US 20150027162A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2015/0027162 A1

(43) Pub. Date: Jan. 29, 2015

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(54) **COOLING SYSTEM**

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(21) Appl. No.: **14/382,276**

(22) PCT Filed: **Mar. 12, 2013**

(86) PCT No.: **PCT/IB2013/000363**

§ 371 (c)(1),
(2) Date: **Aug. 29, 2014**

(30) **Foreign Application Priority Data**

Mar. 16, 2012 (JP) 2012-060121

Publication Classification

(51) **Int. Cl.**
B60H 1/00 (2006.01)

(52) **U.S. Cl.**
CPC *B60H 1/00271* (2013.01)
USPC **62/525**; 62/527

(57) **ABSTRACT**

A three-way valve switches between flow of refrigerant from a heat exchanger toward a cooling portion via a gas-liquid separator and flow of refrigerant from a heat exchanger toward the cooling portion via the gas-liquid separator. A refrigerant line provides fluid communication between the heat exchanger and the gas-liquid separator. A refrigerant line provides fluid communication between the heat exchanger and the gas-liquid separator. A selector valve switches between flow of refrigerant from the cooling portion toward the heat exchanger via a refrigerant line and flow of refrigerant from the cooling portion toward the heat exchanger via a refrigerant line.

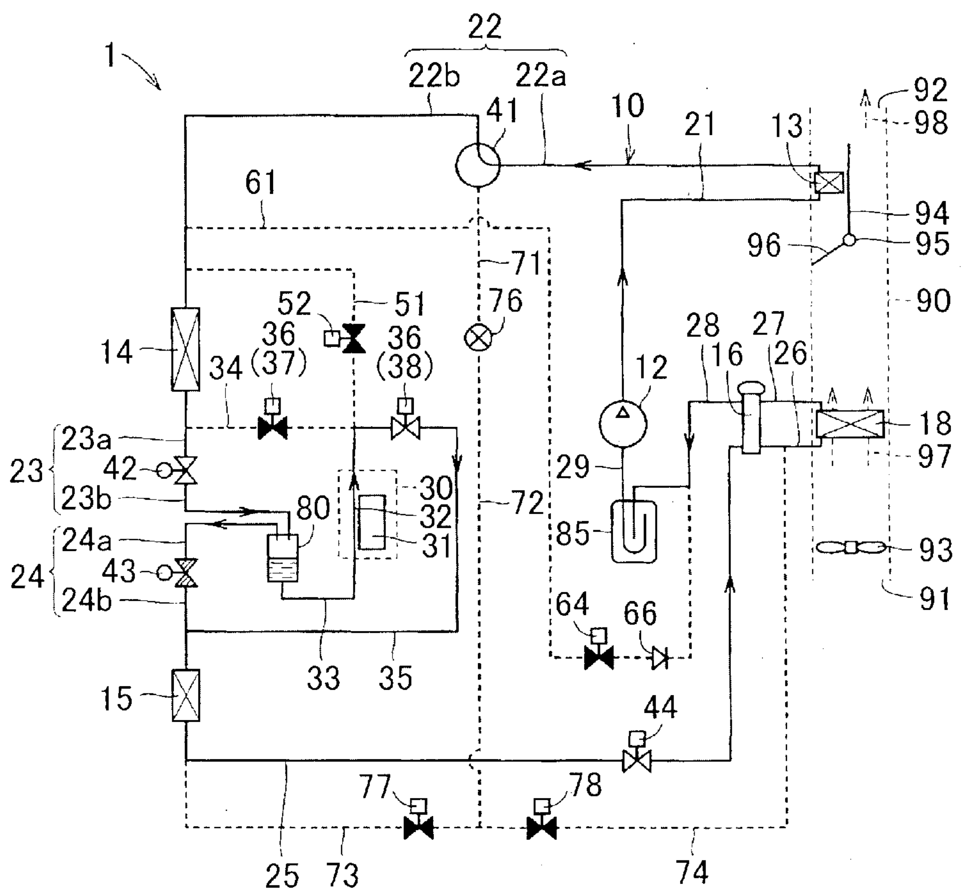

FIG. 1

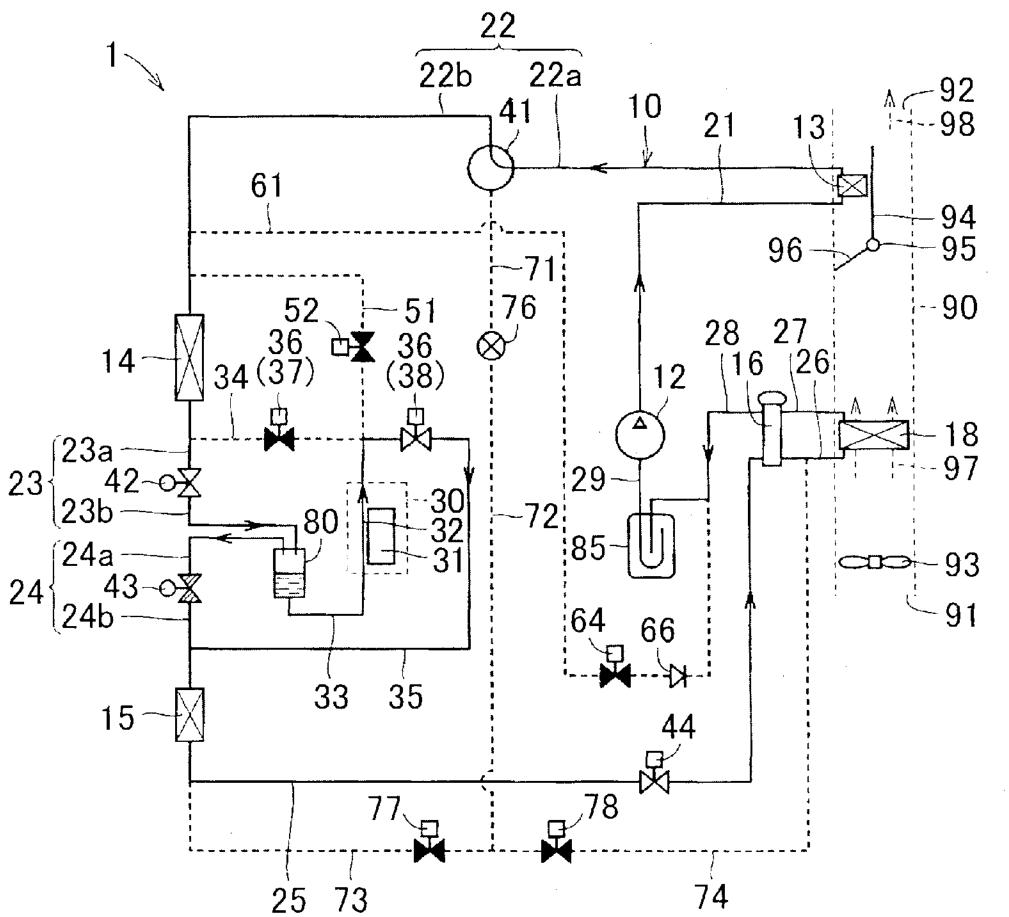
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FIG. 2A

