion is when the degree of superheat at the entry of the low-stage flow passage 32 of the cascade heat exchanger 30 is smaller than a second predetermined value. The second predetermined value is, for example, 5 K. The third criterion is when the degree of superheat at the suction side of the high-stage compressor 11 is smaller than a third predetermined value. The third predetermined value is, for example, 5 K. When the controller 90 determines, based on detection values from the sensors, that the first criterion, the second criterion, or the third criterion applies, the controller 90 performs the liquid backflow mitigation operation.

[0031] Criteria for determining whether there is a high probability of liquid backflow are not limited to the first criterion, the second criterion, or the third criterion. Other criterions may be used when the criterions enable determination of whether there is a high probability of liquid backflow. In this case, sensors may be provided in the high-stage circuit 10 or the low-stage circuit 20 as necessary.

[0032] Fig. 2 is a flowchart of control by the controller 90 of the refrigeration cycle apparatus 1 according to Embodiment 1. As illustrated in Fig. 2, in step S01, the controller 90 determines whether there is a high probability of liquid backflow. Specifically, the controller 90 determines, based on values from the sensors, whether the first criterion, the second criterion, or the third criterion applies. When any of the first criterion, the second criterion, or the third criterion applies, the controller 90 determines that there is a high probability of liquid backflow.

[0033] Specifically, when the air temperature in a space including the intermediate cooler 22 is smaller than the sum of the condensing temperature in the low-stage flow passage 32 of the cascade heat exchanger 30 and the first predetermined value, the controller 90 determines that there is a high probability of liquid backflow of refrigerant in a liquid state flowing into the high-stage compressor 11. The air temperature of a space including the intermediate cooler 22 is obtained by the controller 90 based on the air temperature of a space including the intermediate cooler 22. The condensing temperature in the low-stage flow passage 32 of the cascade heat exchanger 30 is obtained by the controller 90 based on the detection value from the low-stage compressor discharge pressure sensor P21 with reference to the physical properties of the low-stage refrigerant.

[0034] Alternatively, when the degree of superheat at the entry of the low-stage flow passage 32 of the cascade heat exchanger 30 is smaller than the second predetermined value, the controller 90 determines that there is a high probability of liquid backflow to the high-stage compressor 11. The degree of superheat at the entry of the low-stage flow passage 32 of the cascade heat exchanger 30 is obtained by the controller 90 based on the difference to the condensing temperature of the low-stage refrigerant obtained using the low-stage cascade entry temperature sensor T32 and the low-stage compressor discharge pressure sensor P21.

[0035] Alternatively, when the degree of superheat at the suction side of the high-stage compressor 11 is smaller than the third predetermined value, the controller 90 determines that there is a high probability of liquid backflow to the high-stage compressor 11. The degree of superheat at the suction side of the high-stage compressor 11 is obtained by the controller 90 based on the difference to the evaporating temperature of the high-stage refrigerant obtained using the high-stage compressor suction temperature sensor T11 and the high-stage compressor suction pressure sensor P11.

[0036] In step S01, when the controller 90 determines that there is a high probability of liquid backflow to the high-stage compressor 11, the process proceeds to step S02, and the controller 90 performs the liquid backflow mitigation operation in step S02. In the liquid backflow mitigation operation, the low-stage circuit 20 is rerouted such that the low-stage refrigerant at a high temperature discharged from the low-stage compressor 21 flows into the low-stage flow passage 32 of the cascade heat exchanger 30. Specifically, in the liquid backflow mitigation operation, the controller 90 opens the bypass valve 230 provided in the bypass 23 so that the low-stage refrigerant at a high temperature discharged from the low-stage compressor 21 is caused to flow through the bypass 23 into the low-stage flow passage 32 of the cascade heat exchanger 30. The low-stage refrigerant at a high temperature discharged from the low-stage compressor 21 flows, without the intermediate cooler 22 cooling the low-stage refrigerant at a high temperature, through the bypass 23 into the low-stage flow passage 32 of the cascade heat exchanger 30.

[0037] Subsequently, the process proceeds to step S03, and the controller 90 determines whether the probability of liquid backflow has decreased. Specifically, the controller 90 determines whether the first criterion, the second criterion, or the third criterion applies. When the first criterion, the second criterion, or the third criterion applies, the process returns to step S02, and the controller 90 continues to perform the liquid backflow mitigation operation. When the first criterion, the second criterion, or the third criterion does not apply, the controller 90 determines that the probability of liquid backflow has decreased. When the controller 90 determines that the probability of liquid backflow has decreased in step S03, the process ends. The process may be implemented by the controller 90, for example, at regular time intervals.

