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(54) REFRIGERATION CYCLE APPARATUS

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(57) **ABSTRACT**

In a first operation mode, a flow path switching device connects a discharge port to a refrigerant inlet of a first heat exchanger, connects a refrigerant outlet of the first heat exchanger to a refrigerant inlet of a first flow path, connects a refrigerant outlet of a first expansion valve to a refrigerant inlet of a second heat exchanger, and connects a refrigerant outlet of the second heat exchanger to a suction port. In a second operation mode, the flow path switching device connects the discharge port to the refrigerant inlet of the second heat exchanger, connects the refrigerant outlet of the second heat exchanger to the refrigerant inlet of the first flow path, connects the refrigerant outlet of the first expansion valve to the refrigerant inlet of the first heat exchanger, and connects the refrigerant outlet of the first heat exchanger to the suction port.

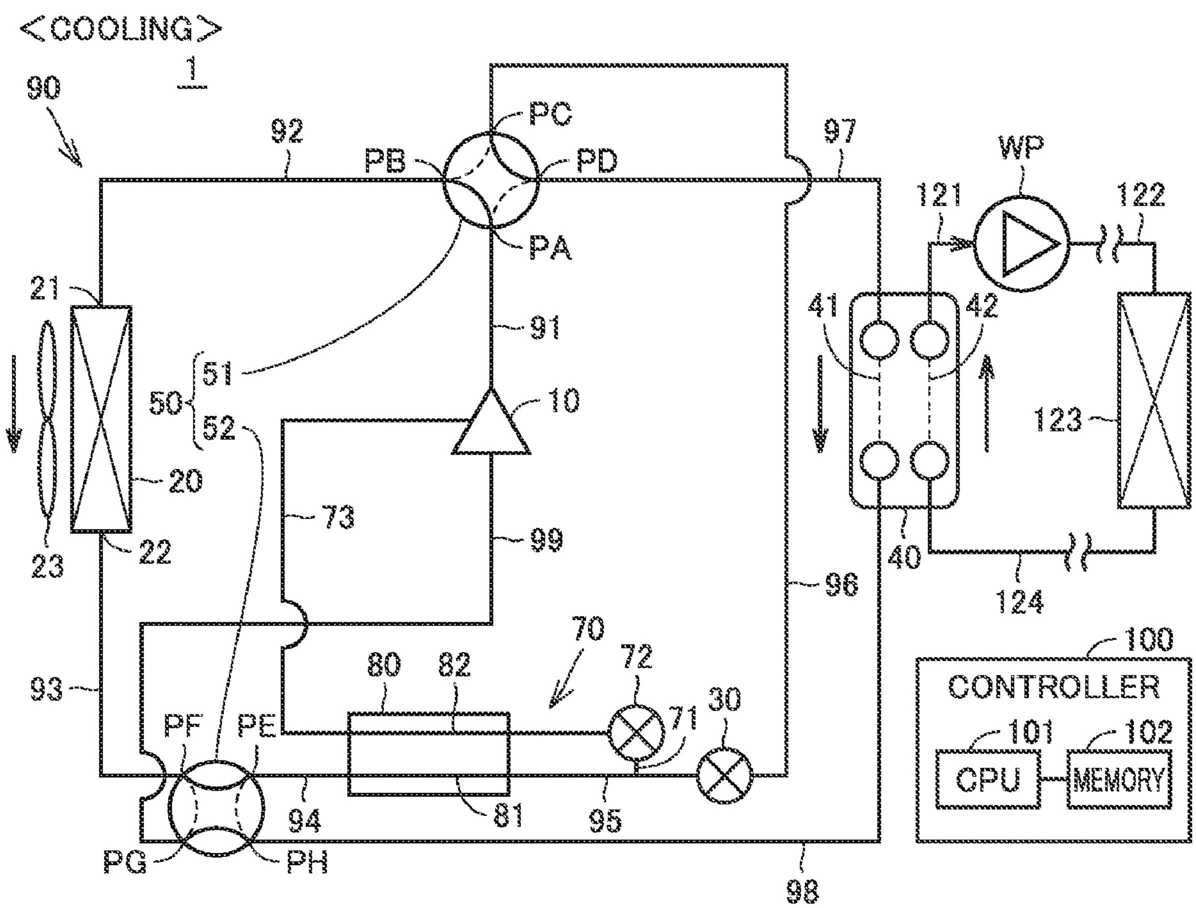
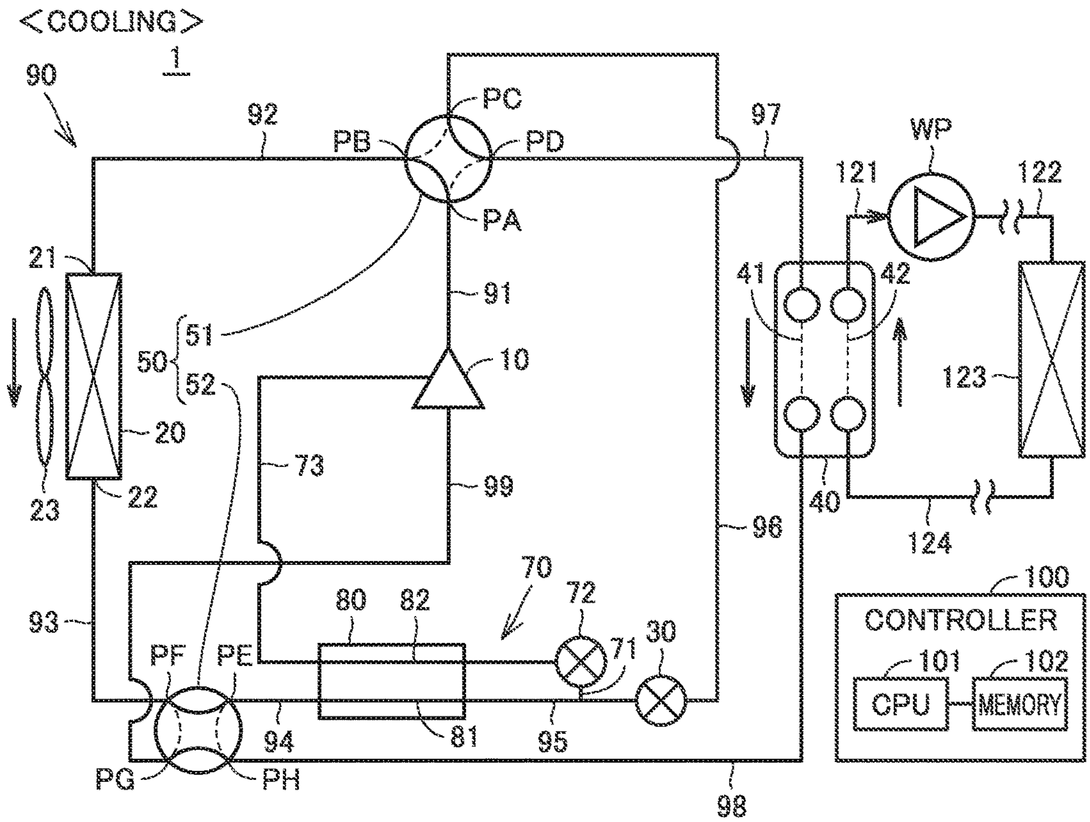


FIG.1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CONTROLLER
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FIG.2

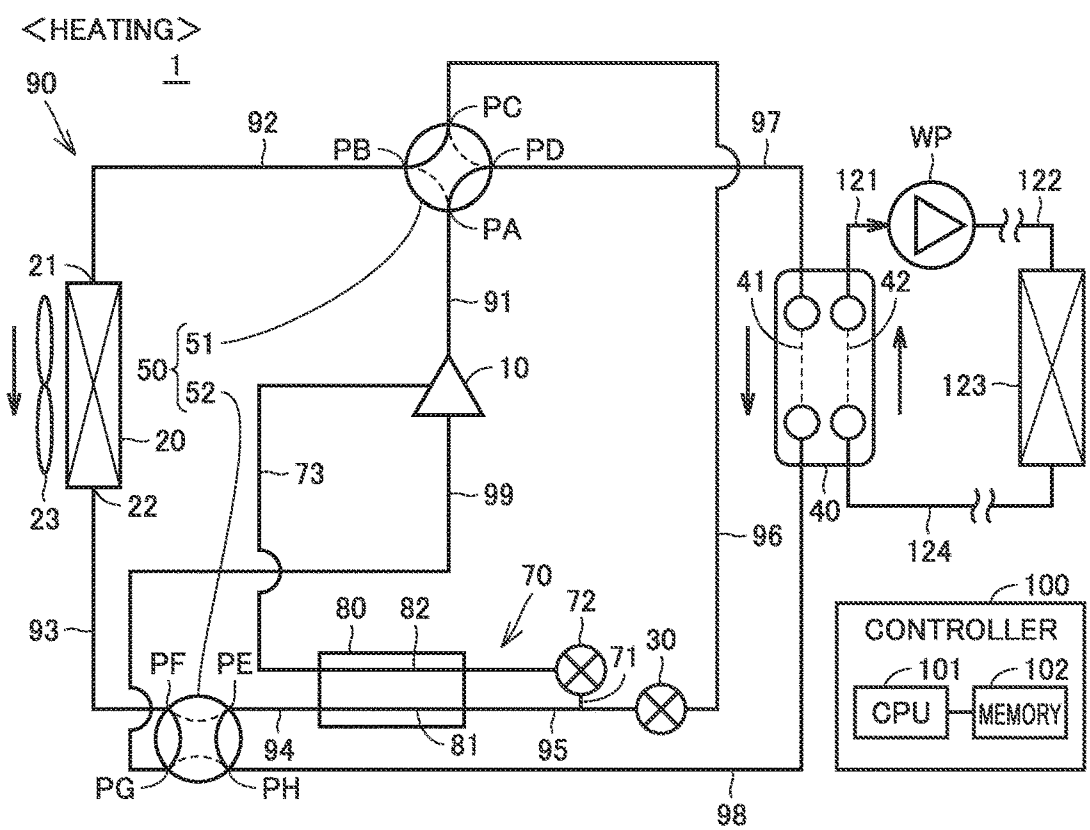
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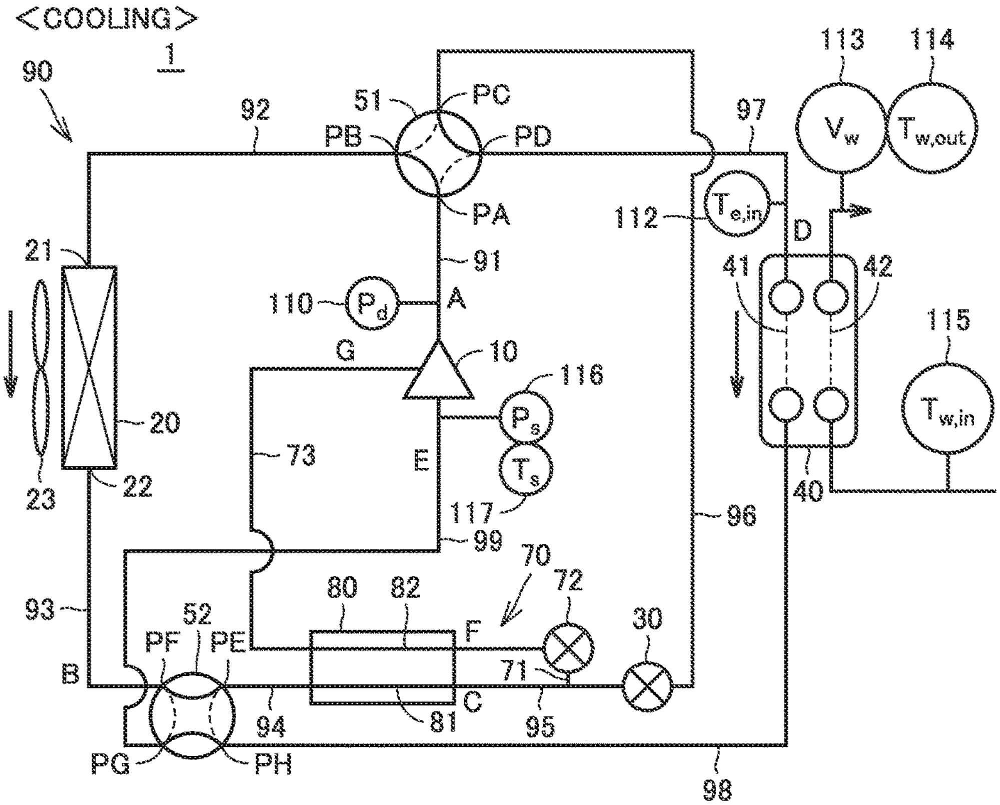
FIG.3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42
21
91
110
P_d
A
G
10
116
P_s
T_s
20
73
E
23
22
117
115
$T_{w,in}$
40
96
99
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C
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PG
PH
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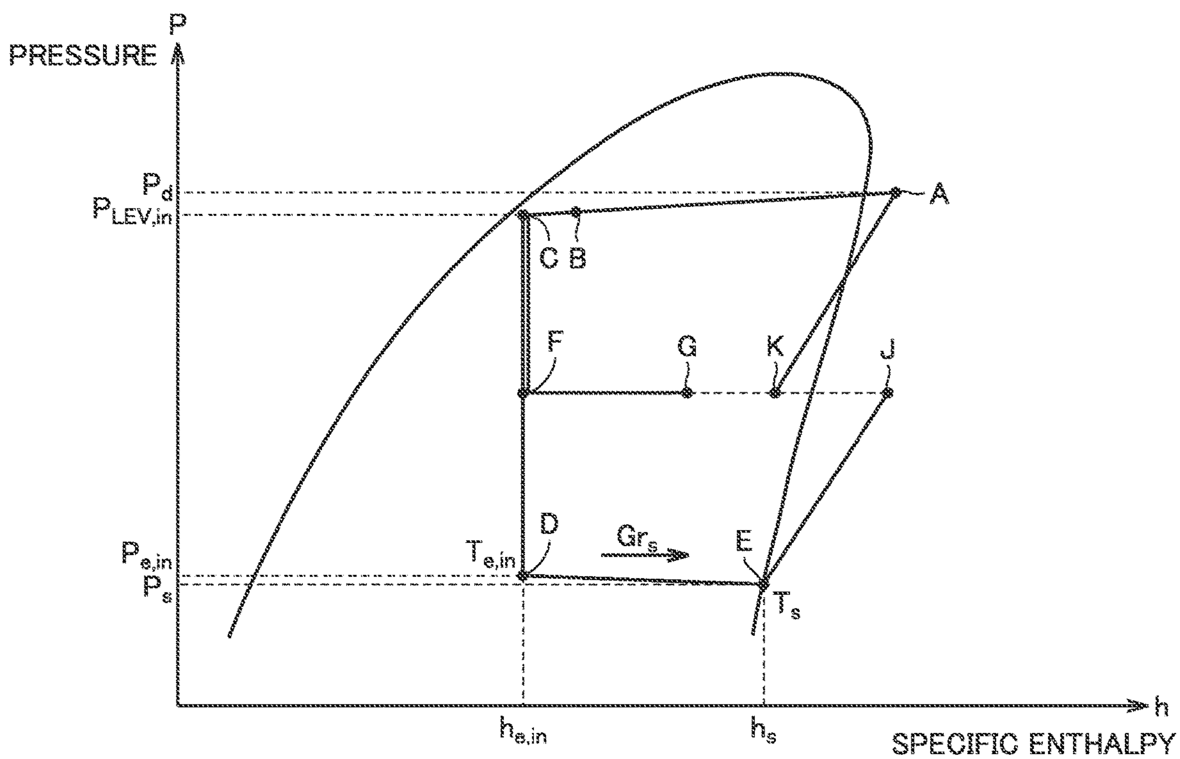
FIG.4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$P_{LEV,in}$
A
C B
F
G
K
J
D
$T_{e,in}$
Gr_s
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$P_{e,in}$
P_s
T_s
h
$h_{e,in}$
h_s
SPECIFIC ENTHALPY