MODE	COMPRESSOR 12	FLOW REGULATING VALVE 42	FLOW REGULATING VALVE 43	THREE-WAY VALVE 41
1	OPERATED	FULLY OPEN	OPENING DEGREE IS ADJUSTED SUCH THAT SUFFICIENT AMOUNT OF REFRIGERANT FLOWS TO COOLING PORTION 30	SET REFRIGERANT LINES 22a, 22b IN FLUID COMMUNICATION STATE
2	OPERATED	OPENING DEGREE IS ADJUSTED SUCH THAT SUFFICIENT AMOUNT OF REFRIGERANT FLOWS TO COOLING PORTION 30	FULLY OPEN	SET REFRIGERANT LINES 22a, 71 IN FLUID COMMUNICATION STATE
3	OPERATED	OPENING DEGREE IS ADJUSTED SUCH THAT SUFFICIENT AMOUNT OF REFRIGERANT FLOWS TO COOLING PORTION 30	FULLY OPEN	SET REFRIGERANT LINES 22a, 71 IN FLUID COMMUNICATION STATE
4	OPERATED	FULLY OPEN	FULLY CLOSED	SET REFRIGERANT LINES 22a, 71 IN FLUID COMMUNICATION STATE
5	STOPPED	FULLY OPEN	FULLY CLOSED	SET REFRIGERANT LINES 22a, 71 IN FLUID COMMUNICATION STATE

FIG. 2B

MODE	VALVE 37	VALVE 38	VALVE 44	VALVE 52	VALVE 64	VALVE 77	VALVE 78	EV DEVICE 31	AIR CONDITIONER
1	CLOSED	OPEN	OPEN	CLOSED	CLOSED	CLOSED	CLOSED	COOLING	COOLING/ DEHUMIDIFYING
2	OPEN	CLOSED	CLOSED	CLOSED	OPEN	OPEN	CLOSED	COOLING	HEATING
3	OPEN	CLOSED	CLOSED	CLOSED	OPEN	OPEN	OPEN	COOLING	HEATING/ DEHUMIDIFYING
4	CLOSED	CLOSED	CLOSED	OPEN	CLOSED	CLOSED	OPEN	COOLING	HEATING/ DEHUMIDIFYING
5	CLOSED	CLOSED	—	OPEN	CLOSED	—	—	COOLING	STOPPED

FIG. 3

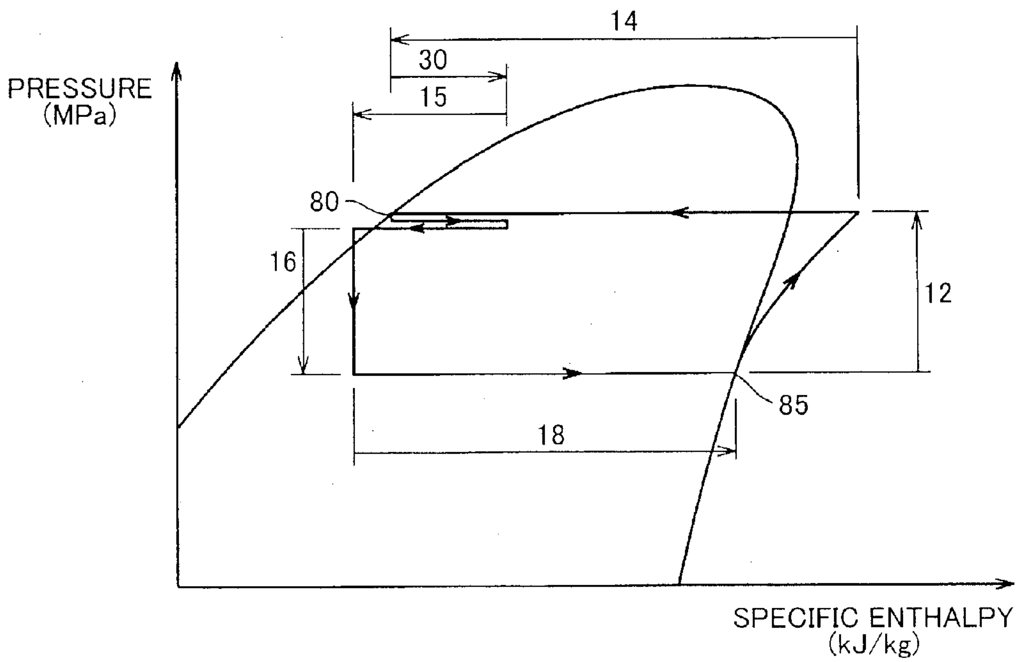
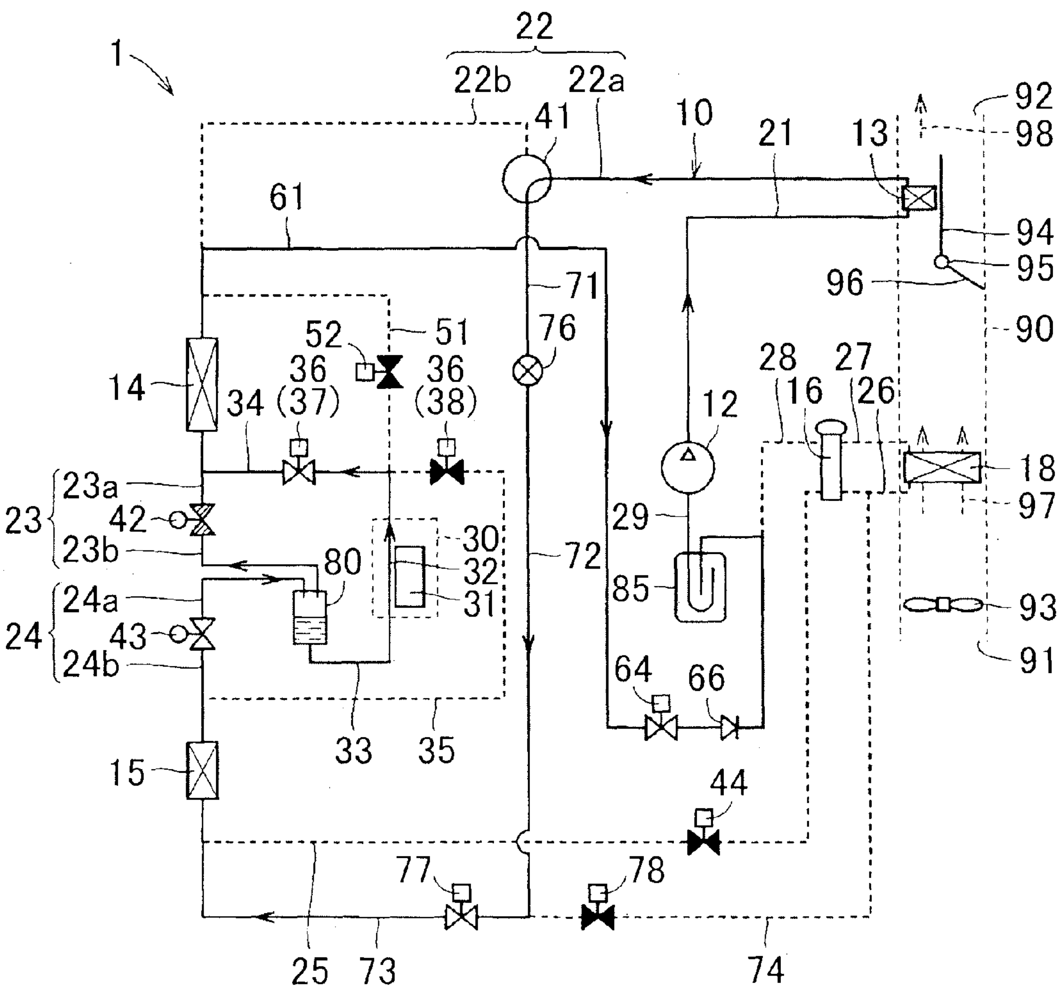


FIG. 4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(38)
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FIG. 5