[0038] As described above, when it is determined that there is a high probability of liquid backflow to the high-stage compressor 11, the low-stage circuit 20 is rerouted to bypass the intermediate cooler 22. As a result, the low-stage refrigerant at a high temperature directly flows into the low-stage flow passage 32 of the cascade heat exchanger 30. As regards the liquid backflow mitigation operation, the low-stage refrigerant at a high temperature means that the low-stage refrigerant has a temperature that allows the high-stage refrigerant flowing in the high-stage flow passage 31 of the cascade heat exchanger 30 to be changed to a heated state. The high-stage refrigerant in a two-phase state flowing in the high-stage flow passage 31 of the cascade heat exchanger 30 is superheated by the low-stage refrigerant at a high temperature, and the superheated high-stage refrigerant is released from the high-stage flow passage 31. As such, the high-stage refrigerant to be transferred to the high-stage compressor 11 is superheated. This inhibits occurrence of liquid backflow to the high-stage compressor 11, thereby reducing the likelihood of damage to the high-stage compressor 11 or degradation of the capacity of the high-stage compressor 11.

[0039] The following describes conditions of the refrigerants in the high-stage circuit 10 and the low-stage circuit 20. Firstly, conditions of the refrigerants when there is no probability of liquid backflow will be described.

[0040] In the high-stage circuit 10, the high-stage refrigerant is sucked by the high-stage compressor 11, compressed, and discharged in a gas state at a high temperature and high pressure. The high-stage refrigerant in a gas state at a high temperature and high pressure is cooled in the high-stage condenser 12 by exchanging heat with air surrounding the high-stage condenser 12, released in the state of low temperature and high pressure high-stage refrigerant from the high-stage condenser 12, and transferred to the high-stage expansion valve 13. The high-stage refrigerant at a low temperature and high pressure is expanded and decompressed by the high-stage expansion valve 13 and changed to a two-phase state at a low temperature and low pressure. The high-stage refrigerant in a two-phase state at a low temperature and low pressure flows into the high-stage flow passage 31 functioning as a high-stage evaporator of the cascade heat exchanger 30 (a point a in Fig. 1) and exchanges heat with the low-stage refrigerant flowing in the low-stage flow passage 32.

[0041] The high-stage refrigerant is evaporated by heat exchanged with the low-stage refrigerant flowing in the low-stage flow passage 32, having being cooled to a low temperature by the intermediate cooler 22 in the low-stage circuit 20, and the high-stage refrigerant is changed into gas at a low temperature and low pressure (a point b in Fig. 1). The high-stage refrigerant in a gas state at a low temperature and low pressure is released from the high-stage flow passage 31 and sucked again by the high-stage compressor 11.

[0042] By contrast, in the low-stage circuit 20, the low-stage refrigerant is sucked by the low-stage compressor 21, compressed, and discharged in a gas state at a high temperature and high pressure. The low-stage refrigerant at a high temperature and high pressure is cooled by the intermediate cooler 22 and released.

[0043] The low-stage refrigerant released from the intermediate cooler 22 is transferred to the low-stage flow passage 32 functioning as a low-stage condenser of the cascade heat exchanger 30 (a point c in Fig. 1), condensed by heat exchanged with the high-stage refrigerant flowing in the high-stage flow passage 31, and changed to the low-stage refrigerant at a low temperature and high pressure (a point d in Fig. 1). The low-stage refrigerant at a low temperature and high pressure is expanded and decompressed by the low-stage expansion valve 24, changed to a two-phase state at a low temperature and low pressure, and then released. The low-stage refrigerant in a two-phase state at a low temperature and low pressure is transferred to the low-stage evaporator 25, evaporated by heat exchanged with air surrounding the low-stage evaporator 25, released in a gas state at a low temperature and low pressure from the low-stage evaporator 25, and sucked again by the low-stage compressor 21.

[0044] As described above, the low-stage refrigerant flowing into the low-stage flow passage 32 of the cascade heat exchanger 30 has been cooled by the intermediate cooler 22 to a low temperature. When the low-stage refrigerant at a high temperature of, for example, 100 degrees C is discharged from the low-stage compressor 21, in the case in which the environmental temperature in a space including the intermediate cooler 22 is, for example, 20 degrees C, the low-stage refrigerant is cooled by the intermediate cooler 22 and changed to a gas state at a low temperature of, for example, 30 degrees C. As such, the amount of cooling by the high-stage refrigerant from the entry to the exit of the high-stage flow passage 31 is reduced as compared to if the low-stage refrigerant at a high temperature directly flows into the low-stage flow passage 32 of the cascade heat exchanger 30. As a result, the high-stage compressor 11 operates with a reduced amount of power.