FIG.5

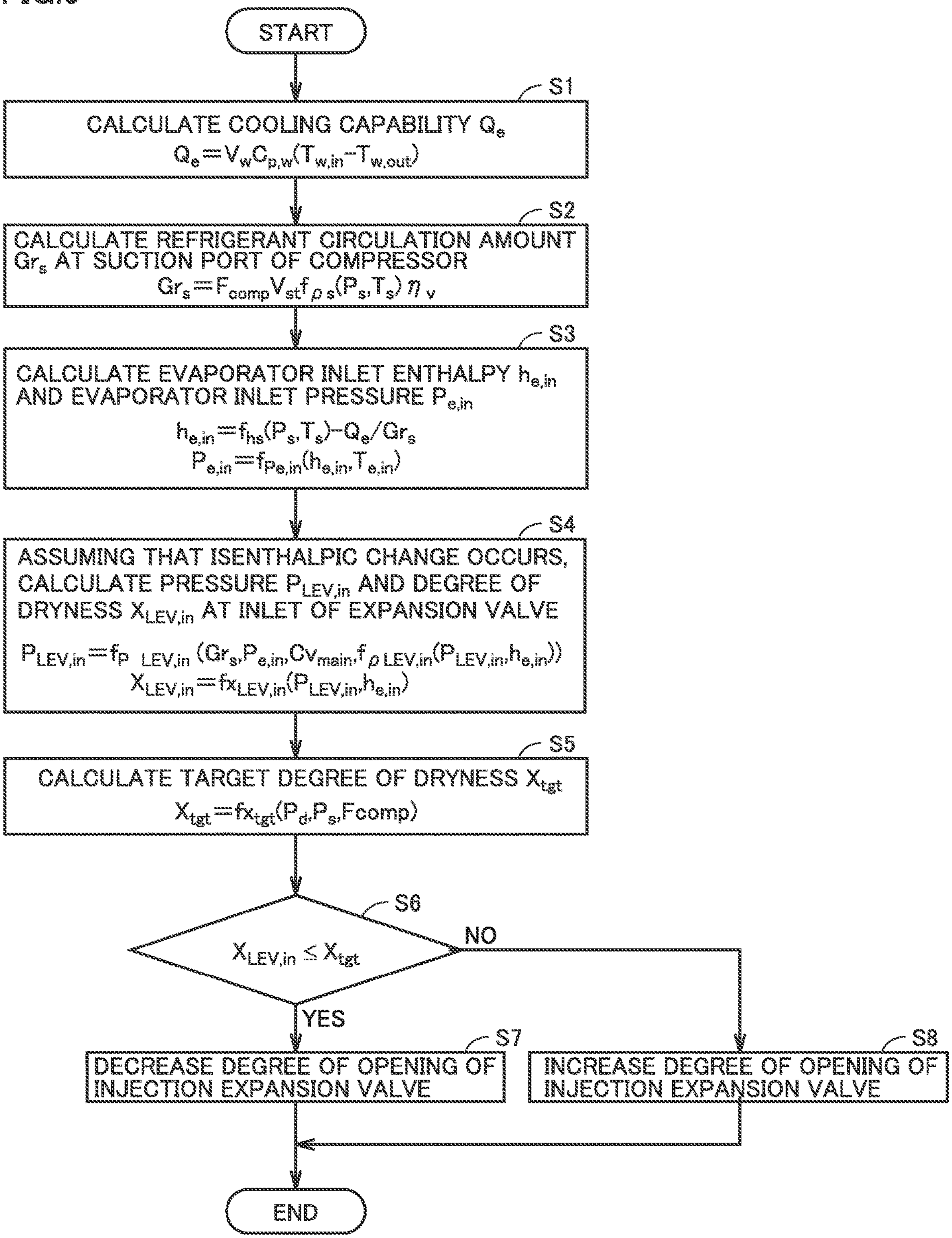
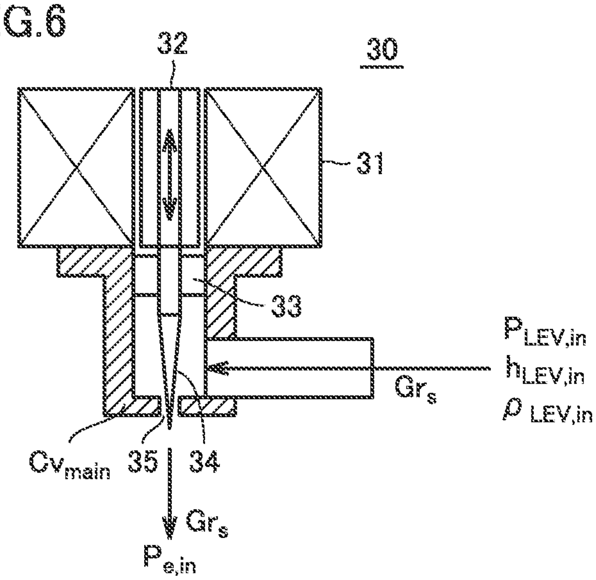

START
S1
CALCULATE COOLING CAPABILITY Q_e
$Q_e = V_w C_{p,w}(T_{w,in} - T_{w,out})$
S2
CALCULATE REFRIGERANT CIRCULATION AMOUNT Gr_s AT SUCTION PORT OF COMPRESSOR
$Gr_s = F_{comp} V_{st} f_{\rho s}(P_s, T_s) \eta_v$
S3
CALCULATE EVAPORATOR INLET ENTHALPY $h_{e,in}$ AND EVAPORATOR INLET PRESSURE $P_{e,in}$
$h_{e,in} = f_{hs}(P_s, T_s) - Q_e / Gr_s$
$P_{e,in} = f_{Pe,in}(h_{e,in}, T_{e,in})$
S4
ASSUMING THAT ISENTHALPIC CHANGE OCCURS, CALCULATE PRESSURE $P_{LEV,in}$ AND DEGREE OF DRYNESS $X_{LEV,in}$ AT INLET OF EXPANSION VALVE
$P_{LEV,in} = f_{P\ LEV,in}(Gr_s, P_{e,in}, Cv_{main}, f_{\rho\ LEV,in}(P_{LEV,in}, h_{e,in}))$
$X_{LEV,in} = fx_{LEV,in}(P_{LEV,in}, h_{e,in})$
S5
CALCULATE TARGET DEGREE OF DRYNESS X_{tgt}
$X_{tgt} = fx_{tgt}(P_d, P_s, Fcomp)$
S6
$X_{LEV,in} \leq X_{tgt}$
NO
YES
S7
DECREASE DEGREE OF OPENING OF INJECTION EXPANSION VALVE
S8
INCREASE DEGREE OF OPENING OF INJECTION EXPANSION VALVE
END

FIG.6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30
31
33
$P_{LEV,in}$
$h_{LEV,in}$
$\rho_{LEV,in}$
Gr_s
Cv_{main}
35
34
Gr_s
$P_{e,in}$

FIG.7

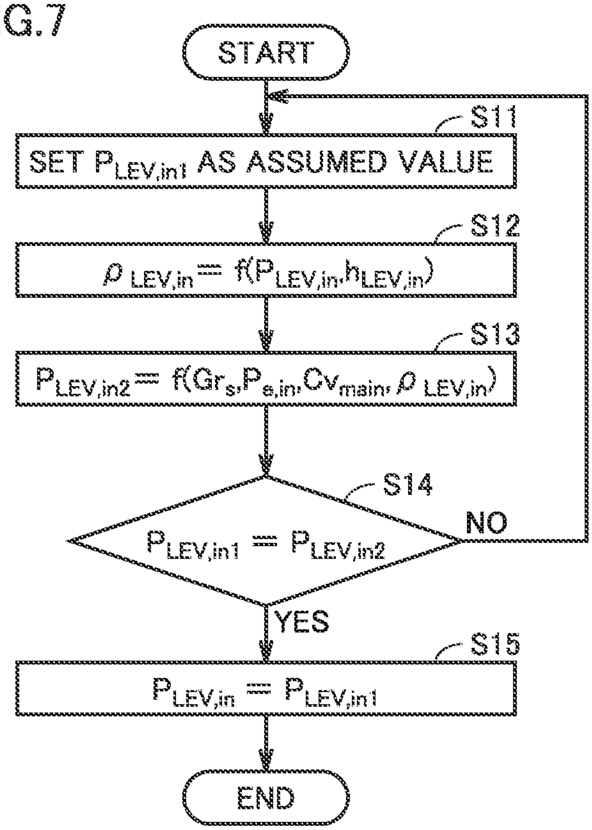
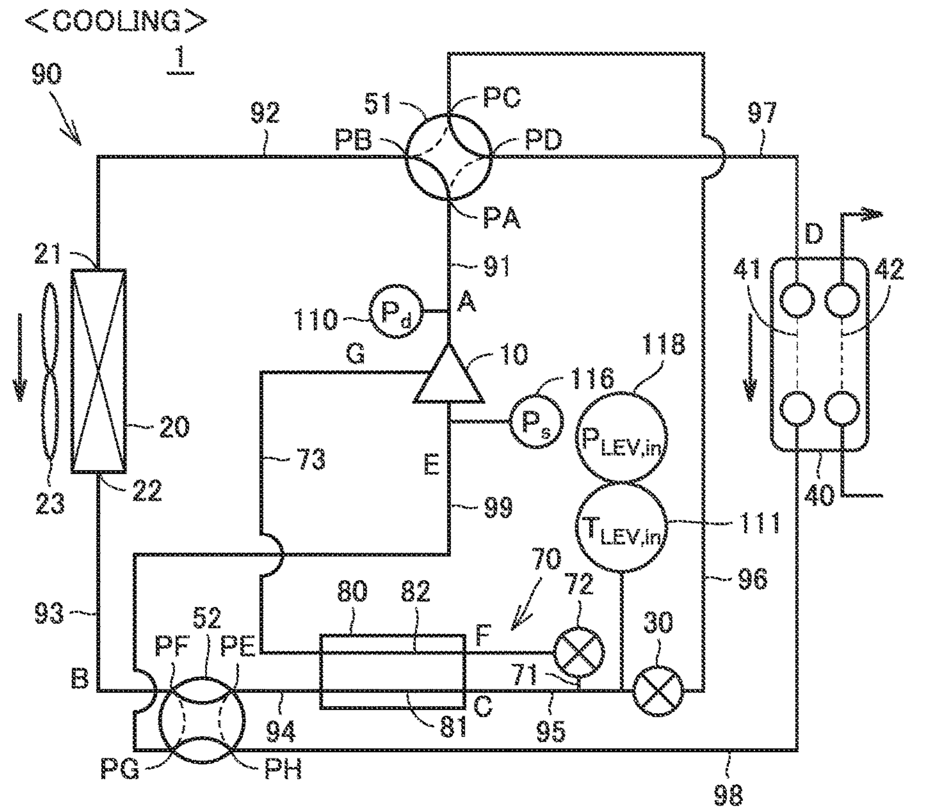

START
S11
SET $P_{LEV,in1}$ AS ASSUMED VALUE
S12
$\rho_{LEV,in} = f(P_{LEV,in}, h_{LEV,in})$
S13
$P_{LEV,in2} = f(Gr_s, P_{e,in}, Cv_{main}, \rho_{LEV,in})$
S14
$P_{LEV,in1} = P_{LEV,in2}$
NO
YES
S15
$P_{LEV,in} = P_{LEV,in1}$
END

FIG.8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P_s
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22
99
$T_{LEV,in}$
111
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F
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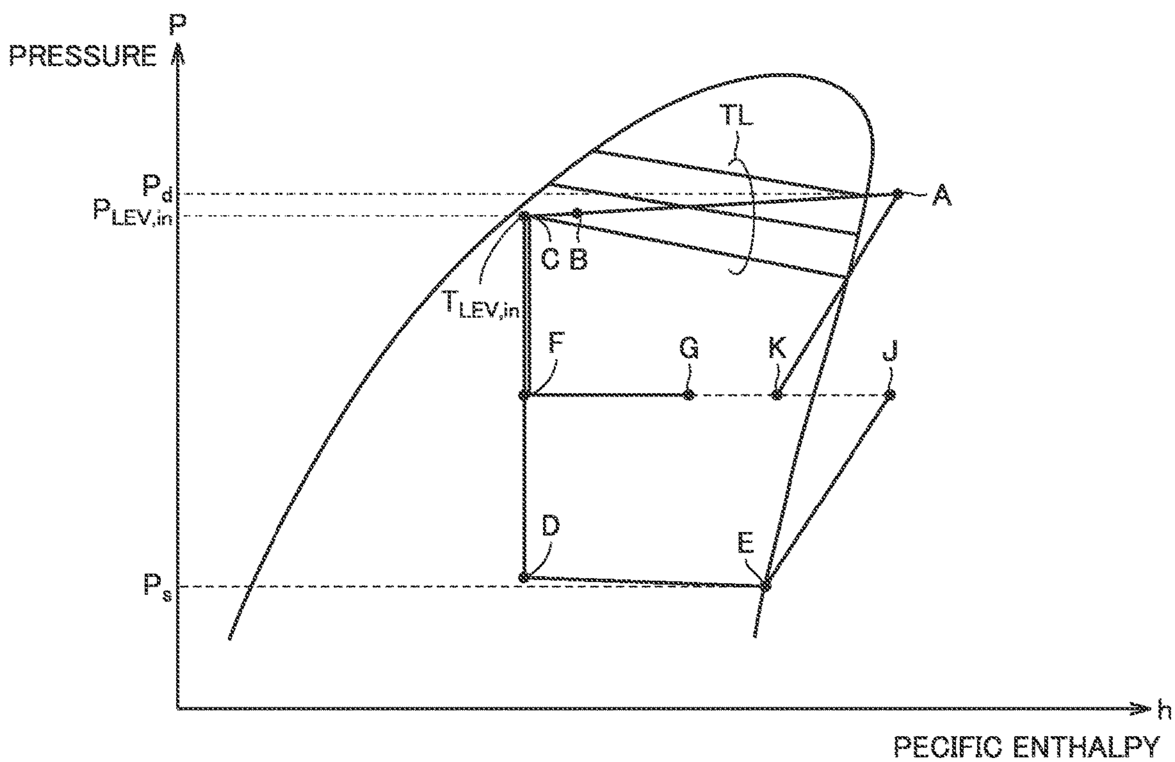
FIG.9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P_s
h
PECIFIC ENTHALPY