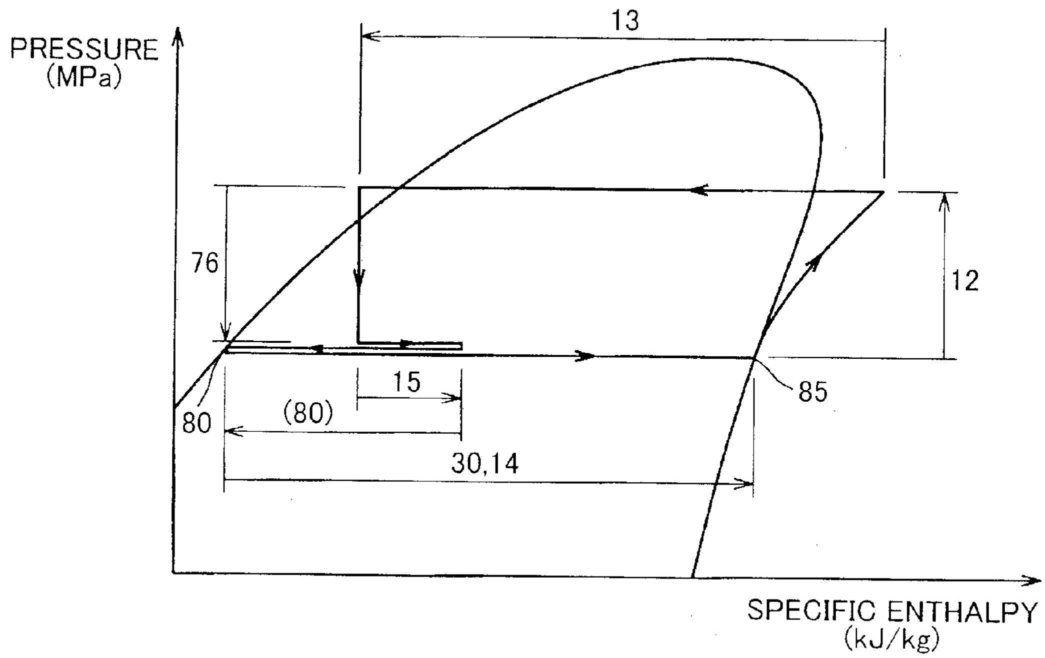

FIG. 6

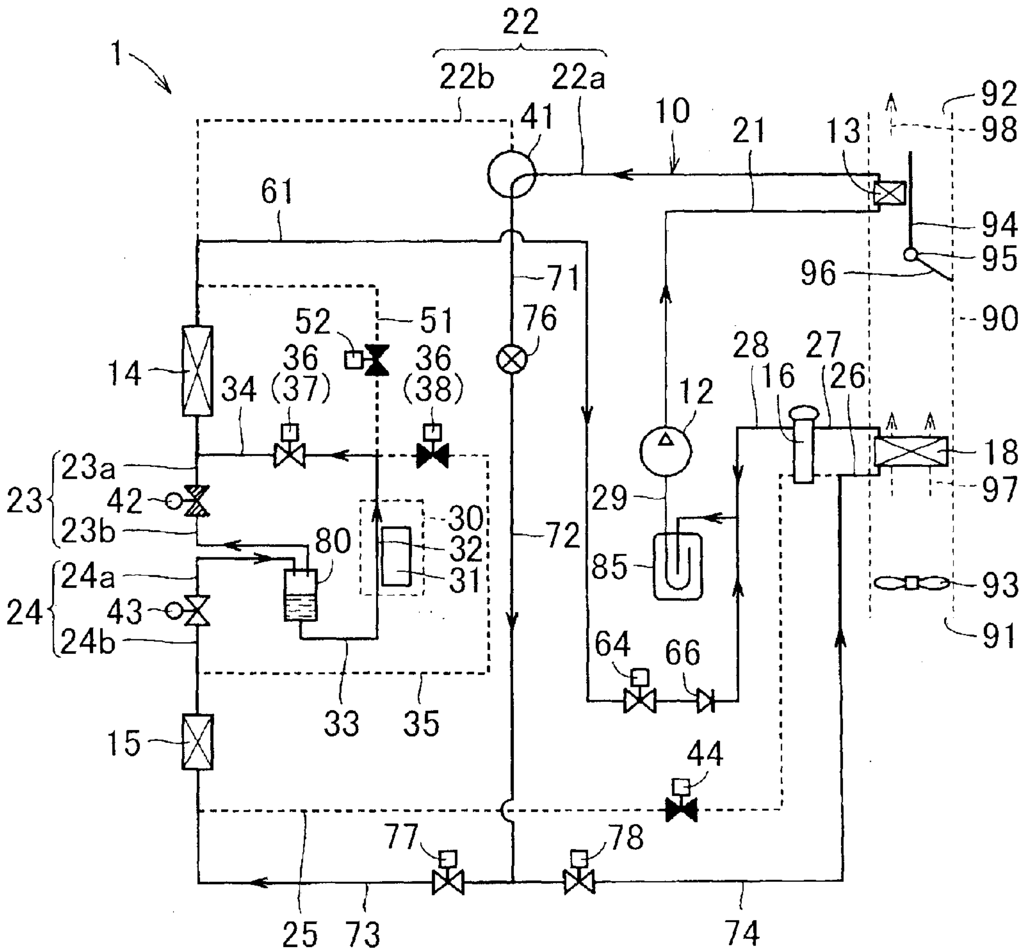

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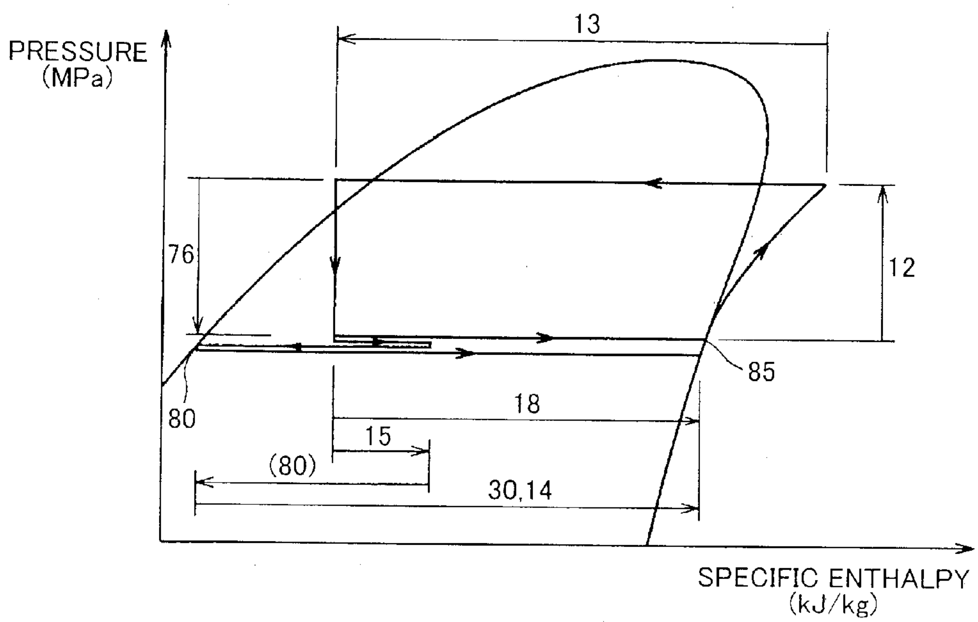
FIG. 7


PRESSURE
(MPa)
13
76
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18
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(80)
30,14
SPECIFIC ENTHALPY
(kJ/kg)