[0045] Secondly, conditions of the refrigerants when there is a high probability of liquid backflow to the high-stage compressor 11 will be described. Fig. 3 is a pressure-enthalpy (ph) diagram of the high-stage circuit 10 of the refrigeration cycle apparatus 1 according to Embodiment 1. Fig. 4 is a ph diagram of the low-stage circuit 20 of the refrigeration cycle apparatus 1 according to Embodiment 1. In Figs. 3 and 4, the horizontal axis indicates specific enthalpy h, and the vertical axis indicates pressure p. In Figs. 3 and 4, the points a, b, c, and d represent the refrigerant condition at the corresponding points in Fig. 1.

[0046] As illustrated in Fig. 3, when the high-stage refrigerant in a two-phase state reaches the exit side of the high-stage flow passage 31 to flow into the high-stage compressor 11, the probability of liquid backflow to the high-stage compressor 11 increases. Specifically, when the high-stage refrigerant is not evaporated into gas by heat received from the low-stage refrigerant flowing in the low-stage flow passage 32, the high-stage refrigerant in a two-phase state reaches the exit side of the high-stage flow passage 31 (the point b in Fig. 3). When the high-stage refrigerant reaching the exit side of the high-stage flow passage 31 is released from the high-stage flow passage 31 with no degree of superheat that is represented by the difference to the evaporating temperature as saturation temperature, the high-stage refrigerant in a liquid state can flow into the high-stage compressor 11, increasing the probability of liquid backflow.

[0047] As illustrated in Fig. 4, because the low-stage refrigerant is cooled by the intermediate cooler 22 on the entry side of the low-stage flow passage 32, the degree of superheat that is represented by the difference to the condensing temperature as saturation temperature is relatively low (the point c in Fig. 4). When the degree of superheat of the low-stage refrigerant is relatively low, the high-stage refrigerant on the exit side of the high-stage flow passage 31 is not superheated over the evaporating temperature, and the high-stage refrigerant fails to evaporate into gas.

[0048] Fig. 5 is a graph plotting temperature of the refrigerants in the cascade heat exchanger 30 of the refrigeration cycle apparatus 1 according to Embodiment 1. In Fig. 5, the horizontal axis indicates distance X from one end side of the cascade heat exchanger 30, and the vertical axis indicates temperature T of refrigerant. In Fig. 5, the points a, b, c, and d represent the refrigerant condition at the corresponding points in Fig. 1.

[0049] As illustrated in Fig. 5, when the low-stage refrigerant on the entry side of the low-stage flow passage 32 is cooled by the intermediate cooler 22, and the degree of superheat of the low-stage refrigerant is thus relatively low, the degree of superheat SH of the high-stage refrigerant on the exit side of the high-stage flow passage 31 is also relatively low. Because the condensing temperature and the evaporating temperature are saturation temperatures, the difference between the condensing temperature and the evaporating temperature does not change. Because the degree of superheat SH of the high-stage refrigerant is relatively low, the high-stage refrigerant is not superheated over the evaporating temperature to evaporate into gas, and the high-stage refrigerant thus flows into the high-stage compressor 11 without changing the state of the high-stage refrigerant. As a result, liquid backflow to the high-stage compressor 11 occurs, thereby causing damage to the high-stage compressor 11 or degradation of the capacity of the high-stage compressor 11.

[0050] Secondly, conditions of the refrigerants in the liquid backflow mitigation operation for the high-stage compressor 11 will be described. Fig. 6 is a ph diagram of the high-stage circuit 10 of the refrigeration cycle apparatus 1 according to Embodiment 1 in the liquid backflow mitigation operation. Fig. 7 is a ph diagram of the low-stage circuit 20 of the refrigeration cycle apparatus 1 according to Embodiment 1 in the liquid backflow mitigation operation. In Figs. 6 and 7, the horizontal axis indicates specific enthalpy h, and the vertical axis indicates pressure. In Figs. 6 and 7, the points a, b, c, and d represent the refrigerant condition at the corresponding points in Fig. 1.

[0051] As illustrated in Figs. 6 and 7, in the liquid backflow mitigation operation, the low-stage refrigerant discharged from the low-stage compressor 21 flows through the bypass 23 into the low-stage flow passage 32 of the cascade heat exchanger 30 (the point c in Fig. 7) and exchanges heat with the high-stage refrigerant on the exit side of the high-stage flow passage 31 (the point b in Fig. 6). The low-stage refrigerant transferred through the bypass 23 is not cooled because the low-stage refrigerant does not pass through the intermediate cooler 22. The low-stage refrigerant with a relatively high degree of superheat reaches the entry side of the low-stage flow passage 32. As a result, the high-stage refrigerant on the exit side of the high-stage flow passage 31 exchanges heat with the low-stage refrigerant with a relatively high degree of superheat at the same high temperature as when the low-stage refrigerant is discharged from the low-stage compressor 21.