FIG.10

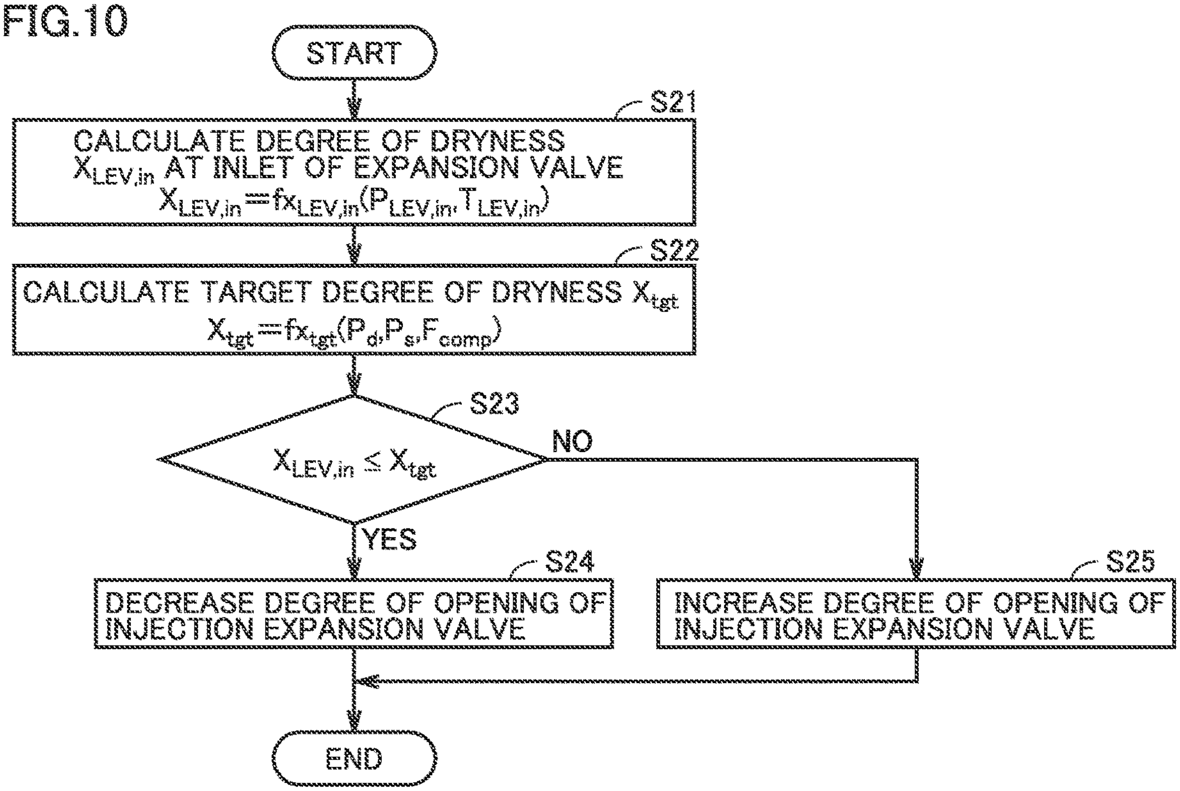
START
S21
CALCULATE DEGREE OF DRYNESS $X_{LEV,in}$ AT INLET OF EXPANSION VALVE
$X_{LEV,in} = fx_{LEV,in}(P_{LEV,in}, T_{LEV,in})$
S22
CALCULATE TARGET DEGREE OF DRYNESS X_{tgt}
$X_{tgt} = fx_{tgt}(P_d, P_s, F_{comp})$
S23
$X_{LEV,in} \leq X_{tgt}$
NO
YES
S24
DECREASE DEGREE OF OPENING OF INJECTION EXPANSION VALVE
S25
INCREASE DEGREE OF OPENING OF INJECTION EXPANSION VALVE
END

FIG.11

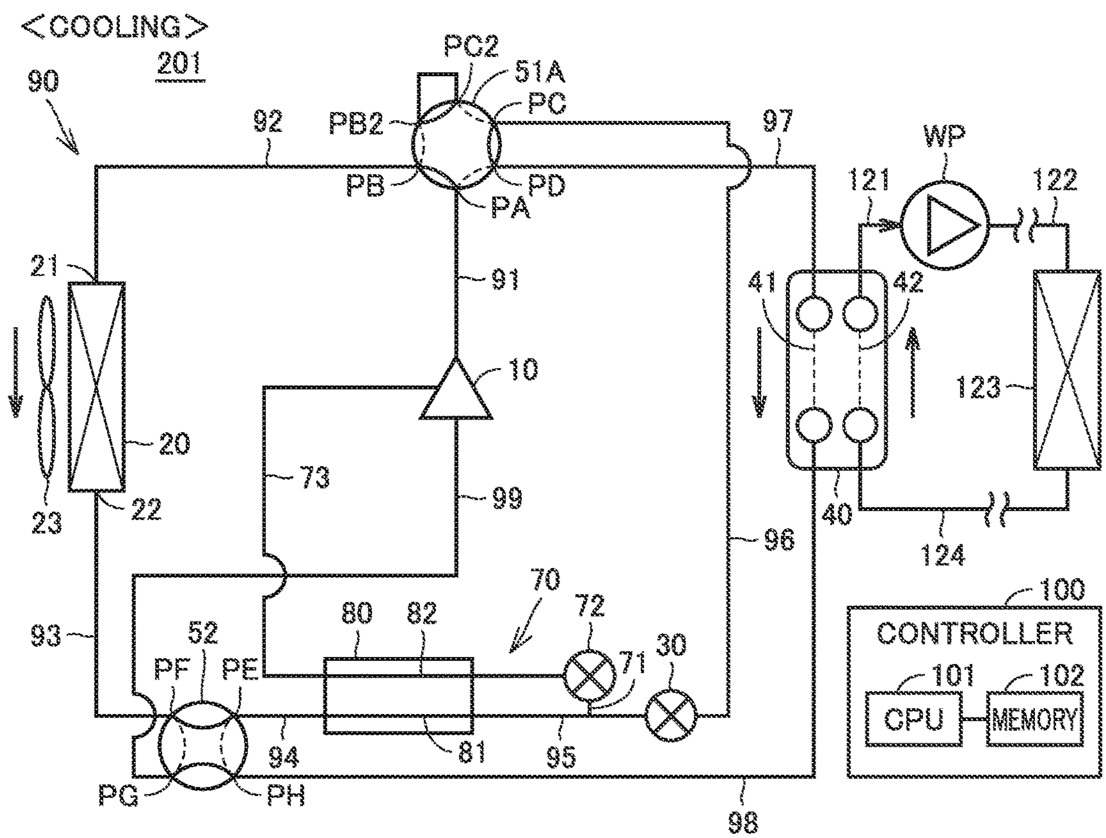
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FIG.12

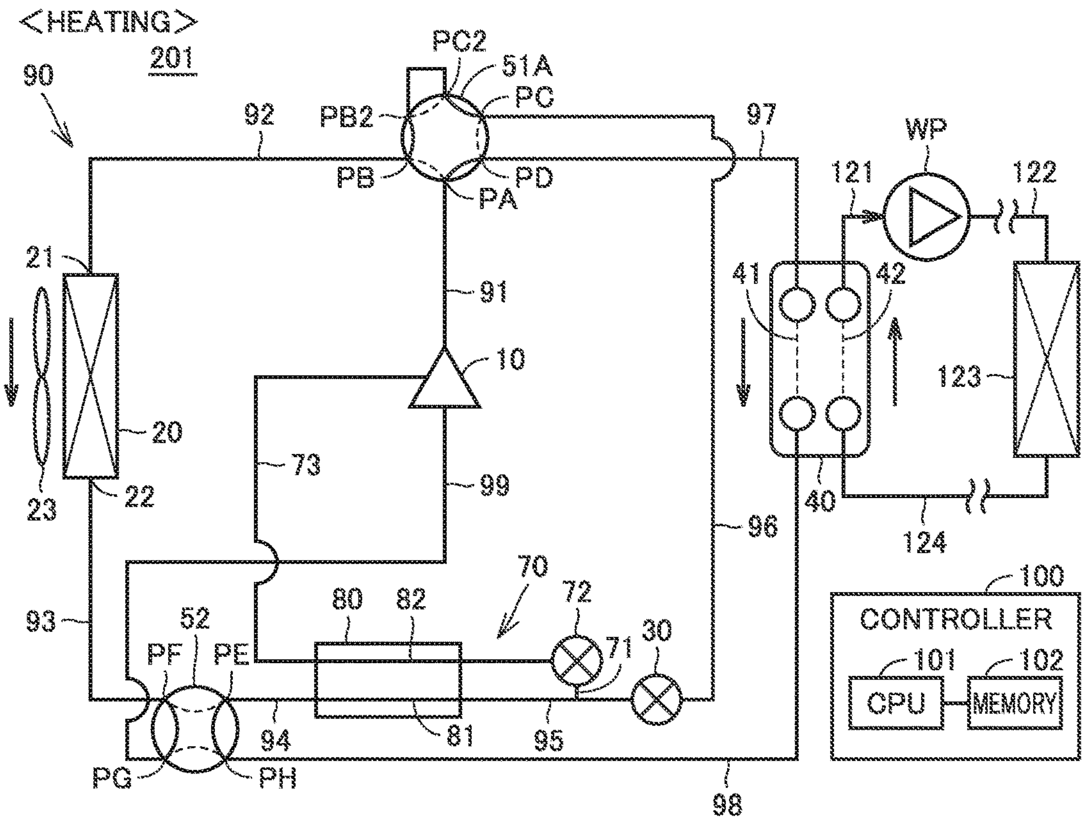
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FIG.13

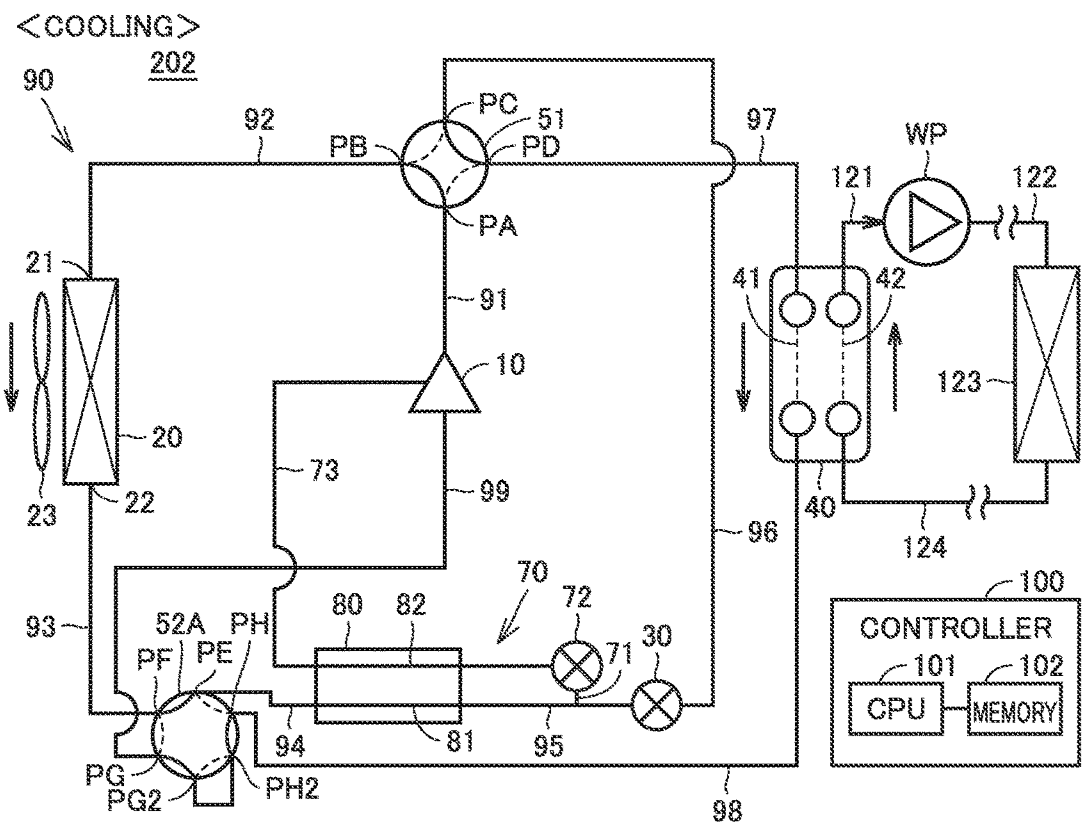
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FIG.14

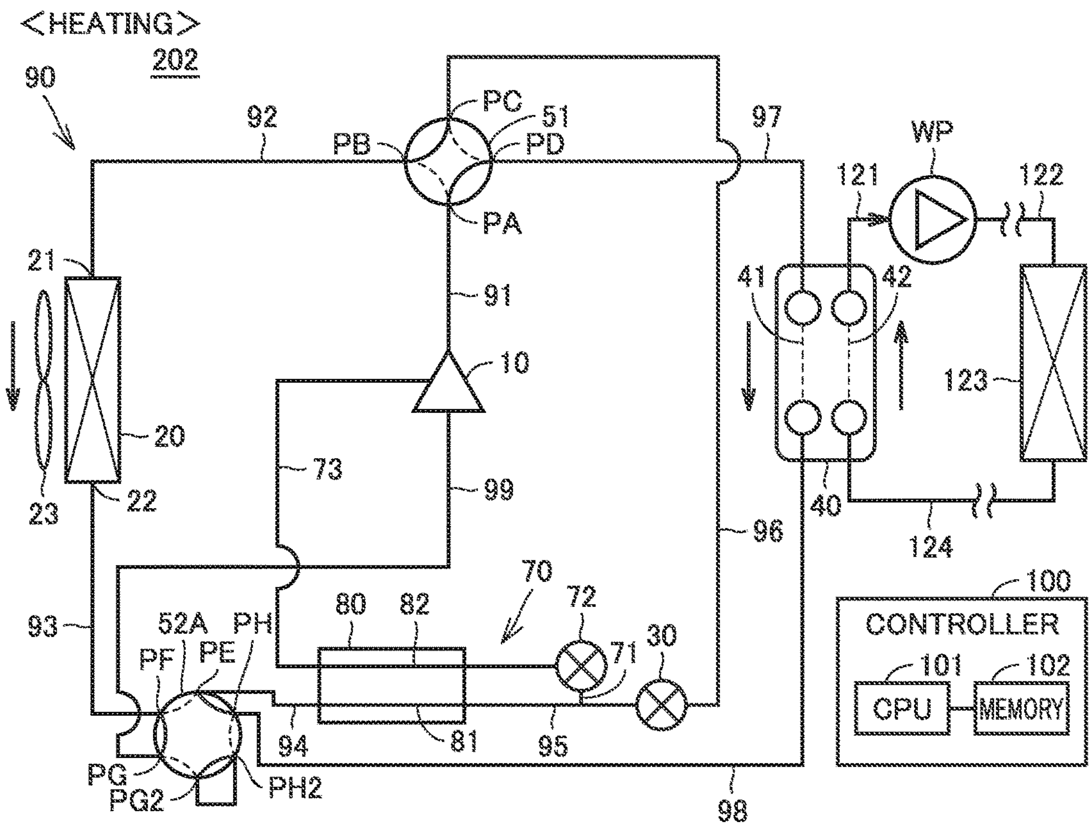
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FIG.15