FIG. 8

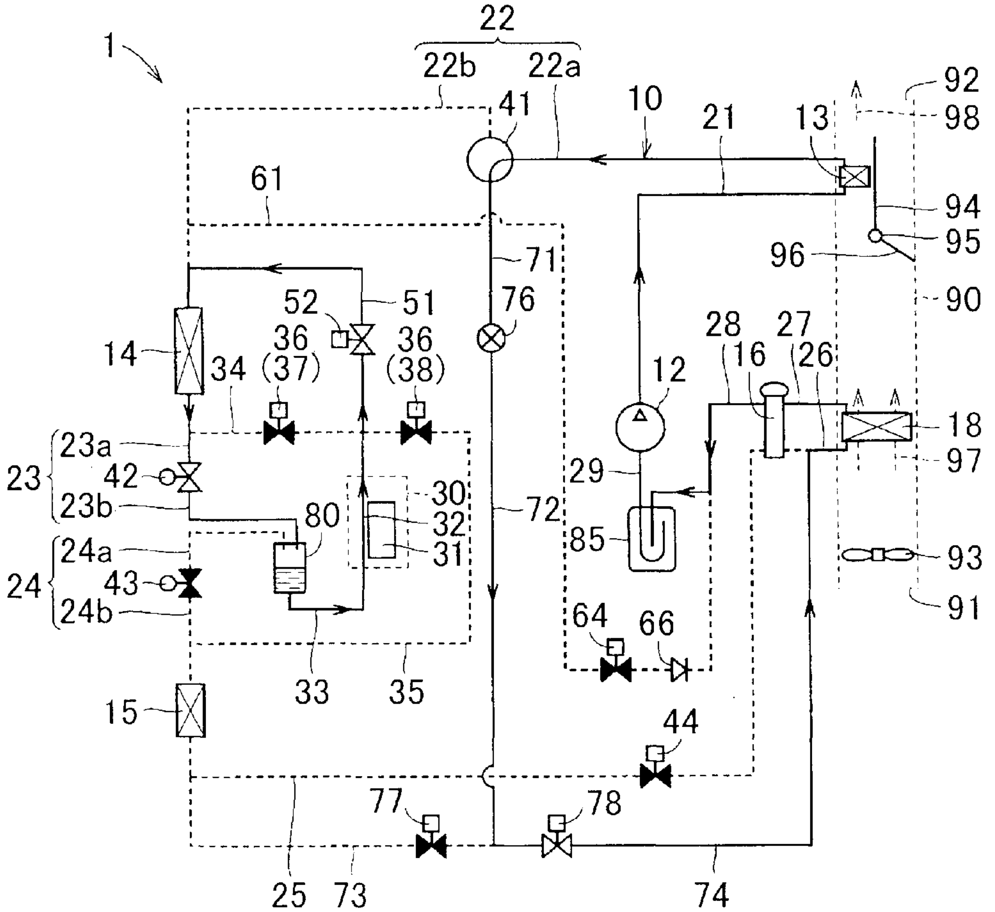
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FIG. 9

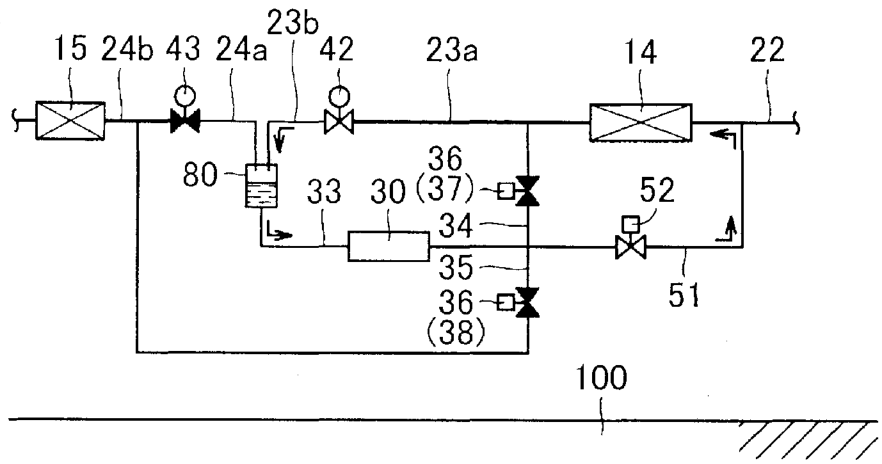
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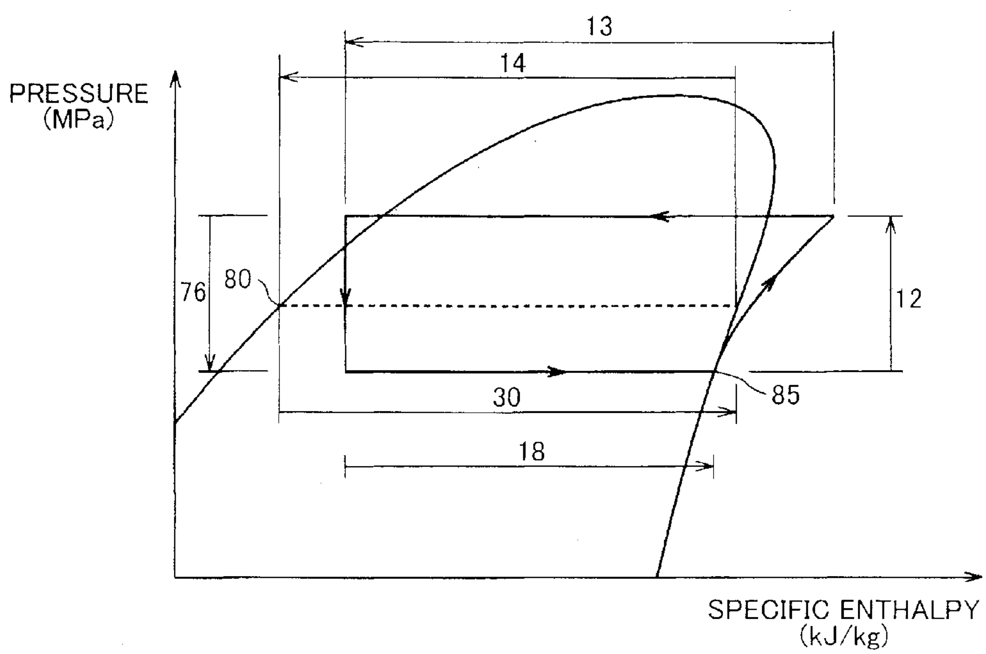
FIG. 10