[0052] Fig. 8 is a graph plotting temperature of the refrigerants in the cascade heat exchanger 30 of the refrigeration cycle apparatus 1 according to Embodiment 1. In Fig. 8, the horizontal axis indicates distance X from one end side of the cascade heat exchanger 30, and the vertical axis indicates temperature T of refrigerant. In Fig. 8, the points a, b, c, and d represent the refrigerant condition at the corresponding points in Fig. 1.

[0053] As illustrated in Fig. 8, because the low-stage refrigerant is transferred through the bypass 23 to the entry side of the low-stage flow passage 32 without the intermediate cooler 22 cooling the low-stage refrigerant, the degree of superheat of the low-stage refrigerant is relatively high (the point c in Fig. 8). As a result, at the exit of the high-stage flow passage 31, the high-stage refrigerant communicates with the low-stage refrigerant with a relatively high degree of superheat at a high temperature (the point b in Fig. 8). As a result of receiving heat from the low-stage refrigerant, the degree of superheat SH of the high-stage refrigerant is increased, and the high-stage refrigerant is evaporated into gas and released from the high-stage flow passage 31. As such, the degree of superheat SH of the high-stage refrigerant to be transferred to the high-stage compressor 11 is increased, and the high-stage refrigerant in a gas state is sucked by the high-stage compressor 11, thereby inhibiting liquid backflow to the high-stage compressor 11.

<Modification>

[0054] The refrigeration cycle apparatus 1 according to a modification is configured such that in the liquid backflow mitigation operation, the rotation speed of the third fan 53 is decreased by the controller 90. In this case, it may be possible that the low-stage circuit 20 does not include the bypass 23 for bypassing the intermediate cooler 22. When the controller 90 determines, based on values from the sensors, that there is a high probability of liquid backflow to the high-stage compressor 11, the controller 90 performs the liquid backflow mitigation operation and decreases the rotation speed of the third fan 53. As a result, the amount of cooling of the low-stage refrigerant by the intermediate cooler 22 is decreased, and the degree of superheat of the refrigerant on the entry side of the low-stage flow passage 32 of the cascade heat exchanger 30 is not decreased much, thereby inhibiting liquid backflow to the high-stage compressor 11.

[0055] The refrigeration cycle apparatus 1 according to Embodiment 1 described above is configured such that, when it is determined that the refrigerant in a liquid state is to be transferred to the high-stage compressor 11, the low-stage refrigerant at a high temperature discharged from the low-stage compressor 21 flows into the low-stage flow passage 32 of the cascade heat exchanger 30. With this configuration, the low-stage refrigerant at a high temperature is transferred to the low-stage flow passage 32 of the cascade heat exchanger 30. The high-stage refrigerant in a two-phase state flowing in the high-stage flow passage 31 of the cascade heat exchanger 30 is thus heated more on the exit side of the high-stage flow passage 31 to be superheated, and the superheated high-stage refrigerant is released from the high-stage flow passage 31. As a result, the high-stage refrigerant to be transferred to the high-stage compressor 11 is superheated. This inhibits occurrence of liquid backflow to the high-stage compressor 11, thereby reducing the likelihood of damage to the high-stage compressor 11 or degradation of the capacity of the high-stage compressor 11.

[0056] The low-stage circuit 20 includes the bypass 23 for bypassing the intermediate cooler 22. The low-stage circuit 20 is configured such that when there is a high probability of liquid backflow, the bypass valve 230 is closed. As a result, the degree of superheat of the low-stage refrigerant to be transferred to the low-stage flow passage 32 of the cascade heat exchanger 30 is not decreased; and thus, the degree of superheat of the low-stage refrigerant in the low-stage flow passage 32 is relatively high, and the degree of superheat SH of the high-stage refrigerant is also relatively high. As such, liquid backflow to the high-stage compressor 11 is inhibited.

[0057] The third fan 53 is configured such that when there is a high probability of liquid backflow in the low-stage circuit 20, the rotation speed of the third fan 53 is decreased. As a result, the amount of cooling of the low-stage refrigerant by the intermediate cooler 22 is decreased, and the degree of superheat of the low-stage refrigerant is not decreased. As such, liquid backflow to the high-stage compressor 11 is inhibited.

[0058] The controller 90 is configured such that when the environmental temperature of the low-stage circuit 20 is smaller than the sum of the condensing temperature in the low-stage flow passage 32 of the cascade heat exchanger 30 and the first predetermined value, the controller 90 determines that there is a high probability of liquid backflow. When it is accordingly determined that there is a high probability of liquid backflow, the liquid backflow mitigation operation is performed. As such, liquid backflow to the high-stage compressor 11 is inhibited.