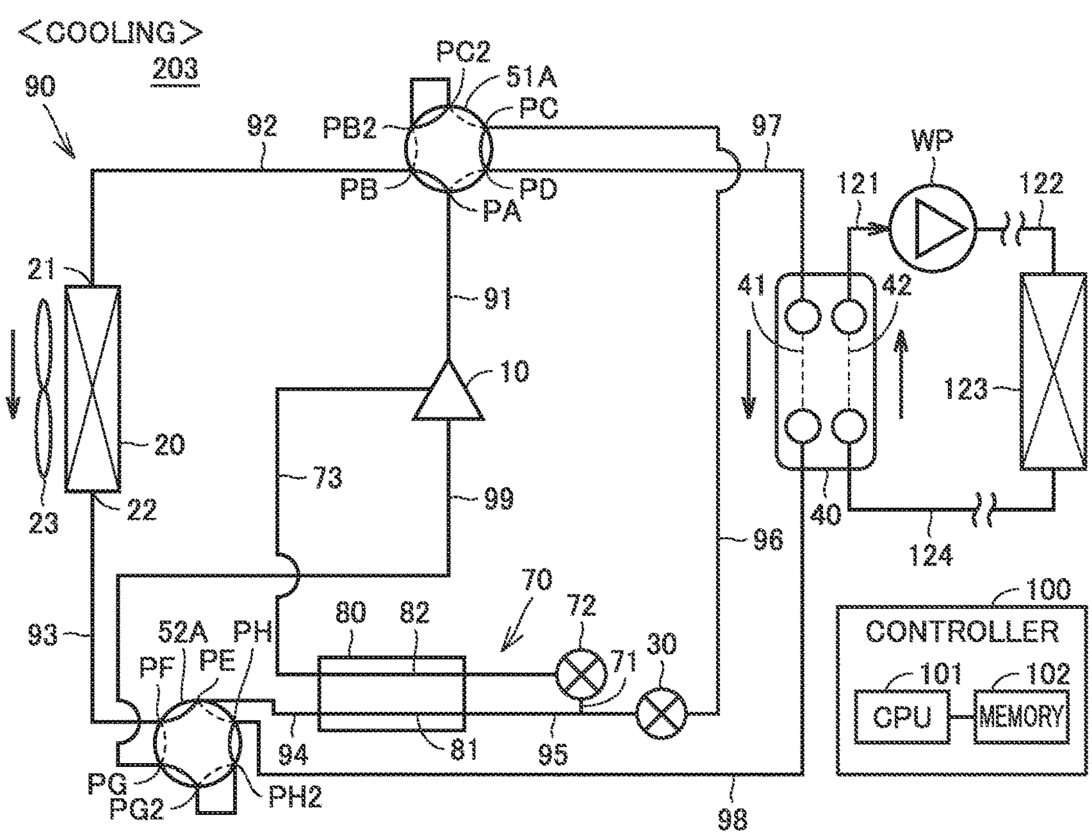
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FIG.16

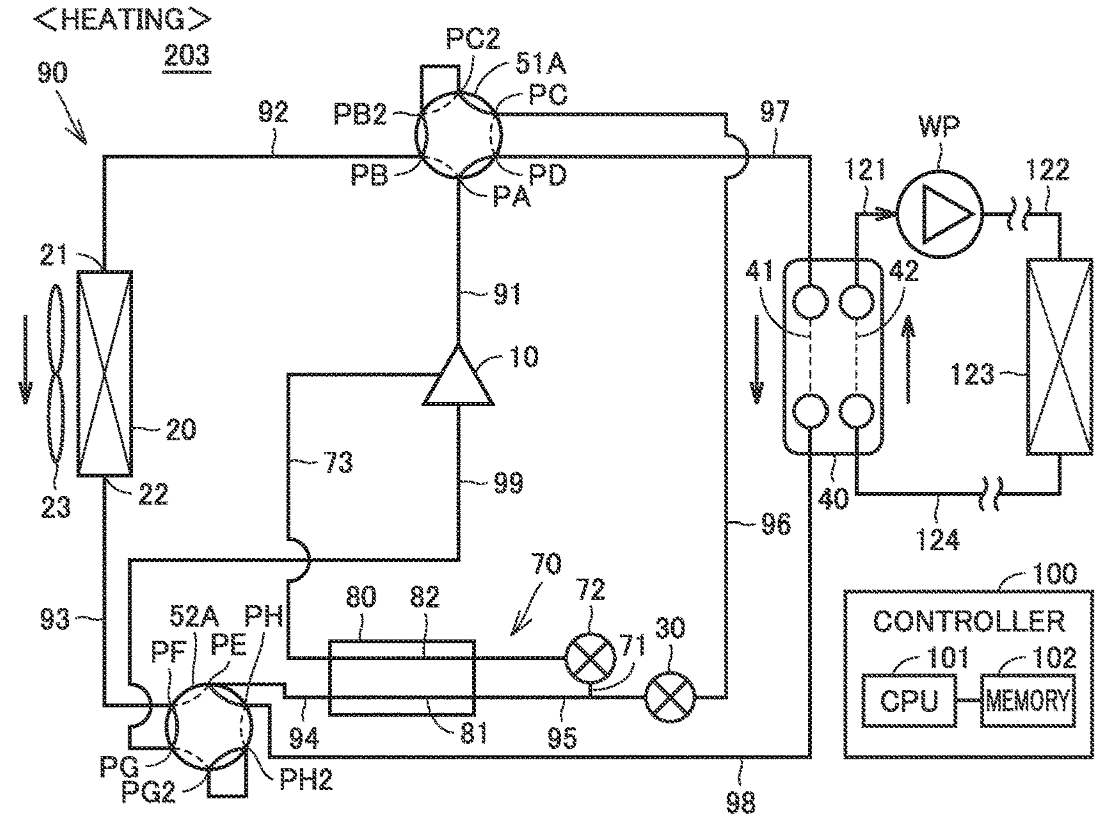
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FIG.17

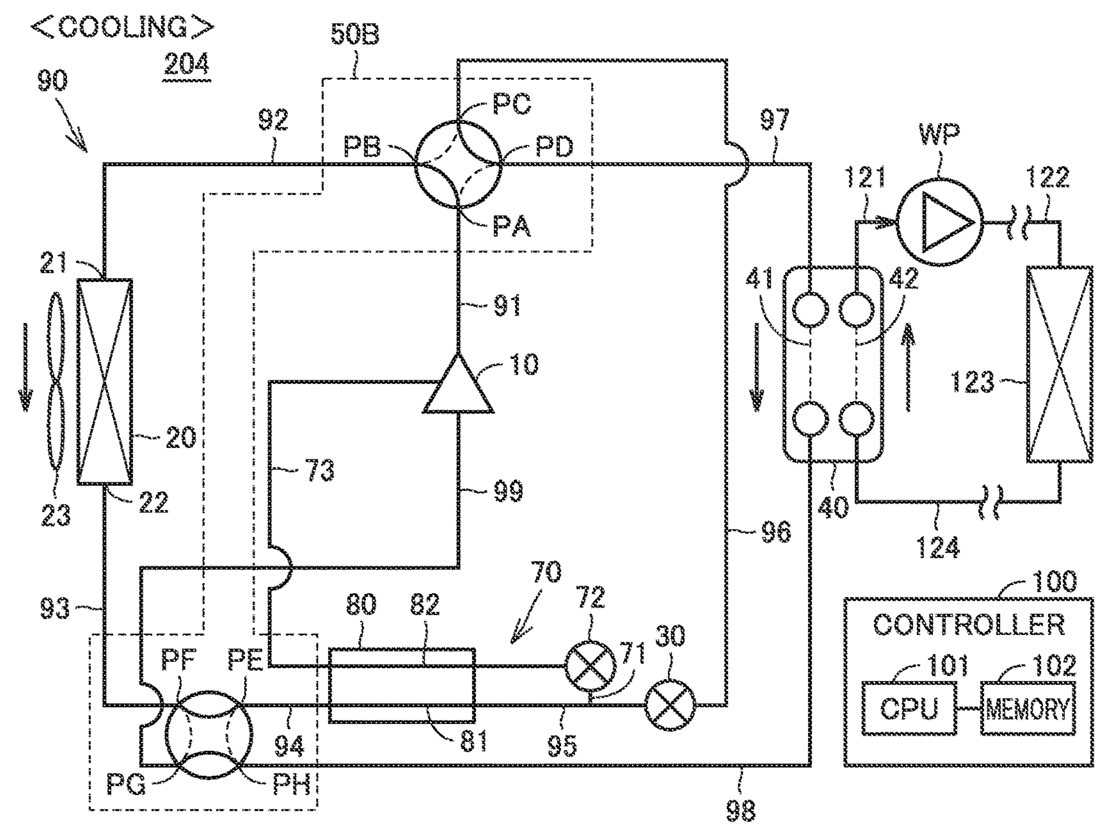
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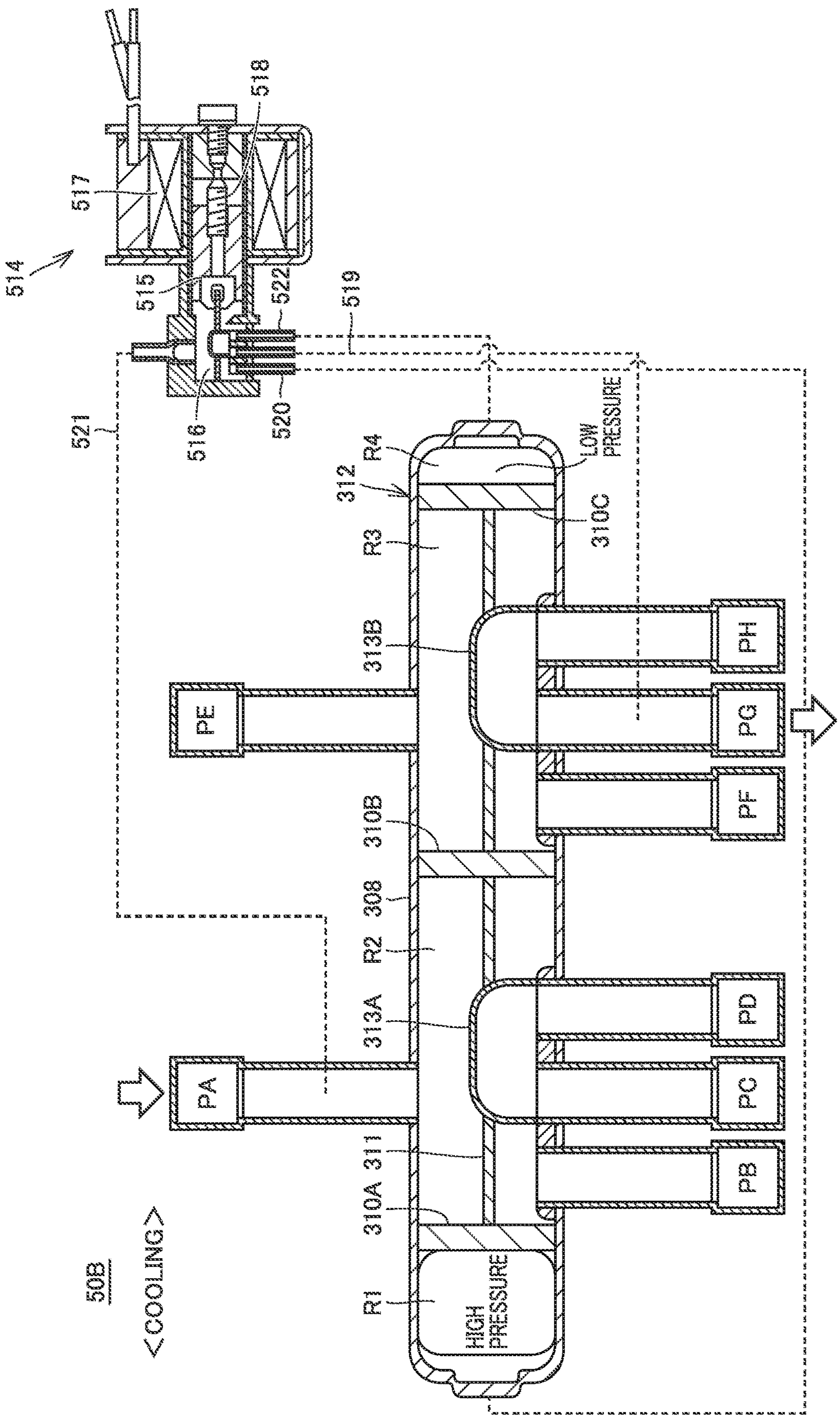
FIG.18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R1
HIGH PRESSURE

FIG.19

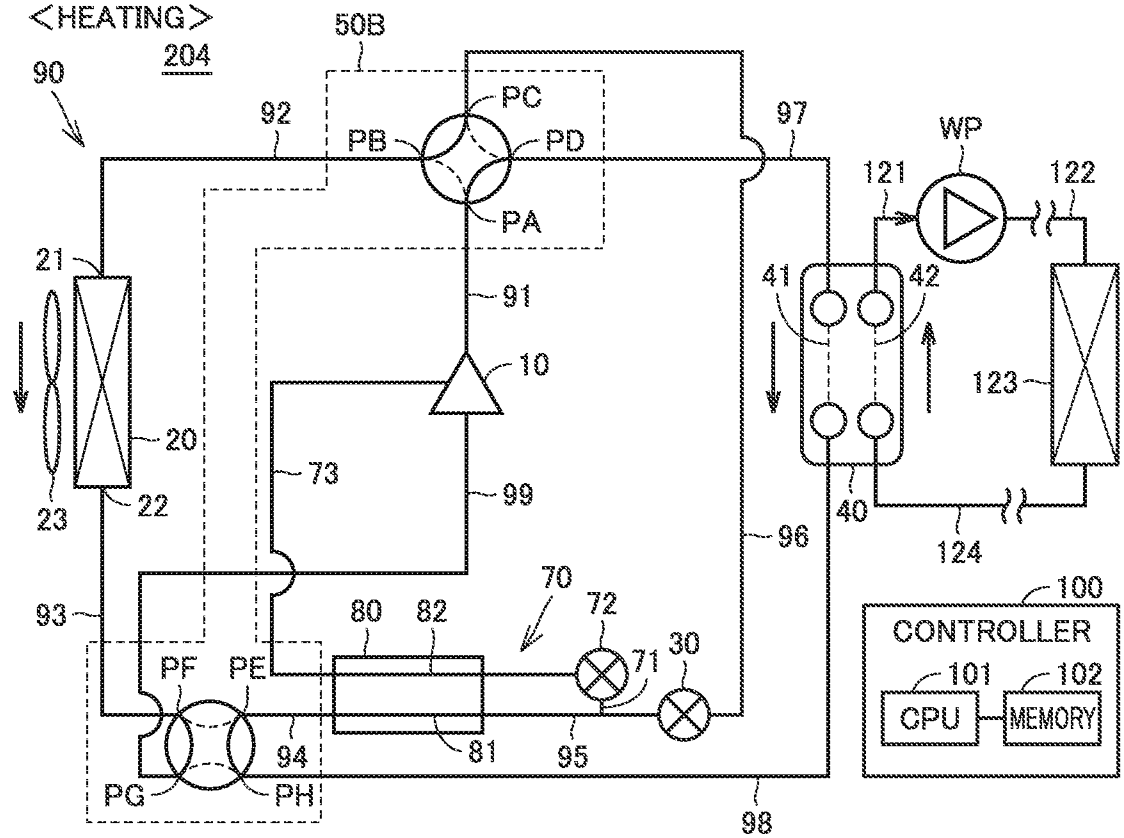
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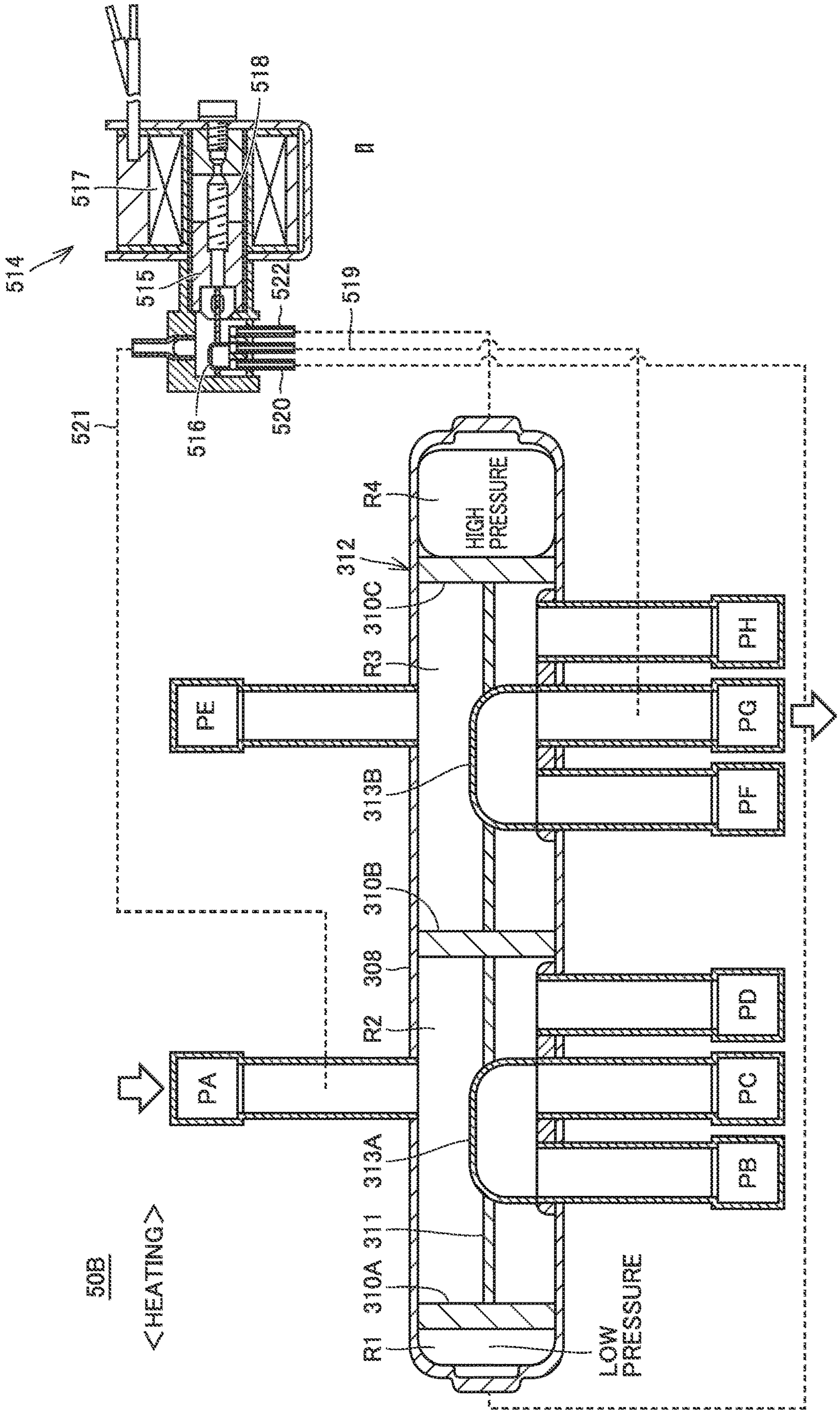
FIG.20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310A
R1
LOW PRESSURE