PRESSURE
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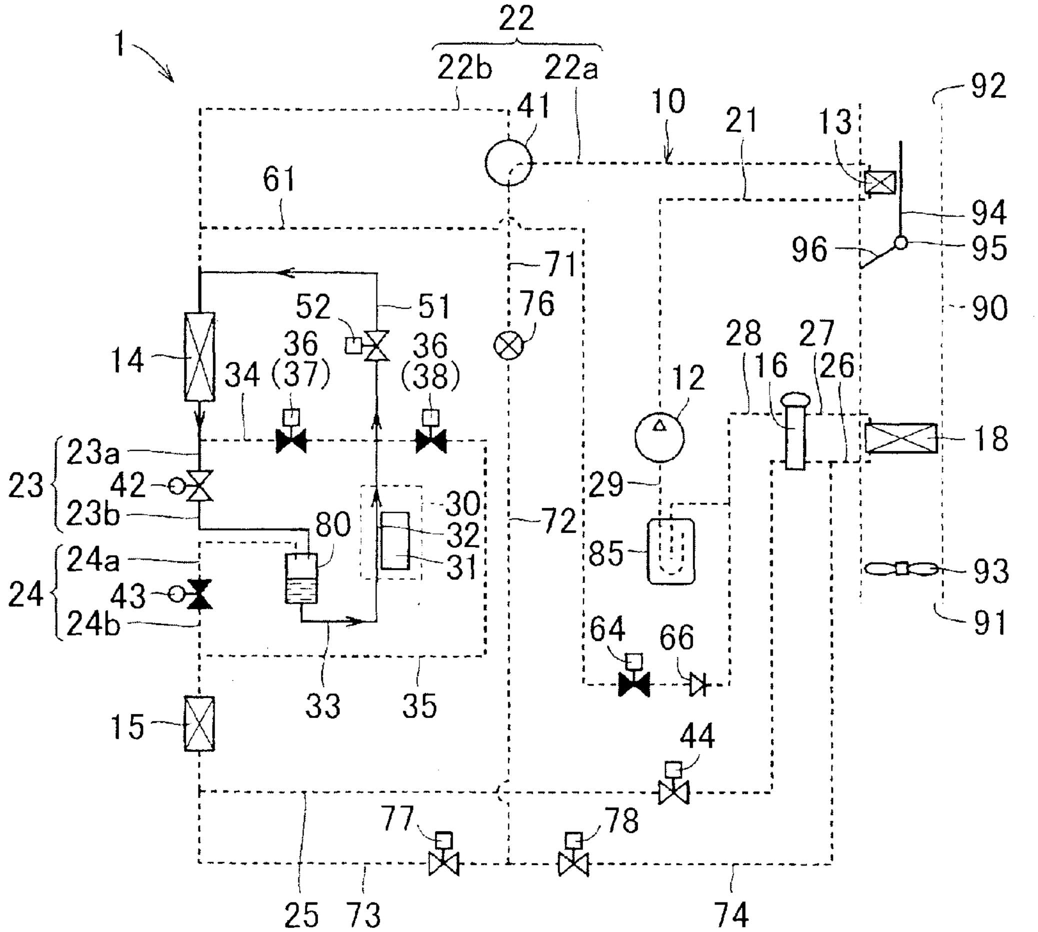
SPECIFIC ENTHALPY
(kJ/kg)

FIG. 11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COOLING SYSTEM

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The invention relates to a cooling system and, more particularly, to a cooling system that cools a heat generating source by utilizing a vapor compression refrigeration cycle.

[0003] 2. Description of Related Art

[0004] As for an existing vehicle air-conditioning system, for example, Japanese Patent Application Publication No. 5-96940 (JP 5-96940 A) describes an air-conditioning system that includes an interior air heat exchanger and that is able to carry out heating mode operation and cooling mode operation with the use of a four-way valve.

[0005] In recent years, hybrid vehicles, fuel cell vehicles, electric vehicles, and the like, that run with driving force of a motor become a focus of attention as one of measures against environmental issues. In such vehicles, electrical devices, such as a motor, a generator, an inverter, a converter and a battery, exchange electric power to generate heat. Therefore, these electrical devices need to be cooled. Then, there is suggested a technique for cooling a heat generator by utilizing a vapor compression refrigeration cycle that is used as a vehicle air-conditioning system.

[0006] For example, Japanese Patent Application Publication No. 2005-90862 (JP 2005-90862 A) describes a cooling system in which heat generator cooling means for cooling a heat generator is provided in a bypass passage that bypasses a decompressor, an evaporator and a compressor of an air-conditioning refrigeration cycle. Japanese Patent Application Publication No. 2007-69733 (JP 2007-69733 A) describes a system in which a heat exchanger that exchanges heat with air-conditioning air and a heat exchanger that exchanges heat with a heat generator are arranged in parallel in a refrigerant line from an expansion valve to a compressor and then the heat generator is cooled by utilizing refrigerant for an air-conditioning system.

[0007] Japanese Patent Application Publication No. 2000-198347 (JP 2000-198347 A) describes a heat pump air-conditioning system that improves heating performance by recovering waste heat from a motor with the use of coolant and then transferring heat from coolant to refrigerant. Japanese Patent Application Publication No. 9-290622 (JP 9-290622 A) describes a technique for effectively improving heating performance at the time of a low outside air temperature while suppressing an increase in electric power consumption by recovering waste heat from a heat generating portion mounted on a vehicle and then causing refrigerant for gas injection to absorb heat.

[0008] In the cooling system described in JP 2005-90862 A, it is required to operate the compressor in order to circulate refrigerant in the vapor compression refrigeration cycle and, in addition, it is required to constantly drive a pump in order to cool a heat generator by supplying refrigerant to the heat generator. Therefore, there is a problem that a fuel consumption and/or an electric power consumption deteriorate.

SUMMARY OF THE INVENTION

[0009] The invention provides a cooling system that is able, to efficiently cool a heat generating source at a lower power during both cooling and heating.

[0010] An aspect of the invention provides a cooling system that cools a heat generating source. The cooling system includes: a compressor that is configured to compress refrigerant; a first heat exchanger and a second heat exchanger that are configured to exchange heat between the refrigerant and outside air; a first decompressor that is configured to decompress the refrigerant; a third heat exchanger that is configured to exchange heat between the refrigerant and air-conditioning air; a reservoir that is configured to store the refrigerant in a liquid phase, condensed in the first heat exchanger or the second heat exchanger; and a cooling portion that is configured to cool the heat generating source using the refrigerant in a liquid phase. The cooling system further includes a first selector valve. The first selector valve is configured to switch between flow of the refrigerant from the first heat exchanger toward the cooling portion via the reservoir and flow of the refrigerant from the second heat exchanger toward the cooling portion via the reservoir. The cooling system further includes: a first line that provides fluid communication between the first heat exchanger and the reservoir; a second line that provides fluid communication between the second heat exchanger and the reservoir; a third line through which the refrigerant in a liquid phase flows from the reservoir toward the cooling portion; a first flow regulating valve that is provided in the first line and that is configured to adjust a flow rate of the refrigerant flowing through the cooling portion; and a second flow regulating valve that is provided in the second line and that is configured to adjust the flow rate of the refrigerant flowing through the cooling portion. The cooling system further includes: a fourth line; a fifth line; and a second selector valve. The fourth line provides fluid communication between an outlet side of the cooling portion and the first line between the first heat exchanger and the first flow regulating valve. The fifth line provides fluid communication between the outlet side of the cooling portion and the second line between the second heat exchanger and the second flow regulating valve. The second selector valve is configured to switch between flow of the refrigerant from the cooling portion toward the first heat exchanger via the fourth line and flow of the refrigerant from the cooling portion toward the second heat exchanger via the fifth line.

[0011] The cooling system may include: a sixth line; a communication line; and an on-off valve. The sixth line constitutes a path of the refrigerant flowing into or flowing out from the first heat exchanger together with the first line. The communication line provides fluid communication between the outlet side of the cooling portion and the sixth line. The on-off valve is configured to open or close the communication line.

[0012] In the cooling system, the heat generating source may be arranged below the first heat exchanger.

[0013] In the cooling system, the first heat exchanger may have a higher heat radiation performance for releasing heat from the refrigerant than the second heat exchanger.

[0014] The cooling system may further include an interior condenser that is arranged on a downstream side of flow of air-conditioning air with respect to the third heat exchanger and that is configured to transfer heat from the refrigerant compressed in the compressor to the air-conditioning air to thereby heat the air-conditioning air.