[0059] The controller 90 is also configured such that when the degree of superheat at the entry of the low-stage flow passage 32 of the cascade heat exchanger 30 is smaller than the second predetermined value, the controller 90 determines that there is a high probability of liquid backflow. When it is accordingly determined that there is a high probability of liquid backflow, the liquid backflow mitigation operation is performed. As such, liquid backflow to the high-stage compressor 11 is inhibited.

[0060] The controller 90 is also configured such that when the degree of superheat SH of the high-stage refrigerant on the suction side of the high-stage compressor 11 is smaller than the third predetermined value, the controller 90 determines that the refrigerant in a liquid state is to be transferred to the high-stage compressor 11. When it is accordingly determined that there is a high probability of liquid backflow, the liquid backflow mitigation operation is performed. As such, liquid backflow to the high-stage compressor 11 is inhibited.

Embodiment 2

[0061] Fig. 9 illustrates a refrigerant circuit of the refrigeration cycle apparatus 1 according to Embodiment 2. The refrigeration cycle apparatus 1 according to Embodiment 2 differs from Embodiment 1 in that the high-stage circuit 10 is provided with a high-low pressure heat exchanger 14. The same elements as Embodiment 1 are assigned the same reference numerals, and descriptions of the same elements are not repeated. As illustrated in Fig. 9, the high-low pressure heat exchanger 14 includes a first flow passage 141 for transferring the high-stage refrigerant on the exit side of the high-stage flow passage 31 of the cascade heat exchanger 30 and also on the suction side of the high-stage compressor 11. The high-low pressure heat exchanger 14 also includes a second flow passage 142 for transferring the high-stage refrigerant between the high-stage condenser 12 and the high-stage expansion valve 13.

[0062] The high-low pressure heat exchanger 14 is a heat exchanger for causing the high-stage refrigerant flowing in the first flow passage 141 and the high-stage refrigerant flowing in the second flow passage 142 to exchange heat. Because the high-low pressure heat exchanger 14 is provided, the high-stage refrigerant on the exit side of the high-stage flow passage 31 of the cascade heat exchanger 30 exchanges heat with the high-stage refrigerant flowing in the second flow passage 142 of the high-low pressure heat exchanger 14. As a result, the degree of superheat SH of the high-stage refrigerant is increased. As a result, the high-stage refrigerant is not sucked by the high-stage compressor 11 while the high-stage refrigerant is in a two-phase state, so that liquid backflow is inhibited. As such, the likelihood of damage to the high-stage compressor 11 or degradation of the capacity of the high-stage compressor 11 is reduced.

[0063] In the refrigeration cycle apparatus 1 according to Embodiment 2 described above, the high-stage refrigerant on the exit side of the high-stage flow passage 31 of the cascade heat exchanger 30 exchanges heat with the high-stage refrigerant flowing in the second flow passage 142 of the high-low pressure heat exchanger 14 in the high-low pressure heat exchanger 14. As a result, the degree of superheat SH of the high-stage refrigerant is increased, and liquid backflow is thus inhibited. As compared to when only the liquid backflow mitigation operation is performed, it is possible to further reduce the likelihood of damage to the high-stage compressor 11 or degradation of the capacity of the high-stage compressor 11.

Reference Signs List

[0064] 1: refrigeration cycle apparatus, 10: high-stage circuit, 11: high-stage compressor, 12: high-stage condenser, 13: high-stage expansion valve, 14: high-low pressure heat exchanger, 20: low-stage circuit, 21: low-stage compressor, 22: intermediate cooler, 23: bypass, 24: low-stage expansion valve, 25: low-stage evaporator, 30: cascade heat exchanger, 31:high-stage flow passage, 32: low-stage flow passage, 51: first fan, 52: second fan, 53: third fan, 90: controller, 141: first flow passage, 142: second flow passage, 230: bypass valve, P11: high-stage compressor suction pressure sensor, P21: low-stage compressor discharge pressure sensor, T0: air temperature sensor, T11: high-stage compressor suction temperature sensor, T32: low-stage cascade entry temperature sensor.

Claims

1. A refrigeration cycle apparatus comprising:

a high-stage circuit in which a high-stage compressor, a high-stage condenser, a high-stage expansion valve, and, a high-stage flow passage of a cascade heat exchanger are connected annularly by pipes and in which high-stage refrigerant circulates;
a low-stage circuit in which a low-stage compressor, an intermediate cooler, a low-stage flow passage of the cascade heat exchanger, a low-stage expansion valve, and, a low-stage evaporator are connected annularly by pipes and in which low-stage refrigerant circulates; and
a controller configured to control operation of the high-stage circuit and the low-stage circuit, wherein
the controller is configured to, when determining that the refrigerant in a liquid state flows into the high-stage compressor, allow high temperature low-stage refrigerant, being the low-stage refrigerant having a high temperature and discharged from the low-stage compressor, to flow into the low-stage flow passage of the cascade heat ex-

changer.