REFRIGERATION CYCLE APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a U.S. National Stage Application of International Application No. PCT/JP2021/039845 filed Oct. 28, 2021, the contents of which are incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to a refrigeration cycle apparatus.

BACKGROUND

[0003] Conventionally, it has been known to use an injection circuit in order to improve the Coefficient of Performance (COP) of a refrigeration cycle apparatus.

[0004] For example, Japanese Patent Laying-Open No. 2020-186909 (PTL 1) discloses an injection circuit that causes part of refrigerant flowing from a heat exchanger to an expansion mechanism to be supplied to a suction side of a compressor, in which the heat exchanger serves as a heat radiator among a heat source-side heat exchanger and a use-side heat exchanger.

PATENT LITERATURE

[0005] PTL 1: Japanese Patent Laying-Open No. 2020-186909

[0006] The injection circuit disclosed in Japanese Patent Laying-Open No. 2020-186909 (PTL 1) is configured such that, in any of heating, cooling, and defrosting operations, part of liquid refrigerant before passing through the expansion mechanism is introduced into the injection circuit from a refrigerant outlet portion of a heat exchanger serving as a heat radiator. Thus, performance improvement by the injection circuit can be expected in any of the heating, cooling and defrosting operations.

[0007] However, since the flow direction of the refrigerant flowing through the heat source-side heat exchanger and the use-side heat exchanger is reversed between heating and cooling/defrosting, the efficiency improvement of the heat exchanger still needs to be enhanced.

SUMMARY

[0008] The present disclosure has been made in order to describe the embodiments that solve the above-described problems, and an object of the present disclosure is to provide a refrigeration cycle apparatus capable of improving the efficiency of a heat exchanger while improving the performance by an injection circuit.

[0009] The present disclosure relates to a refrigeration cycle apparatus. The refrigeration cycle apparatus includes: a compressor; a first heat exchanger; a second heat exchanger; a third heat exchanger; a first expansion valve; a second expansion valve; and a flow path switching device. The compressor, the first heat exchanger, the second heat exchanger, and the first expansion valve constitute a refrigerant circuit through which refrigerant circulates. The second expansion valve forms a portion of an injection flow path, the injection flow path being configured to reduce pressure of the refrigerant before passing through the first expansion valve in the refrigerant circuit and return the refrigerant to the compressor. The third heat exchanger includes a first flow path through which the refrigerant flows and a second flow path through which the refrigerant flows. The third heat exchanger is configured to exchange heat between the refrigerant passing through the first flow path and the refrigerant passing through the second flow path. The first flow path is disposed in the refrigerant circuit to cause the refrigerant to flow toward the first expansion valve. The second flow path is disposed to return, to the compressor, the refrigerant that has passed through the second expansion valve. In a first operation mode, the flow path switching device is configured to: connect a discharge port of the compressor to a refrigerant inlet of the first heat exchanger; connect a refrigerant outlet of the first heat exchanger to a refrigerant inlet of the first flow path; connect a refrigerant outlet of the first expansion valve to a refrigerant inlet of the second heat exchanger; and connect a refrigerant outlet of the second heat exchanger to a suction port of the compressor. In a second operation mode, the flow path switching device is configured to: connect the discharge port of the compressor to the refrigerant inlet of the second heat exchanger; connect the refrigerant outlet of the second heat exchanger to the refrigerant inlet of the first flow path; connect the refrigerant outlet of the first expansion valve to the refrigerant inlet of the first heat exchanger; and connect the refrigerant outlet of the first heat exchanger to the suction port of the compressor.

[0010] According to the refrigeration cycle apparatus of the present disclosure, in each of the heat exchangers, the flow direction of the refrigerant does not change and a branch portion of the injection flow path is located on the inlet side of the first expansion valve, and thereby, the performance of the refrigeration cycle apparatus is improved in any of the plurality of operation modes.

BRIEF DESCRIPTION OF DRAWINGS

[0011] FIG. **1** is a refrigerant circuit diagram of a refrigeration cycle apparatus according to a first embodiment.

[0012] FIG. **2** is a diagram showing a refrigerant circuit and a flow of refrigerant during a heating operation of the refrigeration cycle apparatus according to the first embodiment.

[0013] FIG. **3** is a diagram showing an arrangement of various sensors when refrigerant having no temperature gradient is used.

[0014] FIG. **4** is a p-h diagram showing a change in the state of refrigerant when refrigerant having no temperature gradient is used.

[0015] FIG. **5** is a flowchart for illustrating control of a second expansion valve **72** when refrigerant having no temperature gradient is used.

[0016] FIG. **6** is a diagram for illustrating symbols of various parameters of a first expansion valve **30**.

[0017] FIG. **7** is a diagram for illustrating a process of deriving inlet portion pressure of first expansion valve **30**.

[0018] FIG. **8** is a diagram showing an arrangement of various sensors when non-azeotropic refrigerant is used.

[0019] FIG. **9** is a p-h diagram showing a change in the state of refrigerant when non-azeotropic refrigerant is used.

[0020] FIG. **10** is a flowchart for illustrating control of second expansion valve **72** when non-azeotropic refrigerant is used.

[0021] FIG. **11** is a diagram showing a refrigerant circuit and a flow of refrigerant during a cooling operation of a refrigeration cycle apparatus according to a second embodiment.

[0022] FIG. **12** is a diagram showing the refrigerant circuit and the flow of the refrigerant during a heating operation of the refrigeration cycle apparatus according to the second embodiment.

[0023] FIG. **13** is a diagram showing a refrigerant circuit and a flow of refrigerant during a cooling operation of a refrigeration cycle apparatus according to a third embodiment.

[0024] FIG. **14** is a diagram showing the refrigerant circuit and the flow of the refrigerant during a heating operation of the refrigeration cycle apparatus according to the third embodiment.

[0025] FIG. **15** is a diagram showing a refrigerant circuit and a flow of refrigerant during a cooling operation of a refrigeration cycle apparatus according to a fourth embodiment.

[0026] FIG. **16** is a diagram showing the refrigerant circuit and the flow of the refrigerant during a heating operation of the refrigeration cycle apparatus according to the fourth embodiment.

[0027] FIG. **17** is a diagram showing a refrigerant circuit and a flow of refrigerant during a cooling operation of a refrigeration cycle apparatus according to a fifth embodiment.

[0028] FIG. **18** is a diagram showing the state of an eight-way valve **50**B and the flow of the refrigerant in eight-way valve **50**B during the cooling operation according to the fifth embodiment.

[0029] FIG. **19** is a diagram showing the refrigerant circuit and the flow of the refrigerant during a heating operation of the refrigeration cycle apparatus according to the fifth embodiment.

[0030] FIG. **20** is a diagram showing the state of eight-way valve **50**B and the flow of the refrigerant in eight-way valve **50**B during the heating operation according to the fifth embodiment.

DETAILED DESCRIPTION

[0031] Hereinafter, embodiments of the present invention will be described in detail with reference to the accompanying drawings. Although the following describes a plurality of embodiments, it has been originally intended to combine the configurations described in the respective embodiments as appropriate. In the accompanying drawings, the same or corresponding portions are denoted by the same reference characters, and the description thereof will not be repeated.

First Embodiment

<Configuration of Refrigeration Cycle Apparatus **1**>

[0032] FIG. **1** is a refrigerant circuit diagram of a refrigeration cycle apparatus according to the first embodiment. FIG. **1** shows a refrigerant circuit and a flow of refrigerant during a cooling operation. The refrigerant circuit and the flow of refrigerant shown in FIG. **1** are also similarly applied in a defrosting operation performed during a heating operation. A refrigeration cycle apparatus **1** includes a compressor **10**, a first heat exchanger **20**, a second heat exchanger **40**, a third heat exchanger **80**, a first expansion valve **30**, a second expansion valve **72**, and a flow path switching device **50**.

[0033] Compressor **10**, first heat exchanger **20**, second heat exchanger **40**, first expansion valve **30**, and pipes **91** to **99** constitute a refrigerant circuit **90** through which refrigerant circulates.

[0034] First heat exchanger **20** is configured to exchange heat between the outdoor air blown by a fan **23** and the refrigerant. Second heat exchanger **40** is configured to exchange heat between a heat medium circulating through the use-side circuit and the refrigerant. Second heat exchanger **40** is a plate-type heat exchanger, for example.

[0035] The use-side circuit includes a pump WP, a use-side heat exchanger **123**, and pipes **121**, **122**, and **124**. The heat medium circulating through the use-side circuit is, for example, water, brine, or the like. Use-side heat exchanger **123** is, for example, a water heater, an air-conditioner for heating or cooling, or the like. Second heat exchanger **40** includes flow paths **41** and **42**. Second heat exchanger **40** is configured to exchange heat between the refrigerant flowing through flow path **41** and the heat medium flowing through flow path **42**.

[0036] An injection flow path **70** includes pipes **71** and **73** and a second expansion valve **72**. Injection flow path **70** reduces the pressure of the refrigerant before passing through first expansion valve **30** in refrigerant circuit **90** and returns the refrigerant to compressor **10**.

[0037] Third heat exchanger **80** includes a first flow path **81** and a second flow path **82** through which refrigerant flows. Third heat exchanger **80** is configured to exchange heat between the refrigerant passing through first flow path **81** and the refrigerant passing through second flow path **82**.

[0038] First flow path **81** is disposed in refrigerant circuit **90** to cause the refrigerant to flow toward first expansion valve **30**, and second flow path **82** is disposed to return, to compressor **10**, the refrigerant having passed through second expansion valve **72**.

[0039] In the first operation mode (cooling) shown in FIG. **1**, flow path switching device **50** is configured to connect a discharge port of compressor **10** to a refrigerant inlet **21** of first heat exchanger **20**, connect a refrigerant outlet of first heat exchanger **20** to a refrigerant inlet of first flow path **81**, connect a refrigerant outlet of first expansion valve **30** to a refrigerant inlet of second heat exchanger **40**, and connect a refrigerant outlet of second heat exchanger **40** to a suction port of compressor **10**. In the first operation mode, not only a defrosting operation during cooling but also a defrosting operation during heating may be performed.

[0040] It is conceivable that flow path switching device **50** may have various configurations, but the first embodiment provides an example in which flow path switching device **50** includes a first four-way valve **51** and a second four-way valve **52**.

[0041] First four-way valve **51** has ports PA, PB, PC, and PD. Second four-way valve **52** has ports PE, PF, PG, and PH.

[0042] First, connection of pipes of refrigerant circuit **90** will be described. Pipe **91** connects the discharge port of compressor **10** to port PA. Pipe **92** connects port PB to refrigerant inlet **21** of first heat exchanger **20**. Pipe **93** connects a refrigerant outlet **22** of first heat exchanger **20** to port PF.

[0043] Pipe **94** connects port PE to the refrigerant inlet of first flow path **81**. Pipe **95** connects a refrigerant outlet of first flow path **81** to a refrigerant inlet of first expansion valve **30**. Pipe **96** connects the refrigerant outlet of first expansion valve **30** to port PC. Pipe **97** connects port PD to the refrigerant inlet of second heat exchanger **40**. Pipe **98** connects the refrigerant outlet of second heat exchanger **40** to port PH. Pipe **99** connects port PG to the suction port of compressor **10**.

[0044] The following describes connection of the pipes of injection flow path **70**. Pipe **71** branches from pipe **95** and connects pipe **95** to a refrigerant inlet of second flow path **82**. Second expansion valve **72** is disposed somewhere in the middle of pipe **71**. Pipe **73** connects a refrigerant outlet of second flow path **82** to an intermediate pressure port of compressor **10**.

[0045] Refrigeration cycle apparatus **1** further includes a controller **100** that controls flow path switching device **50**. Controller **100** is configured to include a central processing unit (CPU) **101**, a memory **102** (a read only memory (ROM)) and a random access memory (RAM)), an input/output buffer (not shown), and the like. CPU **101** deploys a program stored in the ROM into the RAM or the like and executes the program. The programs stored in the ROM describe the processing procedure for controller **100**. Controller **100** controls each of devices in refrigeration cycle apparatus **1** according to these programs. Such control is not necessarily processed by software, but can also be processed by dedicated hardware (an electronic circuit).

<Switching Control of Flow Path Switching Device **50**>

[0046] The following describes control of flow path switching device **50** executed by controller **100** in response to switching of the operation mode.

[0047] In the first operation mode (cooling), as indicated by solid lines in FIG. **1**, first four-way valve **51** is set such that port PA communicates with port PB and port PC communicates with port PD. On the other hand, as indicated by broken lines in FIG. **1**, first four-way valve **51** is set such that port PA does not communicate with port PD and port PB does not communicate with port PC. In other words, in the first operation mode (cooling), first four-way valve **51** is configured to connect the discharge port of compressor **10** to refrigerant inlet **21** of first heat exchanger **20** and connect the refrigerant outlet of first expansion valve **30** to the refrigerant inlet of second heat exchanger **40**.