[0015] The cooling system may further include a second decompressor that is provided in a path of the refrigerant flowing from the compressor to the second heat exchanger via the first selector valve and that is configured to decompress the refrigerant; and a branching line that is configured to branch part of the refrigerant decompressed in the second decompressor and to flow the part of the refrigerant to the third heat exchanger.

[0016] With the above-described cooling system, it is possible to efficiently cool the heat generating source at a low power during both cooling operation and heating operation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Features, advantages, and technical and industrial significance of exemplary embodiments of the invention will be described below with reference to the accompanying drawings, in which like numerals denote like elements, and wherein:

[0018] FIG. **1** is a schematic view that shows the configuration of a cooling system according to an embodiment that is one example of the invention;

[0019] FIGS. **2**A and **2**B are views that show settings of a compressor and valves in each operation mode of the cooling system according to the embodiment;

[0020] FIG. **3** is a Mollier chart that shows the state of refrigerant in a vapor compression refrigeration cycle in a first operation mode of the cooling system according to the embodiment;

[0021] FIG. **4** is a schematic view that shows the operation of the cooling system in a second operation mode of the cooling system according to the embodiment;

[0022] FIG. **5** is a Mollier chart that shows the state of refrigerant in the vapor compression refrigeration cycle in the second operation mode;

[0023] FIG. **6** is a schematic view, that shows the operation of the cooling system in a third operation mode of the cooling system according to the embodiment;

[0024] FIG. **7** is a Mollier chart that shows the state of refrigerant in the vapor compression refrigeration cycle in the third operation mode;

[0025] FIG. **8** is a schematic view that shows the operation of the cooling system in a fourth operation mode of the cooling system according to the embodiment;

[0026] FIG. **9** is a schematic view that shows the configuration of part of the cooling system shown in FIG. **8**;

[0027] FIG. **10** is a Mollier chart that shows the state of refrigerant in the vapor compression refrigeration cycle in the fourth operation mode; and

[0028] FIG. **11** is a schematic view that shows the operation of the cooling system in a fifth operation mode of the cooling system according to the embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS

[0029] Hereinafter, an embodiment of the invention will be described with reference to the accompanying drawings. Note that like reference numerals denote the same or corresponding portions in the drawings and the description thereof is not repeated.

Configuration of Cooling System 1

[0030] FIG. **1** is a schematic view that shows the configuration of a cooling system **1**. As shown in FIG. **1**, the cooling system **1** includes a vapor compression refrigeration cycle **10**. The vapor compression refrigeration cycle **10** is, for example, mounted on a vehicle in order to cool or heat the cabin of the vehicle. Cooling using the vapor compression refrigeration cycle **10** is performed, for example, when a switch for cooling is turned on or when an automatic control mode in which the temperature in the cabin of the vehicle is automatically adjusted to a set temperature is selected and the temperature in the cabin is higher than the set temperature. Heating using the vapor compression refrigeration cycle **10** is performed, for example, when a switch for heating is turned on or when the automatic control mode is selected and the temperature in the cabin is lower than the set temperature.

[0031] The vapor compression refrigeration cycle **10** includes a compressor **12**, a heat exchanger **14** that serves as a first heat exchanger, a heat exchanger **15** that serves as a second heat exchanger, an expansion valve **16** that is an example of a decompressor, a heat exchanger **18** that serves as a third heat exchanger, and a heat exchanger **13** that serves as an interior condenser.

[0032] The compressor **12** is actuated by a motor or engine equipped for the vehicle as a power source, and adiabatically compresses refrigerant gas to obtain superheated refrigerant gas. The compressor **12** introduces and compresses gaseous refrigerant flowing during operation of the vapor compression refrigeration cycle **10**, and discharges high-temperature and high-pressure gaseous refrigerant. The compressor **12** discharges refrigerant to the refrigerant line **21** to thereby circulate refrigerant in the vapor compression refrigeration cycle **10**.

[0033] Each of the heat exchangers **14** and **15** includes tubes and fins. The tubes flow refrigerant. The fins are used to exchange heat between refrigerant flowing through the tubes and air around the heat exchanger **14** or **15**. The heat exchangers **14** and **15** exchange heat between refrigerant and outside air, and cause superheated refrigerant gas, compressed in the compressor **12**, to release heat to an external medium with a constant pressure and to become refrigerant liquid. Owing to heat exchange between cooling air and refrigerant in the heat exchangers **14** and **15**, the temperature of refrigerant decreases, and refrigerant liquefies. Outside air may be supplied to the heat exchangers **14** and **15** by natural draft that is generated as the vehicle runs. Alternatively, outside air may be supplied to the heat exchangers **14** and **15** by forced draft from a cooling fan (not shown), such as a condenser fan and an engine cooling radiator fan.

[0034] The expansion valve **16** causes high-pressure liquid refrigerant to be sprayed through a small hole to expand into low-temperature and low-pressure atomized refrigerant. The expansion valve **16** decompresses condensed refrigerant liquid into wet steam in a gas-liquid mixing state. Note that a decompressor for decompressing refrigerant liquid is not limited to the expansion valve **16** that carries out throttle expansion; instead, the decompressor may be a capillary tube.

[0035] The expansion valve **16** may be a thermal expansion valve of which the valve opening degree is determined by a balance between a pressure difference between refrigerant at an outlet of the expansion valve **16** and refrigerant at an outlet of the heat exchanger **18** and a spring force. The valve opening degree of the thermal expansion valve is controlled such that a degree of superheat of refrigerant at the outlet of the heat exchanger **18** is constant. For example, when a degree of superheat of refrigerant at the outlet of the heat exchanger **18** is high, the pressure difference in refrigerant increases. In this case, the valve opening degree increases to increase the flow rate of refrigerant. By so doing, it is possible to reduce a degree of superheat of refrigerant. Conversely, when a degree of superheat of refrigerant at the outlet of the heat exchanger **18** is low, the valve opening degree reduces to reduce the flow rate of refrigerant. By so doing, it is possible to increase a degree of superheat of refrigerant. The expansion valve **16** is not limited to a thermal expansion valve. An electric expansion valve may be employed as the expansion valve **16**.

[0036] Each of the heat exchangers **13** and **18** includes tubes and fins. The tubes flow refrigerant. The fins are used to exchange heat between refrigerant flowing through the tubes and air around the heat exchanger **13** or **18**. The heat exchangers **13** and **18** exchange heat between refrigerant and air-conditioning air flowing through the duct **90** The temperature of air-conditioning air is adjusted by heat exchange between refrigerant that circulates in the vapor compression refrigeration cycle **10** via the heat exchangers **13** and **18** and air-conditioning air. Air-conditioning air may be outside air or may be air in the cabin of the vehicle.

[0037] The vapor compression refrigeration cycle **10** includes an accumulator **85** that is provided in a path of refrigerant on the upstream side of the compressor **12**. The accumulator **85** is provided in order to keep the state of refrigerant, which is introduced into the compressor **12**, constant. The accumulator **85** has the function of, when refrigerant flowing into the accumulator **85** is in a gas-liquid two-phase state, separating refrigerant into gas and liquid, storing refrigerant liquid in the accumulator **85** and returning gaseous refrigerant in a saturated steam state to the compressor **12**. The accumulator **85** introduces only gaseous refrigerant steam into the compressor **12**, and serves to prevent refrigerant liquid from flowing into the compressor **12**.