2. The refrigeration cycle apparatus of claim 1, wherein the high temperature low-stage refrigerant is the low-stage refrigerant having a temperature that allows the high-stage refrigerant flowing in the high-stage flow passage to be changed to a heated state.

3. The refrigeration cycle apparatus of claim 1 or 2, further comprising:

a bypass configured to bypass the intermediate cooler; and
a bypass valve provided in the bypass,
wherein
the controller is configured to, when determining that the refrigerant in a liquid state flows into the high-stage compressor, open the bypass valve.

4. The refrigeration cycle apparatus of any one of claims 1 to 3, further comprising:

a fan configured to send air to the intermediate cooler,
wherein
the controller is configured to, when determining that the refrigerant in a liquid state flows into the high-stage compressor, decrease a rotation speed of the fan.

5. The refrigeration cycle apparatus of any one of claims 1 to 4, wherein
the controller is configured to, when an environmental temperature of the low-stage circuit is smaller than a sum of a condensing temperature in a low-stage flow passage of the cascade heat exchanger and a first predetermined value, determine that the refrigerant in a liquid state flows into the high-stage compressor.

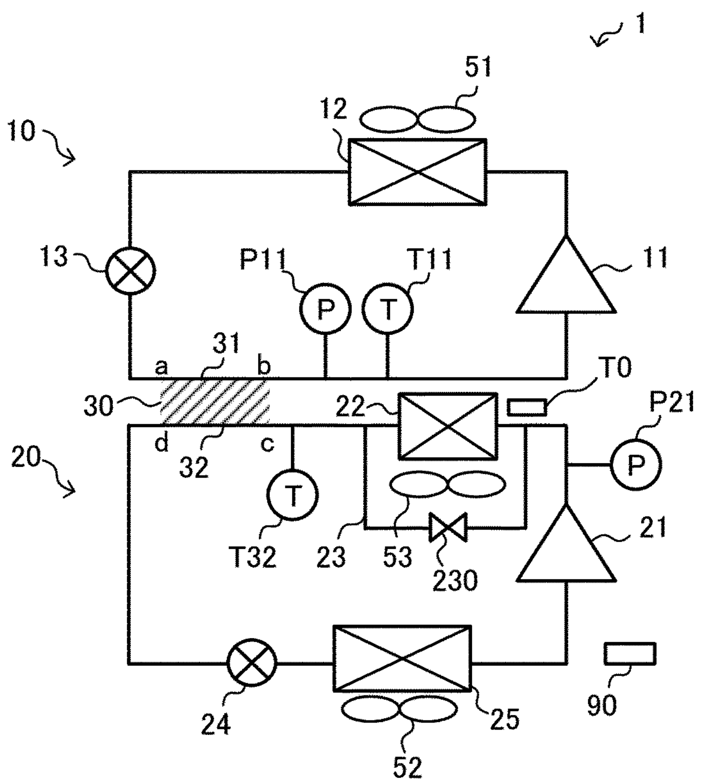
6. The refrigeration cycle apparatus of any one of claims 1 to 5, wherein
the controller is configured to, when a degree of superheat at an entry of a low-stage flow passage of the cascade heat exchanger is smaller than a second predetermined value, determine that the refrigerant in a liquid state flows into the high-stage compressor.

7. The refrigeration cycle apparatus of any one of claims 1 to 6, wherein
the controller is configured to, when a degree of superheat at a suction side of the high-stage compressor is smaller than a third predetermined value, determine that the refrigerant in a liquid state flows into the high-stage compressor.

8. The refrigeration cycle apparatus of any one of claims 1 to 7, further comprising:

a high-low pressure heat exchanger configured to cause the high-stage refrigerant on an exit side of the high-stage flow passage of the cascade heat exchanger and the high-stage refrigerant on a suction side of the high-stage compressor to exchange heat.