[0048] In the first operation mode (cooling), as indicated by solid lines in FIG. **1**, second four-way valve **52** is set such that port PE communicates with port PF and port PG communicates with port PH. On the other hand, as indicated by broken lines in FIG. **1**, second four-way valve **52** is set such that port PE does not communicate with port PH and port PF does not communicate with port PG. In other words, in the first operation mode (cooling), second four-way valve **52** is configured to connect the refrigerant outlet of first heat exchanger **20** to the refrigerant inlet of first flow path **81** and connect the refrigerant outlet of second heat exchanger **40** to the suction port of compressor **10**.

[0049] FIG. **2** is a diagram showing the refrigerant circuit and the flow of the refrigerant during the heating operation of the refrigeration cycle apparatus according to the first embodiment.

[0050] In the second operation mode (heating), flow path switching device **50** is configured to connect the discharge port of compressor **10** to the refrigerant inlet of second heat exchanger **40**, connect the refrigerant outlet of second heat exchanger **40** to the refrigerant inlet of first flow path **81**, connect the refrigerant outlet of first expansion valve **30** to refrigerant inlet **21** of first heat exchanger **20**, and connect refrigerant outlet **22** of first heat exchanger **20** to the suction port of compressor **10**. In the second operation mode, not only a heating operation but also a warming operation to warm cold water by a water heater may be performed.

[0051] In the second operation mode (heating), first four-way valve **51** is set such that port PA communicates with port PD and port PC communicates with port PB. On the other hand, as indicated by broken lines in FIG. **2**, first four-way valve **51** is set such that port PA does not communicate with port PB and port PC does not communicate with port PD. In other words, in the second operation mode (heating), first four-way valve **51** is configured to connect the discharge port of compressor **10** to the refrigerant inlet of second heat exchanger **40** and connect the refrigerant outlet of first expansion valve **30** to the refrigerant inlet of first heat exchanger **20**.

[0052] In the second operation mode (heating), second four-way valve **52** is set such that port PE communicates with port PH and port PG communicates with port PF. On the other hand, as indicated by broken lines in FIG. **2**, second four-way valve **52** is set such that port PE does not communicate with port PF and port PG does not communicate with port PH. In other words, in the second operation mode (heating), second four-way valve **52** is configured to connect the refrigerant outlet of second heat exchanger **40** to the refrigerant inlet of first flow path **81** and connect the refrigerant outlet of first heat exchanger **20** to the suction port of compressor **10**.

[0053] In general, the heat exchange efficiency of the heat exchanger is higher in the relation in which the heat medium that exchanges heat flows as a counterflow than in the relation in which the heat medium flows as a parallel-flow. In a heat exchanger in which the flow direction of the refrigerant is reversed between cooling and heating, when the heat medium flows in the counterflow relation during cooling, the heat medium flows in the parallel-flow relation during heating, with the result that the heat exchange efficiency in one of the two operation modes tends to deteriorate.

[0054] In contrast, as shown in FIGS. **1** and **2**, in refrigeration cycle apparatus **1** according to the first embodiment, flow path switching device **50** is controlled to cause the refrigerant to flow in the same direction in any of the first operation mode (cooling) and the second operation mode (heating) in each of first heat exchanger **20**, second heat exchanger **40**, and third heat exchanger **80**.

[0055] Therefore, regardless of whether the heating operation or the cooling operation, the counterflow relation can be implemented in each heat exchanger, so that the heat exchange efficiency can be improved in these two operation modes.

[0056] Further, regardless of whether the heating operation or the cooling operation, due to pipe **95** located on the refrigerant inlet side of each of first expansion valve **30** and second expansion valve **72**, controlling the degree of dryness of the refrigerant in pipe **95** to be kept close to the state of a liquid phase makes it possible to satisfactorily achieve the pressure adjusting performance of first expansion valve **30** and second expansion valve **72**.

<Control of Expansion Valve in Injection Flow Path **70**>

[0057] Controller **100** calculates the degree of dryness of the refrigerant in pipe **95** on the inlet side of each of first expansion valve **30** and second expansion valve **72**, and controls second expansion valve **72** such that the degree of dryness reaches a target value. If the degree of dryness of the refrigerant in pipe **95** rises too high, the gas-phase refrigerant is mixed into the inlets of first expansion valve **30** and second expansion valve **72**, so that the pressure adjusting performance of the expansion valves decreases. Accordingly, when the degree of dryness rises too high, controller **100** controls the degree of opening of second expansion valve **72** to decrease the degree of dryness.

(a) Refrigerant Having No Temperature Gradient

[0058] FIG. **3** is a diagram showing an arrangement of various sensors when refrigerant having no temperature gradient is used. Controller **100** controls the degree of opening of second expansion valve **72** based on the outputs from various sensors shown in FIG. **3**. Refrigeration cycle apparatus **1** includes pressure sensors **110** and **116**, temperature sensors **112**, **114**, **115**, and **117**, and a flow rate sensor **113**.

[0059] Pressure sensor **110** detects a discharge pressure Pd[MPa] of compressor **10**. Pressure sensor **116** detects a suction pressure P_s[MPa] of compressor **10**. Temperature sensor **112** detects a refrigerant inlet temperature $T_{e,in}$[° C.] of second heat exchanger **40**. Temperature sensor **117** detects a refrigerant suction temperature Ts[° C.] of compressor **10**. Temperature sensor **115** detects an inlet water temperature $T_{w,in}$[° C.] of second heat exchanger **40**. Temperature sensor **114** detects an outlet water temperature $T_{w,out}$[° C.] of second heat exchanger **40**. Flow rate sensor **113** detects a flow rate V_w[L/min] of water in second heat exchanger **40**.

[0060] FIG. **4** is a p-h diagram showing a change in the state of refrigerant when refrigerant having no temperature gradient is used. The refrigerant discharged from compressor **10** flows through refrigerant circuit **90**, and the state of the refrigerant changes in order of states A, B, C, D, and E. Further, the refrigerant branched from the outlet portion of first flow path **81** of refrigerant circuit **90** flows through injection flow path **70** and the state of the refrigerant changes in order of states C, F, and G.

[0061] The positions in FIG. **3** corresponding to states A to G are denoted by the same respective reference characters A to G.

[0062] The refrigerant in state J compressed to intermediate pressure by compressor **10** merges with the refrigerant in state G supplied through injection flow path **70**, thus resulting in refrigerant in state K. The refrigerant in state K is further compressed by compressor **10**, thus resulting in refrigerant in state A.

[0063] In the p-h diagram as described above, a target degree of dryness X_{tgt} is set such that state C is not significantly apart from a liquidus line, and controller **100** controls the degree of opening of second expansion valve **72** to achieve the target degree of dryness X_{tgt}.

[0064] FIG. **5** is a flowchart for illustrating control of second expansion valve **72** when refrigerant having no temperature gradient is used.

[0065] In the following flowchart, each symbol represents as follows. Cv_{main}[mm^2] represents a Cv value of an expansion valve **30**. $C_{p,w}$[kJ/(kg·K)] represents a specific heat of water. F_{comp}[Hz] represents an operating frequency of compressor **10**. Gr_s[kg/h] represents a refrigerant circulation amount at the suction port of compressor **10**. P_d[MPa] represents pressure of the refrigerant discharged from compressor **10**. P_s[MPa] represents pressure of the refrigerant suctioned into compressor **10**. $T_{e,in}$[° C.] represents a temperature of the refrigerant at the inlet of the evaporator. Ts[° C.] represents a temperature of the refrigerant suctioned into compressor **10**.

[0066] $T_{w,in}$[° C.] represents a temperature of water at an inlet of a heat exchanger **40**. $T_{w,out}$[° C.] represents a temperature of water at an outlet of heat exchanger **40**. V_w[L/min] represents a flow rate of water in heat exchanger **40**.

[0067] V_{st}[cc] represents a stroke volume of compressor **10**. η_v[−] represents volumetric efficiency of compressor **10**. $\rho_{LEV,in}$[kg/m] represents a refrigerant density at the inlet of expansion valve **30**. ρ_s[kg/m^3] represents a density of the refrigerant suctioned into compressor **10**. Also, h_s represents an enthalpy at the suction port of compressor **10**.

[0068] Further, fx(A,B) represents a function adopting A and B as inputs and x as an output, and this function is mapped in advance.

[0069] First, in step S**1**, controller **100** calculates a cooling capability Q_e by the following equation (1).

$$Q_e = V_w \cdot C_{p,w}(T_{w,in} - T_{w,out}) \tag{1}$$

[0070] Then, in step S**2**, controller **100** calculates a refrigerant circulation amount Gr_s on the low pressure side by the following equation (2).

$$Gr_s = Fcomp \cdot V_{st} \cdot f\rho_s(P_s, T_s) \cdot \eta_v \tag{2}$$

[0071] In step S**3**, controller **100** calculates an evaporator inlet enthalpy $h_{e,in}$ and an evaporator inlet pressure $P_{e,in}$ by the following equations (3) and (4), respectively.

$$h_{e,in} = f_{hs}(P_s, T_s) - Q_e/Gr_s \tag{3}$$

$$P_{e,in} = f_{Pe,in}(h_{e,in}, T_{e,in}) \tag{4}$$

[0072] Then, assuming that the change by expansion valve **30** is defined as an isenthalpic change, in step S**4**, controller **100** calculates a pressure $P_{LEV,in}$ and a degree of dryness $X_{LEV,in}$ of the refrigerant at the inlet portion of expansion valve **30** by the following equations (5) and (6), respectively.

$$P_{LEV,in} = f_{PLEV,in}(Gr_s, P_{e,in}, Cv_{main}, f\rho_{LEV,in}(P_{LEV,in}, h_{e,in})) \tag{5}$$

$$X_{LEV,in} = f_{XLEV,in}(P_{LEV,in}, h_{e,in}) \tag{6}$$

[0073] The degree of dryness X is defined such that 0<X<1 in the case of two-phase refrigerant, X≤0 in the case of liquid refrigerant (supercooled liquid), and X is negative in the case of supercooled liquid.

[0074] Then, in step S**5**, controller **100** calculates the target degree of dryness X_{tgt} of the refrigerant at the inlet portion of expansion valve **30** by the following equation (7).

$$X_{tgt} = f_{Xtgt}(P_d, P_s, Fcomp) \tag{7}$$

[0075] In step S**6**, controller **100** compares the target degree of dryness X_{tgt} with the calculated current degree of dryness $X_{LEV,in}$. When the degree of dryness $X_{LEV,in}$ is equal to or less than the target degree of dryness X_{tgt}(YES in S6), then in step S**7**, controller **100** decreases the degree of opening of second expansion valve **72** disposed in injection flow path **70**. On the other hand, when the degree of dryness $X_{LEV,in}$ is not equal to or less than the target degree of dryness X_{tgt}(NO in S6), then in step S**8**, controller **100** increases the degree of opening of second expansion valve **72** disposed in injection flow path **70**.

[0076] By the process as described above, controller **100** controls the degree of opening of second expansion valve **72** such that the degree of dryness $X_{LEV,in}$ of the refrigerant flowing into first expansion valve **30** from first flow path **81** of third heat exchanger **80** does not increase above the target degree of dryness X_{tgt}.

[0077] In this case, it is necessary to perform convergence calculation in order to calculate inlet portion pressure $P_{LEV,in}$ at first expansion valve **30** in step S4 in FIG. **5**, which will be described below to some extent.

[0078] FIG. **6** is a diagram for illustrating symbols of various parameters of first expansion valve **30**. First expansion valve **30** includes a stator coil **31** and a rotor **32** of a pulse motor, a screw **33**, and a needle **34**. When rotor **32** rotates, the amount of needle **34** inserted into an orifice **35** by screw **33** is changed. Thereby, the degree of opening of expansion valve **30** can be changed.

[0079] As shown in FIG. **6**, $P_{LEV,in}$, $h_{LEV,in}$, and $\rho_{LEV,in}$ represent the refrigerant pressure, the enthalpy, and the refrigerant density, respectively, at the inlet portion of first expansion valve **30**. Further, Cv_{main}[mm^2] represents the Cv value of expansion valve **30**, Gr_s[kg/h] represents the refrigerant circulation amount at the suction port of compressor **10**, $h_{LEV,in}$[kJ/kg] represents the enthalpy of the refrigerant at the inlet of expansion valve **30**, and $P_{e,in}$[MPa] represents the pressure of the refrigerant at the inlet of expansion valve **30**.

[0080] FIG. **7** is a diagram for illustrating a process of deriving the inlet portion pressure of first expansion valve **30**.

[0081] First, in step S**11**, controller **100** sets an assumed value $P_{LEV,in1}$ of the inlet portion pressure of first expansion valve **30**. In step S**12**, controller **100** calculates a refrigerant density $\rho_{LEV,in}$ at the inlet portion of expansion valve **30** by applying assumed value $P_{LEV,in1}$ to the following equation (8).

$$\rho_{LEV,in} = f(P_{LEV,in}, h_{LEV,in}) \tag{8}$$

[0082] Further, in step S**13**, controller **100** calculates a refrigerant pressure $P_{LEV,in2}$ at the inlet portion of expansion valve **30** by the following equation (9).

$$P_{LEV,in2} = f(Grs, P_{e,in}, Cv_{main}, \rho_{LEV,in}) \tag{9}$$

[0083] Then, in step S**14**, controller **100** compares assumed value $P_{LEV,in1}$ with the calculated refrigerant pressure $P_{LEV,in2}$, and determines whether or not these values are equal to each other. Note that $P_{LEV,in1}=P_{LEV,in2}$ represented in step S**14** means whether or not the convergence condition is satisfied, and the convergence condition includes a condition that the error between the two values to be compared falls within a certain value.

[0084] When the convergence condition is not satisfied (NO in S14), the process returns to step S**11**, and the assumed value is reset. The assumed value may be reset by using Newton's Method, a binary method, or the like, each of which is generally used for convergence calculation.

(b) Non-Azeotropic Refrigerant Having Temperature Gradient

[0085] In contrast to the above-described case in which refrigerant having no temperature gradient is used, in the case of non-azeotropic refrigerant having a temperature gradient, the number of sensors can be reduced, and the degree of dryness $X_{LEV,in}$ of the refrigerant can be calculated in a simplified process.

[0086] FIG. **8** is a diagram showing an arrangement of various sensors when non-azeotropic refrigerant is used. When FIG. **8** is compared with FIG. **3**, FIG. **8** is the same as FIG. **3** in that refrigeration cycle apparatus **1** includes pressure sensors **110** and **116** except that, in FIG. **8**, temperature sensor **111** and pressure sensor **118** are additionally provided but temperature sensors **112**, **114**, **115**, **117**, and flow rate sensor **113** are not provided.

[0087] FIG. **9** is a p-h diagram showing a change in the state of refrigerant when non-azeotropic refrigerant is used. When FIG. **9** is compared with FIG. **4**, in FIG. **9**, an isothermal line TL is not parallel to the horizontal axis in a two-phase region, and thus, condensing steps A to C show a temperature change. When the degree of dryness X increases, a point C shifts in the direction approaching a point A, so that a temperature $T_{LEV,in}$ also rises. Therefore, it is understood that, when non-azeotropic refrigerant exhibiting a temperature gradient in the two-phase region is used, the degree of dryness $X_{LEV,in}$ can be calculated from pressure $P_{LEV,in}$ and temperature $T_{LEV,in}$ also in the two-phase region.

[0088] FIG. **10** is a flowchart for illustrating control of second expansion valve **72** when non-azeotropic refrigerant is used.