[0038] The vapor compression refrigeration cycle **10** further includes refrigerant lines **21** to **29**. The refrigerant line **21** provides fluid communication between the compressor **12** and the heat exchanger **13**. Refrigerant flows from the compressor **12** toward the heat exchanger **13** between the compressor **12** and the heat exchanger **13** via the refrigerant line **21**. The refrigerant line **22** provides fluid communication between the heat exchanger **13** and the heat exchanger **14**. Refrigerant flows from the heat exchanger **13** toward the heat exchanger **14** between the heat exchanger **13** and the heat exchanger **14** via the refrigerant line **22**. The refrigerant lines **23** and **24** provide fluid communication between the heat exchanger **14** and the heat exchanger **15**. Refrigerant flows from one of the heat exchanger **14** and the heat exchanger **15** toward the other between the heat exchanger **14** and the heat exchanger **15** via the refrigerant lines **23** and **24**.

[0039] The refrigerant line **25** provides fluid communication between the heat exchanger **15** and the expansion valve **16**. Refrigerant flows from the heat exchanger **15** toward the expansion valve **16** between the heat exchanger **15** and the expansion valve **16** via the refrigerant line **25**. An on-off, valve **44** that is able to open or close the refrigerant line **25** is provided in the refrigerant line **25**. The on-off valve **44** switches between the open state and the closed state to thereby switch between fluid communication and interruption of the refrigerant line **25**. By so doing, the on-off valve **44** allows or prohibits flow of refrigerant through the refrigerant line **25**.

[0040] The refrigerant line **26** provides fluid communication between the expansion valve **16** and the heat exchanger **18**. Refrigerant flows from the expansion valve **16** toward the heat exchanger **18** between the expansion valve **16** and the heat exchanger **18** via the refrigerant line **26**. The refrigerant line **27** provides fluid communication between the heat exchanger **18** and the expansion valve **16**. Refrigerant flows from the heat exchanger **18** toward the expansion valve **16** between the heat exchanger **18** and the expansion valve **16** via the refrigerant line **27**.

[0041] The refrigerant line **28** provides fluid communication between the expansion valve **16** and the accumulator **85**. Refrigerant flows from the expansion valve **16** toward the accumulator **85** between the expansion valve **16** and the accumulator **85** via the refrigerant line **28**. The refrigerant line **29** provides fluid communication between the accumulator **85** and the compressor **12**. Refrigerant flows from the accumulator **85** toward the compressor **12** between the heat exchanger **18** and the compressor **12** via the refrigerant line **29**.

[0042] The vapor compression refrigeration cycle **10** is formed such that the compressor **12**, the heat exchangers **13**, **14**, **15**, the expansion valve **16** and the heat exchanger **18** are coupled by the refrigerant lines **21** to **29**. Note that refrigerant used in the vapor compression refrigeration cycle **10** may be, for example, carbon dioxide, hydrocarbon, such as propane and isobutane, ammonia, chlorofluorocarbons, water, or the like.

[0043] The vapor compression refrigeration cycle **10** further includes a gas-liquid separator **80**. The gas-liquid separator **80** is arranged in a path of refrigerant between the heat exchanger **14** and the heat exchanger **15**. The gas-liquid separator **80** separates refrigerant flowing into the gas-liquid separator **80** into gaseous refrigerant and liquid refrigerant. Refrigerant liquid that is liquid refrigerant and refrigerant steam that is gaseous refrigerant are stored inside the gas-liquid separator **80**. The refrigerant lines **23** and **24** and a refrigerant line **33** (described later) are coupled to the gas-liquid separator **80**.

[0044] Refrigerant condensed in the heat exchanger **14** is in a wet steam gas-liquid two-phase state, mixedly containing saturated liquid and saturated steam. Refrigerant flowing out from the heat exchanger **14** is supplied to the gas-liquid separator **80** through the refrigerant line **23**. Refrigerant flowing from the refrigerant line **23** into the gas-liquid separator **80** is separated into gas and liquid inside the gas-liquid separator **80**. The gas-liquid separator **80** separates refrigerant into liquid-state refrigerant liquid and gaseous refrigerant steam and temporarily stores them. The gas-liquid separator **80** has the function of a reservoir that temporarily stores refrigerant liquid that is liquid refrigerant inside. Thus, the gas-liquid separator **80** is also referred to as the reservoir **80**.

[0045] The path of refrigerant that flows between the heat exchanger **14** and the heat exchanger **15** includes the refrigerant line **23** and the refrigerant line **24**. The refrigerant line **23** serves as a first line that provides fluid communication between the heat exchanger **14** and the gas-liquid separator **80**. The refrigerant line **24** serves as a second line that provides fluid communication between the gas-liquid separator **80** and the heat exchanger **15**. A flow regulating valve **42** that serves as a first flow regulating valve is provided in the refrigerant line **23**. The refrigerant line **23** includes a refrigerant line **23*a*** and a refrigerant line **23*b***. The refrigerant line **23*a*** provides fluid communication between the heat exchanger **14** and the flow regulating valve **42**. The refrigerant line **23*b*** provides fluid communication between the flow regulating valve **42** and the gas-liquid separator **80**. A flow regulating valve **43** that serves as a second flow regulating valve is provided in the refrigerant line **24**. The refrigerant line **24** includes a refrigerant line **24*a*** and a refrigerant line **24*b***. The refrigerant line **24*a*** provides fluid communication between the gas-liquid separator **80** and the flow regulating valve **43**. The refrigerant line **24***b* provides fluid communication between the flow regulating valve **43** and the heat exchanger **15**.

[0046] The path of refrigerant flowing between the heat exchanger **14** and the heat exchanger **15** further includes the refrigerant line **33** that serves as a third line, a refrigerant line **34** that serves as a fourth line, and a refrigerant line **35** that serves as a fifth line. The refrigerant line **33** provides fluid communication between the gas-liquid separator **80** and the inlet side of a cooling portion **30**. The refrigerant line **34** provides fluid communication between the outlet side of the cooling portion **30** and the refrigerant line **23***a*. The refrigerant line **35** provides fluid communication between the outlet side of the cooling portion **30** and the refrigerant line **24***b*. The cooling portion **30** is provided in the path of refrigerant flowing between the heat exchanger **14** and the heat exchanger **15**. Liquid refrigerant flows from the gas-liquid separator **80** toward the cooling portion **30** via the refrigerant line **33**. Refrigerant passing through the cooling portion **30** returns to the refrigerant line **24***b* via the refrigerant line **35** or returns to the refrigerant line **23***a* via the refrigerant line **34**.

[0047] Refrigerant liquid separated by the gas-liquid separator **80** flows out to the outside of the gas-liquid separator **80** via the refrigerant line **33**. The end portion of the refrigerant line **33** is connected to a refrigerant liquid storage portion in which liquid refrigerant is stored inside the gas-liquid separator **80**, and forms an outlet port through which liquid refrigerant flows out from the gas-liquid separator **80**. Refrigerant steam separated by the gas-liquid separator **80** flows out to the outside of the gas-liquid separator **80** via the refrigerant line **23** or the refrigerant line **24**. The end portions of the refrigerant lines **23** and **24** are connected to a refrigerant steam storage portion in which gaseous refrigerant is stored in the gas-liquid separator **80**. One of the end portions forms an inlet port through which refrigerant flows into the gas-liquid separator **80**, and the other one of the end portions forms an outlet port through which gaseous refrigerant flows out from the gas-liquid separator **80**. The refrigerant lines **23** and **24** form lines through which gaseous refrigerant separated in the gas-liquid separator **80** flows out from the gas-liquid separator **80**.