FIG. 1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12
10
13
P11
T11
11
P
T
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31
b
30
T0
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P21
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d
32
c
20
T
T32
23
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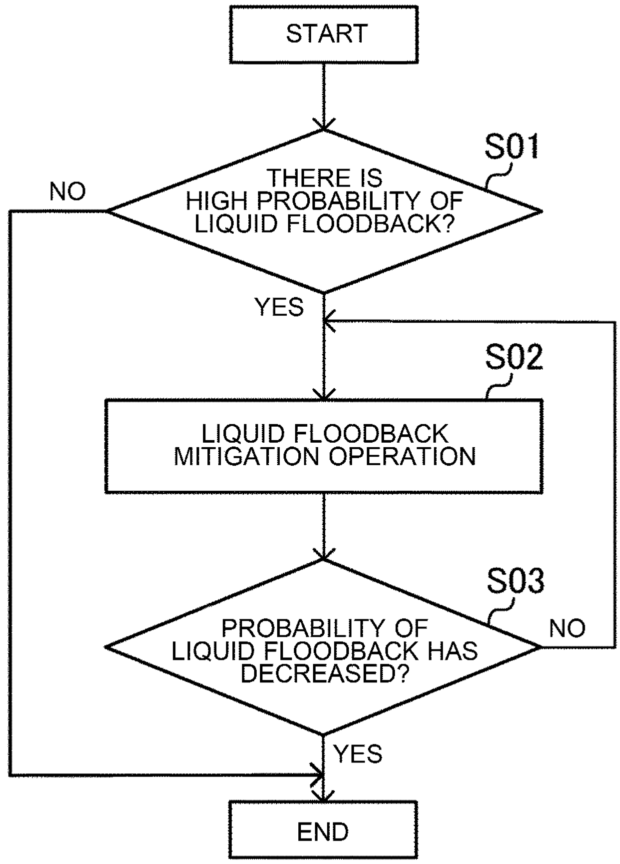
90
52

FIG. 2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YES
S02
LIQUID FLOODBACK MITIGATION OPERATION
S03
PROBABILITY OF LIQUID FLOODBACK HAS DECREASED?
NO
YES
END