[0089] First, in step S**21**, controller **100** calculates the degree of dryness $X_{LEV,in}$ of the refrigerant at the inlet portion of expansion valve **30** by the following equation (10).

$$X_{LEV,in} = f_{XLEV,in}(P_{LEV,in}, T_{LEV,in}) \tag{10}$$

[0090] Then, in step S**22**, controller **100** calculates the target degree of dryness X_{tgt} of the refrigerant at the inlet portion of expansion valve **30** by the following equation (11).

$$X_{tgt} = f_{Xtgt}(P_d, P_s, F_{comp}) \tag{11}$$

[0091] Then, controller **100** changes the degree of opening of second expansion valve **72** such that $X_{LEV,in}$ becomes equal to X_{tgt}. Specifically, in step S**23**, controller **100** compares the target degree of dryness X_{tgt} with the calculated current degree of dryness $X_{LEV,in}$. When the degree of dryness $X_{LEV,in}$ is equal to or less than the target degree of dryness X_{tgt}(YES in S23), then in step S**24**, controller **100** decreases the degree of opening of second expansion valve **72** disposed in injection flow path **70**. On the other hand, when the degree of dryness $X_{LEV,in}$ is not equal to or less than the target degree of dryness X_{tgt}(NO in S23), then in step S**25**, controller **100** increases the degree of opening of second expansion valve **72** disposed in injection flow path **70**.

[0092] By repeatedly performing the process in FIG. **10**, the degree of opening of second expansion valve **72** is controlled such that the degree of dryness $X_{LEV,in}$ becomes equal to the target degree of dryness X_{tgt}.

<Comparison with Study Example>

[0093] The following describes a study of comparison between a refrigeration cycle apparatus designed mainly for heating as a study example and the refrigeration cycle apparatus according to the first embodiment.

[0094] In particular, the refrigeration cycle apparatus according to the present embodiment is suitably used in a heat pump machine mainly for heating, such as a water heater or a circulation-type warmer.

[0095] In a heat pump machine mainly for heating, such as a water heater or a circulation-type warmer, the amount of refrigerant required during a heating operation is generally enclosed, and the amount of refrigerant becomes insufficient during a cooling operation. This is because, during the cooling operation, an air heat exchanger larger in volume than a load-side heat exchanger serves as a condenser (high pressure), and thus, the amount of refrigerant required to fill the outlet of the condenser with liquid refrigerant increases.

[0096] In recent years, low GWP refrigerant has been increasingly used due to regulations for refrigerant, but such refrigerant is less available in market and higher in unit cost than conventional refrigerant (R410A, R32, and the like). This causes a concern that a larger amount of refrigerant may lead to a higher prime cost of each device. Therefore, the amount of refrigerant enclosed in a heat pumping machine also tends to be reduced. Although natural refrigerant such as propane (R290) is used due to regulations for refrigerant, such natural refrigerant is flammable refrigerant, and thus, the maximum amount of such natural refrigerant to be enclosed may be limited from the viewpoint of safety.

[0097] At this time, when the refrigerant becomes insufficient during the cooling operation or the defrosting operation, the refrigerant at the inlet of the expansion valve becomes two-phase refrigerant and the refrigerant density decreases, which consequently decreases the pressure on the low pressure side due to insufficient degree of opening of the expansion valve. When the low pressure decreases, freezing occurs in the load-side heat exchanger, and when the load-side heat exchanger is damaged, there is a possibility that refrigerant may leak due to rupture.

[0098] When the refrigeration cycle apparatus is designed mainly for a heating operation, the refrigerant and the heat medium (air, water, refrigerant, and the like) are arranged to flow as counterflows to each other in the heat exchanger during a heating operation for the purpose of ensuring the performance during the heating operation. Thus, during the cooling operation and the defrosting operation, the flow direction of the refrigerant in the heat exchanger is reversed and a parallel flow occurs, so that the performance decreases.

[0099] On the other hand, according to the refrigeration cycle apparatus of the first embodiment as described above, the following effects are achieved.

[0100] In any of the heating operation, the cooling operation, and the defrosting operation, each refrigerant flowing into a respective one of three heat exchangers can be caused to flow in the same direction as a counterflow, and therefore, the performance is expected to be improved as compared with the conventional refrigeration cycle apparatus in which a parallel flow mixedly exists.

[0101] In any of the heating operation, the cooling operation, and the defrosting operation, the internal heat exchange using third heat exchanger **80** and second expansion valve **72** disposed in injection flow path **70** can be used for the refrigerant at the outlet portion of the condenser, and therefore, the performance of the refrigeration cycle apparatus is expected to be improved by injection of the refrigerant.

[0102] Further, since the degree of dryness $X_{LEV,in}$ of the refrigerant on the inlet side of first expansion valve **30** can be decreased, the refrigerant density at the inlet of first expansion valve **30** increases, so that the pressure decrease of the refrigerant suctioned into compressor **10** can be suppressed.

[0103] Further, suppressing a pressure decrease in the low pressure portion can avoid freezing in the load-side heat exchanger.

<Various Modifications of Flow Path Switching Device>

[0104] In the following second to fifth embodiments, various modifications of the flow path switching device will be described.

Second Embodiment

[0105] FIG. **11** is a diagram showing a refrigerant circuit and a flow of refrigerant during a cooling operation of a refrigeration cycle apparatus according to the second embodiment. Flow path switching device **50** in a refrigeration cycle apparatus **201** shown in FIG. **11** includes a six-way valve **51**A and a four-way valve **52**.

[0106] Six-way valve **51**A includes ports PB**2** and PC**2** in addition to ports PA to PD. Ports PA to PD are connected to the respective pipes of the refrigerant circuit as in FIG. **1**. Ports PB**2** and PC**2** are connected by a pipe outside six-way valve **51**A.

[0107] By the connection as described above, six-way valve **51**A can be used for switching the connection similarly to four-way valve **51** shown in FIG. **1**. In recent years, a six-way valve has become produced, and if a six-way valve can be used in place of a four-way valve, it may be convenient, for example, in terms of inventory adjustment for raw materials.

[0108] Since four-way valve **52** and other connection portions in refrigeration cycle apparatus **201** shown in FIG.

11 have the same configurations as those in refrigeration cycle apparatus 1 shown in FIG. 1, the description thereof will not be repeated.

[0109] In the first operation mode (cooling), six-way valve 51A is configured to connect the discharge port of compressor 10 to refrigerant inlet 21 of first heat exchanger 20 and connect the refrigerant outlet of first expansion valve 30 to the refrigerant inlet of second heat exchanger 40. At this time, a flow path is formed inside six-way valve 51A such that port PA communicates with port PB, port PC communicates with port PD, and port PB2 communicates with port PC2.

[0110] In the first operation mode (cooling), four-way valve 52 is configured to connect refrigerant outlet 22 of first heat exchanger 20 to the refrigerant inlet of first flow path 81 and connect the refrigerant outlet of second heat exchanger 40 to the suction port of compressor 10.

[0111] FIG. 12 is a diagram showing the refrigerant circuit and the flow of the refrigerant during a heating operation of the refrigeration cycle apparatus according to the second embodiment.

[0112] In the second operation mode (heating), six-way valve 51A is configured to connect the discharge port of compressor 10 to the refrigerant inlet of second heat exchanger 40 and connect the refrigerant outlet of first expansion valve 30 to refrigerant inlet 21 of first heat exchanger 20. At this time, a flow path is formed inside six-way valve 51A such that port PA communicates with port PD, port PB communicates with port PB2, and port PC2 communicates with port PC. As a result, port PB communicates with port PC through an external pipe.

[0113] In the second operation mode (heating), four-way valve 52 is configured to connect the refrigerant outlet of second heat exchanger 40 to the refrigerant inlet of first flow path 81 and connect refrigerant outlet 22 of first heat exchanger 20 to the suction port of compressor 10.

[0114] According to refrigeration cycle apparatus 201 of the second embodiment configured as described above, the same effect as that in the first embodiment can be achieved.

Third Embodiment

[0115] FIG. 13 is a diagram showing a refrigerant circuit and a flow of refrigerant during a cooling operation of a refrigeration cycle apparatus according to the third embodiment. Flow path switching device 50 of a refrigeration cycle apparatus 202 shown in FIG. 13 includes a four-way valve 51 and a six-way valve 52A.

[0116] Six-way valve 52A includes ports PG2 and PH2 in addition to ports PE to PH. Ports PE to PH are connected to the respective pipes of the refrigerant circuit as in FIG. 1. Ports PG2 and PH2 are connected by a pipe outside six-way valve 52A.

[0117] By the connection as described above, six-way valve 52A can be used for switching the connection similarly to four-way valve 52 shown in FIG. 1.

[0118] In the first operation mode (cooling), the four-way valve is configured to connect the discharge port of compressor 10 to refrigerant inlet 21 of first heat exchanger 20 and connect the refrigerant outlet of first expansion valve 30 to the refrigerant inlet of second heat exchanger 40.

[0119] In the first operation mode (cooling), six-way valve 52A is configured to connect refrigerant outlet 22 of first heat exchanger 20 to the refrigerant inlet of first flow path 81 and connect the refrigerant outlet of second heat exchanger 40 to the suction port of compressor 10. At this time, a flow path is formed inside six-way valve 52A such that port PE communicates with port PF, port PG communicates with port PG2, and port PH2 communicates with port PH. As a result, ports PG and PH communicate with each other through an external pipe.

[0120] FIG. 14 is a diagram showing the refrigerant circuit and the flow of the refrigerant during a heating operation of the refrigeration cycle apparatus according to the third embodiment.

[0121] In the second operation mode (heating), four-way valve 51 is configured to connect the discharge port of compressor 10 to the refrigerant inlet of second heat exchanger 40 and connect the refrigerant outlet of first expansion valve 30 to refrigerant inlet 21 of first heat exchanger 20.

[0122] In the second operation mode (heating), six-way valve 52A is configured to connect the refrigerant outlet of second heat exchanger 40 to the refrigerant inlet of first flow path 81 and connect refrigerant outlet 22 of first heat exchanger 20 to the suction port of compressor 10. At this time, a flow path is formed inside six-way valve 52A such that port PG communicates with port PF, port PE communicates with port PH, and port PG2 communicates with port PH2.

[0123] According to refrigeration cycle apparatus 202 of the third embodiment configured as described above, the same effect as that in the first and second embodiments can also be achieved.

Fourth Embodiment

[0124] FIG. 15 is a diagram showing a refrigerant circuit and a flow of refrigerant during a cooling operation of a refrigeration cycle apparatus according to the fourth embodiment. Flow path switching device 50 in a refrigeration cycle apparatus 203 shown in FIG. 15 includes a first six-way valve 51A and a second six-way valve 52A. Since first six-way valve 51A is connected in the same way as that in the second embodiment and second six-way valve 52A is connected in the same way as that in the third embodiment, the description thereof will not be repeated.

[0125] In the first operation mode (cooling), first six-way valve 51A is configured to connect the discharge port of compressor 10 to refrigerant inlet 21 of first heat exchanger 20 and connect the refrigerant outlet of first expansion valve 30 to the refrigerant inlet of second heat exchanger 40.

[0126] In the first operation mode (cooling), second six-way valve 52A is configured to connect refrigerant outlet 22 of first heat exchanger 20 to the refrigerant inlet of first flow path 81 and connect the refrigerant outlet of second heat exchanger 40 to the suction port of compressor 10.

[0127] FIG. 16 is a diagram showing the refrigerant circuit and the flow of the refrigerant during a heating operation of the refrigeration cycle apparatus according to the fourth embodiment.

[0128] In the second operation mode (heating), first six-way valve 51A is configured to connect the discharge port of compressor 10 to the refrigerant inlet of second heat exchanger 40 and connect the refrigerant outlet of first expansion valve 30 to refrigerant inlet 21 of first heat exchanger 20.

[0129] In the second operation mode (heating), second six-way valve 52A is configured to connect the refrigerant outlet of second heat exchanger 40 to the refrigerant inlet of first flow path **81** and connect refrigerant outlet **22** of first heat exchanger **20** to the suction port of compressor **10**.

[0130] According to refrigeration cycle apparatus **203** of the fourth embodiment configured as described above, the same effect as that in the first to third embodiments can also be achieved.

Fifth Embodiment

[0131] Flow path switching device **50** in a refrigeration cycle apparatus **204** according to the fifth embodiment includes an eight-way valve **50**B.

[0132] FIG. **17** is a diagram showing a refrigerant circuit and a flow of refrigerant during a cooling operation of a refrigeration cycle apparatus according to the fifth embodiment. FIG. **18** is a diagram showing the state of eight-way valve **50**B and the flow of the refrigerant in eight-way valve **50**B during the cooling operation according to the fifth embodiment.

[0133] As shown in FIG. **18**, eight-way valve **50**B includes a cylindrical valve main body **308**. Ports PA and PE are formed on one side in the circumferential direction of valve main body **308** while ports PB, PC, PD, PF, PG, and PH are formed on the other side thereof.

[0134] Since ports PA to PH are connected to the same destinations as those in FIG. **1**, the description thereof will not be repeated. A piston **312** formed by connecting three pressure receiving slide members **310**A, **310**B, and **310**C to a connecting rod **311** is provided inside valve main body **308** of eight-way valve **50**B. Slide valve bodies **313**A and **313**B are fixed to connecting rod **311**.

[0135] As piston **312** moves, slide valve body **313**A slides on a valve seat provided with ports PB, PC, and PD, and slide valve body **313**B slides on a valve seat provided with ports PF, PG, and PH.

[0136] Piston **312** provides partitions between a first chamber R**1**, a second chamber R**2**, a third chamber R**3**, and a fourth chamber R**4**. Eight-way valve **50**B further includes a pilot solenoid valve **514** for switching the slide valve body. Pilot solenoid valve **514** includes a valve body **516** coupled to a plunger **515**, a solenoid coil **517**, and a coil spring **518**.

[0137] When the refrigeration cycle apparatus is started while solenoid coil **517** of pilot solenoid valve **514** is energized, plunger **515** is suctioned so that valve body **516** is moved to thereby: cause a low-pressure communication pipe **519** reaching a suction pipe of compressor **10** to communicate with a conduit **522** for fourth chamber R**4**; and cause a high-pressure introduction pipe **521** to communicate with a conduit **520** for first chamber R**1**. When compressor **10** is started in this state, high pressure is introduced into first chamber R**1**, and piston **312** and slide valve bodies **313**A and **313**B are moved toward fourth chamber R**4** and fixed as shown in FIG. **18**.

[0138] Slide valve body **313**A is provided with two communication inner cavities through which two ports adjacent in phase between ports PB, PC, and PD communicate with each other. In the state in FIG. **18**, the communication inner cavities allow communication between ports PC and PD, and port PA communicates with port PB through second chamber R**2**.

[0139] Slide valve body **313**B is provided with two communication inner cavities through which two ports adjacent in phase between ports PF, PG, and PH communicate with each other. In the state in FIG. **18**, the communication inner cavities allow communication between ports PG and PH, and port PE communicates with port PF through third chamber R**3**.

[0140] In this way, eight-way valve **50**B is arranged at the cooling operation position in which refrigerant circulates through the path indicated by a solid line in FIG. **17**.

[0141] FIG. **19** is a diagram showing the refrigerant circuit and the flow of the refrigerant during a heating operation of the refrigeration cycle apparatus according to the fifth embodiment. FIG. **20** is a diagram showing the state of eight-way valve **50**B and the flow of the refrigerant in eight-way valve **50**B during the heating operation according to the fifth embodiment.

[0142] Valve body **516** biased by coil spring **518** when solenoid coil **517** is not energized causes low-pressure communication pipe **519** to communicate with conduit **520** for first chamber R**1** and causes high-pressure introduction pipe **521** to communicate with conduit **522** for fourth chamber R**4**. Thus, high pressure is introduced into fourth chamber R**4**, so that piston **312** and slide valve bodies **313**A and **313**B move toward first chamber R**1**.

[0143] In the state in FIG. **20**, the communication inner cavities of slide valve body **313**A allow communication between ports PB and PC, and port PA communicates with port PD through second chamber R**2**.

[0144] Similarly, in the state in FIG. **20**, the communication inner cavities of slide valve body **313**B allow communication between ports PF and PG, and port PE communicates with port PH through third chamber R**3**.

[0145] In this way, eight-way valve **50**B is arranged at the heating operation position in which refrigerant circulates through the path indicated by a solid line in FIG. **19**.

[0146] By using the eight-way valve as described above, in the refrigeration cycle apparatus according to the fifth embodiment, the same effect as that in the first to fourth embodiments can be achieved, and the number of components and the number of ports used in a substrate can be reduced.

Summary

[0147] The following summarizes the first to fifth embodiments again with reference to the accompanying drawings.

[0148] A refrigeration cycle apparatus **1** shown in FIG. **1** includes a compressor **10**, a first heat exchanger **20**, a second heat exchanger **40**, a third heat exchanger **80**, a first expansion valve **30**, a second expansion valve **72**, and a flow path switching device **50**.

[0149] Compressor **10**, first heat exchanger **20**, second heat exchanger **40**, and first expansion valve **30** constitute a refrigerant circuit **90** through which refrigerant circulates. Second expansion valve **72** forms a portion of injection flow path **70**, injection flow path **70** being configured to reduce pressure of the refrigerant before passing through first expansion valve **30** in refrigerant circuit **90** and return the refrigerant to compressor **10**.

[0150] Third heat exchanger **80** includes a first flow path **81** through which the refrigerant flows, and a second flow path **82** through which the refrigerant flows. Third heat exchanger **80** is configured to exchange heat between the refrigerant passing through first flow path **81** and the refrigerant passing through second flow path **82**. First flow path **81** is disposed in refrigerant circuit **90** to cause the refrigerant to flow toward first expansion valve **30**. Second flow path **82**

is disposed to return, to compressor **10**, the refrigerant that has passed through second expansion valve **72**.

[0151] In a first operation mode (cooling), flow path switching device **50** is configured to connect a discharge port of compressor **10** to a refrigerant inlet of first heat exchanger **20**, connect a refrigerant outlet of first heat exchanger **20** to a refrigerant inlet of first flow path **81**, connect a refrigerant outlet of first expansion valve **30** to a refrigerant inlet of second heat exchanger **40**, and connect a refrigerant outlet of second heat exchanger **40** to a suction port of compressor **10**.

[0152] In a second operation mode (heating), flow path switching device **50** is configured to connect the discharge port of compressor **10** to the refrigerant inlet of second heat exchanger **40**, connect the refrigerant outlet of second heat exchanger **40** to the refrigerant inlet of first flow path **81**, connect the refrigerant outlet of first expansion valve **30** to the refrigerant inlet of first heat exchanger **20**, and connect the refrigerant outlet of first heat exchanger **20** to the suction port of compressor **10**.

[0153] Preferably, in any of the first operation mode and the second operation mode, the refrigerant flows in the same direction in each of first heat exchanger **20**, second heat exchanger **40**, third heat exchanger **80**, first expansion valve **30**, and second expansion valve **72**.

[0154] Preferably, first heat exchanger **20**, second heat exchanger **40**, and third heat exchanger **80** are configured to perform heat exchange in a relation in which a heat medium that exchanges heat flows as a counterflow in any of the first operation mode and the second operation mode. In this case, the heat medium that exchanges heat with the refrigerant is air in first heat exchanger **20**, water or brine in second heat exchanger **40**, and refrigerant in third heat exchanger **80**.

[0155] Preferably, as shown in FIGS. **1** and **2**, flow path switching device **50** includes a first four-way valve **51** and a second four-way valve **52**. In the first operation mode (cooling), first four-way valve **51** is configured to connect the discharge port of compressor **10** to the refrigerant inlet of first heat exchanger **20** and connect the refrigerant outlet of first expansion valve **30** to the refrigerant inlet of second heat exchanger **40**, and in the second operation mode (heating), first four-way valve **51** is configured to connect the discharge port of compressor **10** to the refrigerant inlet of second heat exchanger **40** and connect the refrigerant outlet of first expansion valve **30** to the refrigerant inlet of first heat exchanger **20**. In the first operation mode (cooling), second four-way valve **52** is configured to connect the refrigerant outlet of first heat exchanger **20** to the refrigerant inlet of first flow path **81** and connect the refrigerant outlet of second heat exchanger **40** to the suction port of compressor **10**, and in the second operation mode (heating), second four-way valve **52** is configured to connect the refrigerant outlet of second heat exchanger **40** to the refrigerant inlet of first flow path **81** and connect the refrigerant outlet of first heat exchanger **20** to the suction port of compressor **10**.

[0156] Preferably, as shown in FIGS. **11** and **12**, flow path switching device **50** includes a six-way valve **51**A and a four-way valve **52**. In the first operation mode (cooling), six-way valve **51**A is configured to connect the discharge port of compressor **10** to the refrigerant inlet of first heat exchanger **20** and connect the refrigerant outlet of first expansion valve **30** to the refrigerant inlet of second heat exchanger **40**, and in the second operation mode (heating), six-way valve **51**A is configured to connect the discharge port of compressor **10** to the refrigerant inlet of second heat exchanger **40** and connect the refrigerant outlet of first expansion valve **30** to the refrigerant inlet of first heat exchanger **20**. In the first operation mode (cooling), four-way valve **52** is configured to connect the refrigerant outlet of first heat exchanger **20** to the refrigerant inlet of first flow path **81** and connect the refrigerant outlet of second heat exchanger **40** to the suction port of compressor **10**, and in the second operation mode (heating), four-way valve **52** is configured to connect the refrigerant outlet of second heat exchanger **40** to the refrigerant inlet of first flow path **81** and connect the refrigerant outlet of first heat exchanger **20** to the suction port of compressor **10**.

[0157] Preferably, as shown in FIGS. **13** and **14**, flow path switching device **50** includes a four-way valve **51** and a six-way valve **52**A. In the first operation mode (cooling), four-way valve **51** is configured to connect the discharge port of compressor **10** to the refrigerant inlet of first heat exchanger **20** and connect the refrigerant outlet of first expansion valve **30** to the refrigerant inlet of second heat exchanger **40**, and in the second operation mode (heating), four-way valve **51** is configured to connect the discharge port of compressor **10** to the refrigerant inlet of second heat exchanger **40** and connect the refrigerant outlet of first expansion valve **30** to the refrigerant inlet of first heat exchanger **20**. In the first operation mode (cooling), six-way valve **52**A is configured to connect the refrigerant outlet of first heat exchanger **20** to the refrigerant inlet of first flow path **81** and connect the refrigerant outlet of second heat exchanger **40** to the suction port of compressor **10**, and in the second operation mode (heating), six-way valve **52**A is configured to connect the refrigerant outlet of second heat exchanger **40** to the refrigerant inlet of first flow path **81** and connect the refrigerant outlet of first heat exchanger **20** to the suction port of compressor **10**.

[0158] Preferably, as shown in FIGS. **15** and **16**, the flow path switching device includes a first six-way valve **51**A and a second six-way valve **52**A. In the first operation mode (cooling), first six-way valve **51**A is configured to connect the discharge port of compressor **10** to the refrigerant inlet of first heat exchanger **20** and connect the refrigerant outlet of first expansion valve **30** to the refrigerant inlet of second heat exchanger **40**, and in the second operation mode (heating), first six-way valve **51**A is configured to connect the discharge port of compressor **10** to the refrigerant inlet of second heat exchanger **40** and connect the refrigerant outlet of first expansion valve **30** to the refrigerant inlet of first heat exchanger **20**. In the first operation mode (cooling), second six-way valve **52**A is configured to connect the refrigerant outlet of first heat exchanger **20** to the refrigerant inlet of first flow path **81** and connect the refrigerant outlet of second heat exchanger **40** to the suction port of compressor **10**, and in the second operation mode (heating), second six-way valve **52**A is configured to connect the refrigerant outlet of second heat exchanger **40** to the refrigerant inlet of first flow path **81** and connect the refrigerant outlet of first heat exchanger **20** to the suction port of compressor **10**.

[0159] Preferably, as shown in FIGS. **17** to **20**, flow path switching device **50** includes an eight-way valve **50**B.

[0160] Preferably, as shown in FIGS. **5** and **7**, the refrigeration cycle apparatus further includes a controller **100** configured to control first expansion valve **30** and second expansion valve **72**. Controller **100** is configured to control a degree of opening of second expansion valve **72** such that a degree of dryness of refrigerant flowing into first expansion valve **30** from first flow path **81** of third heat exchanger **80** does not increase above a target degree of dryness.

[0161] It should be understood that the embodiments disclosed herein are illustrative and non-restrictive in every respect. The scope of the present disclosure is defined by the terms of the claims, rather than the description of the embodiments set forth above, and is intended to include any modifications within the meaning and scope equivalent to the terms of the claims.

1. A refrigeration cycle apparatus comprising: a compressor; a first heat exchanger; a second heat exchanger; a third heat exchanger; a first expansion valve; a second expansion valve; and a flow path switching device, wherein

the compressor, the first heat exchanger, the second heat exchanger, and the first expansion valve constitute a refrigerant circuit through which refrigerant circulates,

the second expansion valve forms a portion of an injection flow path, the injection flow path being configured to reduce pressure of the refrigerant before passing through the first expansion valve in the refrigerant circuit and return the refrigerant to the compressor,

the third heat exchanger comprises a first flow path through which the refrigerant flows and a second flow path through which the refrigerant flows, and the third heat exchanger is configured to exchange heat between the refrigerant passing through the first flow path and the refrigerant passing through the second flow path,

the first flow path is disposed in the refrigerant circuit to cause the refrigerant to flow toward the first expansion valve,

the second flow path is disposed to return, to the compressor, the refrigerant that has passed through the second expansion valve,

in a first operation mode, the flow path switching device is configured to

connect a discharge port of the compressor to a refrigerant inlet of the first heat exchanger,

connect a refrigerant outlet of the first heat exchanger to a refrigerant inlet of the first flow path,

connect a refrigerant outlet of the first expansion valve to a refrigerant inlet of the second heat exchanger, and

connect a refrigerant outlet of the second heat exchanger to a suction port of the compressor,

in a second operation mode, the flow path switching device is configured to

connect the discharge port of the compressor to the refrigerant inlet of the second heat exchanger,

connect the refrigerant outlet of the second heat exchanger to the refrigerant inlet of the first flow path,

connect the refrigerant outlet of the first expansion valve to the refrigerant inlet of the first heat exchanger, and

connect the refrigerant outlet of the first heat exchanger to the suction port of the compressor and

in any of the first operation mode and the second operation mode, the refrigerant flows in a same direction in each of the first heat exchanger, the second heat exchanger, the third heat exchanger, the first expansion valve, and the second expansion valve.

2. (canceled)

3. The refrigeration cycle apparatus according to claim **1**, wherein the first heat exchanger, the second heat exchanger, and the third heat exchanger are configured to perform heat exchange in a relation in which a heat medium that exchanges heat flows as a counterflow.

4. The refrigeration cycle apparatus according to claim **1**, wherein

the flow path switching device comprises a first four-way valve and a second four-way valve,

in the first operation mode, the first four-way valve is configured to

connect the discharge port of the compressor to the refrigerant inlet of the first heat exchanger,

connect the refrigerant outlet of the first expansion valve to the refrigerant inlet of the second heat exchanger,

in the second operation mode, the first four-way valve is configured to connect the discharge port of the compressor to the refrigerant inlet of the second heat exchanger, and

connect the refrigerant outlet of the first expansion valve to the refrigerant inlet of the first heat exchanger,

in the first operation mode, the second four-way valve is configured to

connect the refrigerant outlet of the first heat exchanger to the refrigerant inlet of the first flow path, and

connect the refrigerant outlet of the second heat exchanger to the suction port of the compressor, and

in the second operation mode, the second four-way valve is configured to

connect the refrigerant outlet of the second heat exchanger to the refrigerant inlet of the first flow path, and

connect the refrigerant outlet of the first heat exchanger to the suction port of the compressor.

5. The refrigeration cycle apparatus according to claim **1**, wherein

the flow path switching device comprises a six-way valve and a four-way valve,

in the first operation mode, the six-way valve is configured to

connect the discharge port of the compressor to the refrigerant inlet of the first heat exchanger, and

connect the refrigerant outlet of the first expansion valve to the refrigerant inlet of the second heat exchanger,

in the second operation mode, the six-way valve is configured to

connect the discharge port of the compressor to the refrigerant inlet of the second heat exchanger, and

connect the refrigerant outlet of the first expansion valve to the refrigerant inlet of the first heat exchanger,

in the first operation mode, the four-way valve is configured to

connect the refrigerant outlet of the first heat exchanger to the refrigerant inlet of the first flow path, and

connect the refrigerant outlet of the second heat exchanger to the suction port of the compressor, and

in the second operation mode, the four-way valve is configured to

connect the refrigerant outlet of the second heat exchanger to the refrigerant inlet of the first flow path, and connect the refrigerant outlet of the first heat exchanger to the suction port of the compressor.

6. The refrigeration cycle apparatus according to claim **1**, wherein

the flow path switching device comprises a six-way valve and a four-way valve,

in the first operation mode, the four-way valve is configured to

connect the discharge port of the compressor to the refrigerant inlet of the first heat exchanger, and

connect the refrigerant outlet of the first expansion valve to the refrigerant inlet of the second heat exchanger,

in the second operation mode, the four-way valve is configured to

connect the discharge port of the compressor to the refrigerant inlet of the second heat exchanger, and

connect the refrigerant outlet of the first expansion valve to the refrigerant inlet of the first heat exchanger,

in the first operation mode, the six-way valve is configured to

connect the refrigerant outlet of the first heat exchanger to the refrigerant inlet of the first flow path, and

connect the refrigerant outlet of the second heat exchanger to the suction port of the compressor, and

in the second operation mode, the six-way valve is configured to connect the refrigerant outlet of the second heat exchanger to the refrigerant inlet of the first flow path, and

connect the refrigerant outlet of the first heat exchanger to the suction port of the compressor.

7. The refrigeration cycle apparatus according to claim **1**, wherein

the flow path switching device comprises a first six-way valve and a second six-way valve,

in the first operation mode, the first six-way valve is configured to

connect the discharge port of the compressor to the refrigerant inlet of the first heat exchanger, and

connect the refrigerant outlet of the first expansion valve to the refrigerant inlet of the second heat exchanger,

in the second operation mode, the first six-way valve is configured to

connect the discharge port of the compressor to the refrigerant inlet of the second heat exchanger, and

connect the refrigerant outlet of the first expansion valve to the refrigerant inlet of the first heat exchanger,

in the first operation mode, the second six-way valve is configured to

connect the refrigerant outlet of the first heat exchanger to the refrigerant inlet of the first flow path, and

connect the refrigerant outlet of the second heat exchanger to the suction port of the compressor, and

in the second operation mode, the second six-way valve is configured to

connect the refrigerant outlet of the second heat exchanger to the refrigerant inlet of the first flow path, and

connect the refrigerant outlet of the first heat exchanger to the suction port of the compressor.

8. The refrigeration cycle apparatus according to claim **1**, wherein the flow path switching device comprises an eight-way valve.

9. The refrigeration cycle apparatus according to claim **1**, further comprising a controller configured to control the first expansion valve and the second expansion valve, wherein

the controller is configured to control a degree of opening of the second expansion valve such that a degree of dryness of the refrigerant flowing into the first expansion valve from the first flow path of the third heat exchanger does not increase above a target degree of dryness.

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