FIG. 3

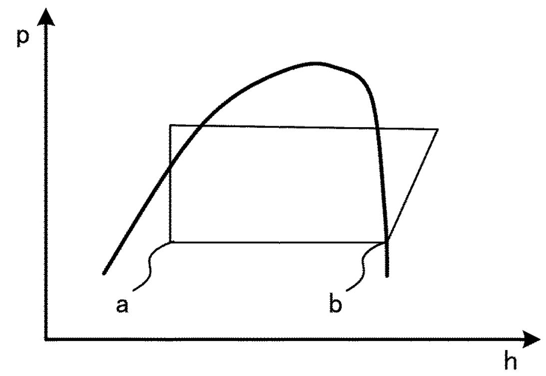


FIG. 4

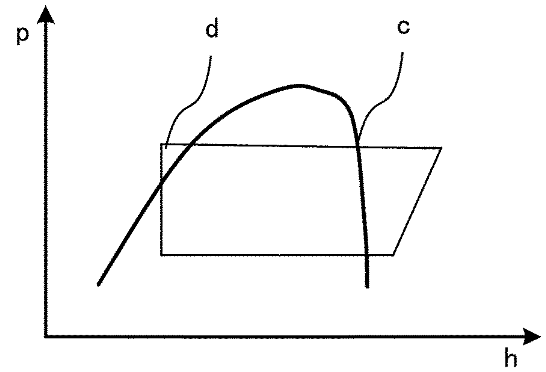


FIG. 5

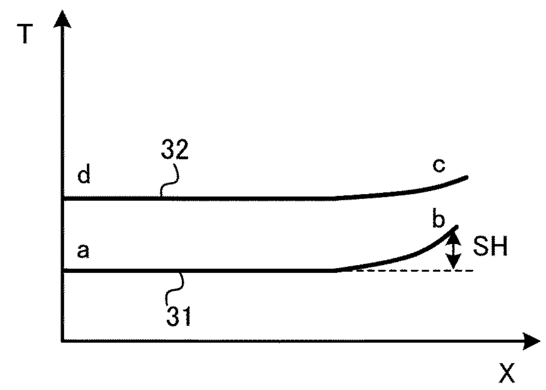


FIG. 6

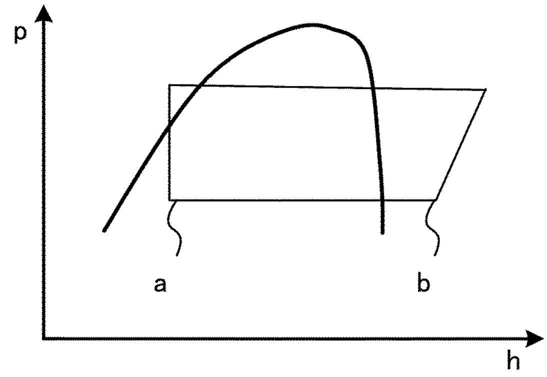


FIG. 7

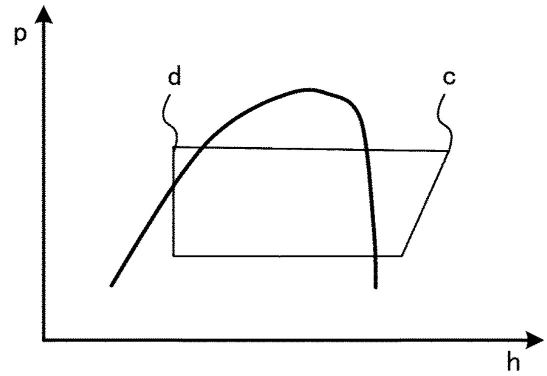


FIG. 8

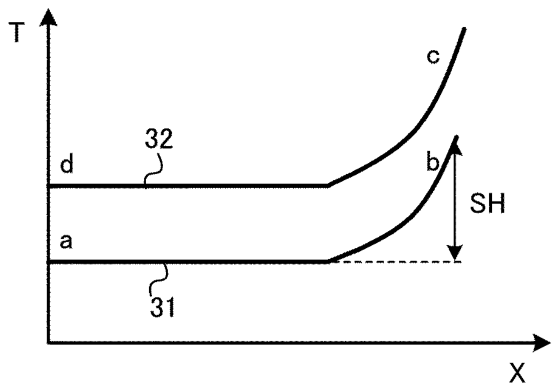
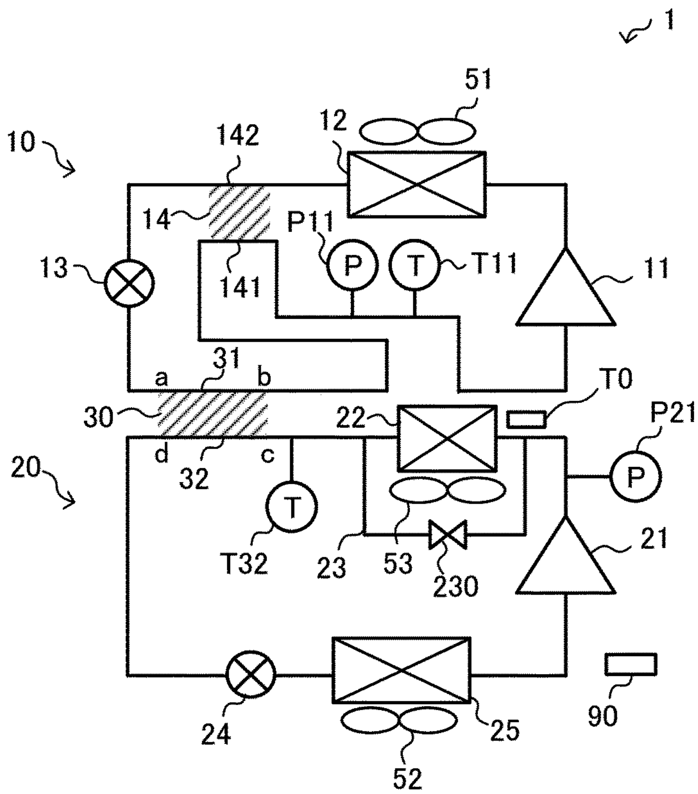


FIG. 9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T11
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b
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P21
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c
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32
T32
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230
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INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2021/018771

A. CLASSIFICATION OF SUBJECT MATTER
F25B 7/00(2006.01)i; F25B 1/00(2006.01)n
FI: F25B7/00 D; F25B1/00 101G

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)
F25B7/00; F25B1/00

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

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2018/008053 A1 (MITSUBISHI ELECTRIC CORP) 11 January 2018 (2018-01-11) fig. 8, paragraphs [0087]-[0088]	1-8
A	JP 2012-112617 A (MITSUBISHI ELECTRIC CORP) 14 June 2012 (2012-06-14) fig. 10, paragraphs [0091]-[0101]	1-8
A	JP 2013-213591 A (TOYO ENG WORKS LTD) 17 October 2013 (2013-10-17) entire text, all drawings	1-8
A	JP 2012-107805 A (MITSUBISHI ELECTRIC CORP) 07 June 2012 (2012-06-07) entire text, all drawings	1-8
A	JP 2013-148330 A (DAIKIN INDUSTRIES LTD) 01 August 2013 (2013-08-01) paragraphs [0071]-[0072]	1-8

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
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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
09 June 2021 (09.06.2021)	22 June 2021 (22.06.2021)

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2021/018771

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
WO 2018/008053 A1	11 Jan. 2018	(Family: none)	
JP 2012-112617 A	14 Jun. 2012	(Family: none)	
JP 2013-213591 A	17 Oct. 2013	(Family: none)	
JP 2012-107805 A	07 Jun. 2012	(Family: none)	
JP 2013-148330 A	01 Aug. 2013	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

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- JP 2012107805 A **[0004]**