[0048] Inside the gas-liquid separator **80**, the refrigerant liquid accumulates at the lower side and the refrigerant steam accumulates at the upper side. The end portions of the refrigerant lines **23** and **24** are coupled to the ceiling portion of the gas-liquid separator **80**. The end portion of the refrigerant line **33** is coupled to the bottom portion of the gas-liquid separator **80**. Refrigerant in a gas-liquid two-phase state is supplied to the inside of the gas-liquid separator **80** via any one of the refrigerant lines **23** and **24**, only refrigerant steam is delivered to the outside of the gas-liquid separator **80** from the ceiling side of the gas-liquid separator **80** via the other one of the refrigerant lines **23** and **24**, and only refrigerant liquid is delivered to the outside of the gas-liquid separator **80** from the bottom side of the gas-liquid separator **80** via the refrigerant line **33**. By so doing, the gas-liquid separator **80** is able to reliably separate gaseous refrigerant and liquid refrigerant from each other.

[0049] The cooling system **1** includes two refrigerant paths connected in parallel between the heat exchangers **14** and **15**. More specifically, the cooling system **1** includes two refrigerant paths connected in parallel between the heat exchanger **14** and the gas-liquid separator **80** and two refrigerant paths connected in parallel between the heat exchanger **15** and the gas-liquid separator **80**.

[0050] The cooling portion **30** is provided in one of the plurality of refrigerant paths connected in parallel between the heat exchanger **14** and the heat exchanger **15**. The cooling portion **30** includes an electric vehicle (EV) device **31** and a cooling line **32**. The EV device **31** is an electrical device mounted on the vehicle. The cooling line **32** is a line through which refrigerant flows. The EV device **31** is an example of a heat generating source. The inlet-side end portion of the cooling line **32** is connected to the refrigerant line **33**. The outlet-side end portion of the cooling line **32** is in fluid communication with the refrigerant lines **34** and **35**.

[0051] The refrigerant line **23** constitutes one of the refrigerant paths connected in parallel between the heat exchanger **14** and the gas-liquid separator **80**. The refrigerant line **33** that provides fluid communication between the gas-liquid separator **80** and the cooling portion **30**, the cooling line **32** that is included in the cooling portion **30** and the refrigerant line **34** that provides fluid communication between the outlet side of the cooling portion **30** and the refrigerant line **23***a* constitute the other one of the refrigerant paths connected in parallel between the heat exchanger **14** and the gas-liquid separator **80**. The refrigerant line **33** is a refrigerant path on the upstream side of the cooling portion **30**, and refrigerant flows into the cooling portion **30** via the refrigerant line **33**. The refrigerant line **33** is a line through which liquid refrigerant flows from the gas-liquid separator **80** to the cooling portion **30**. The refrigerant line **34** is a refrigerant path on the downstream side of the cooling portion **30**, and refrigerant flows out from the cooling portion **30** and flows into the refrigerant line **34**. The refrigerant line **34** is a line through which refrigerant is returned from the cooling portion **30** to the refrigerant line **23**.

[0052] The refrigerant line **24** constitutes one of the refrigerant paths connected in parallel between the heat exchanger **15** and the gas-liquid separator **80**. The refrigerant line **33** that provides fluid communication between the gas-liquid separator **80** and the cooling portion **30**, the cooling line **32** that is included in the cooling portion **30** and the refrigerant line **35** that provides fluid communication between the outlet side of the cooling portion **30** and the refrigerant line **24***b* constitute the other one of the refrigerant paths connected in parallel between the heat exchanger **15** and the gas-liquid separator **80**. The refrigerant line **35** is a refrigerant path on the downstream side of the cooling portion **30**, and refrigerant flows out from the cooling portion **30** and flows into the refrigerant line **35**. The refrigerant line **35** is a line through which refrigerant is returned from the cooling portion **30** to the refrigerant line **24**.

[0053] Refrigerant liquid flowing out from the gas-liquid separator **80** flows toward the cooling portion **30** via the refrigerant line **33**. Refrigerant that flows to the cooling portion **30** and that flows via the cooling line **32** takes heat from the EV device **31**, which serves as the heat generating source, to cool the EV device **31** in accordance with a temperature difference between the EV device **31**, which serves as the heat generating source, and refrigerant. The cooling portion **30** uses refrigerant in a saturated liquid state, separated in the gas-liquid separator **80**, to cool the EV device **31**. Refrigerant flowing through the cooling line **32** exchanges heat with the EV device **31** in the cooling portion **30** to cool the EV device **31**, and the refrigerant is heated.

[0054] Refrigerant liquid in a saturated liquid state is stored inside the gas-liquid separator **80**. The gas-liquid separator **80** functions as a reservoir that temporarily stores refrigerant liquid that is liquid refrigerant inside. When refrigerant liquid in a predetermined amount is stored in the gas-liquid separator **80**, the flow rate of refrigerant flowing from the gas-liquid separator **80** to the cooling portion **30** may be maintained at the time of fluctuations in load. Because the gas-liquid separator **80** has the function of storing liquid, serves as a buffer against load fluctuations and is able to absorb load fluctuations, the cooling performance for cooling the EV device **31** may be stabilized.

[0055] The cooling portion **30** is configured to be able to exchange heat between the EV device **31** and refrigerant in the cooling line **32**. In the present embodiment, the cooling portion **30**, for example, has the cooling line **32** that is formed such that the outer periphery of the cooling line **32** is in direct contact with the casing of the EV device **31**. The cooling line **32** has a portion adjacent to the casing of the EV device **31**. At that portion, heat is exchangeable between refrigerant, flowing through the cooling line **32**, and the EV device **31**.

[0056] The EV device **31** is directly connected to the outer periphery of the cooling line **32** that forms part of the refrigerant path between the heat exchanger **14** and the heat exchanger **15** in the vapor compression refrigeration cycle **10**, and is cooled. Refrigerant and the EV device **31** may directly exchange heat with each other or refrigerant and secondary medium, such as water or oil flowing through the EV device **31**, may exchange heat with each other. The EV device **31** is arranged on the outside of the cooling line **32**, so the EV device **31** does not interfere with flow of refrigerant flowing inside the cooling line **32**. Therefore, the pressure loss of the vapor compression refrigeration cycle **10** does not increase, so the EV device **31** may be cooled without increasing the power of the compressor **12**.

[0057] Alternatively, the cooling portion **30** may include a selected known heat transfer device that is interposed between the EV device **31** and the cooling line **32**. In this case, the EV device **31** is connected to the outer periphery of the cooling line **32** via the heat transfer device, and heat is transferred from the EV device **31** to the cooling line **32** via the heat transfer device to thereby cool the EV device **31**. For example, a Wick heating pipe may be used as the heat transfer device. The EV device **31** serves as a heating portion for heating the heat pipe, and the cooling line **32** serves as a cooling portion for cooling the heat pipe to thereby increase the heat-transfer efficiency between the cooling line **32** and the EV device **31**, so it is possible to improve the cooling efficiency of the EV device **31**.

[0058] The heat transfer device is able to reliably transfer heat from the EV device **31** to the cooling line **32**, so there may be a distance between the EV device **31** and the cooling line **32**, and complex arrangement of the cooling line **32** is not required to bring the cooling line **32** into contact with the EV device **31**. As a result, arrangement of the EV device **31** is not restricted, and it is possible to improve the flexibility of arrangement of the EV device **31**.

[0059] The EV device **31** includes an electrical device that exchanges electric power to generate heat. The electrical device includes at least any one of, for example, an inverter used to convert direct-current power to alternating-current power, a motor generator that is a rotating electrical machine, a battery that is an electrical storage device, a step-up converter that is used to step up the voltage of the battery and a DC/DC converter that is used to step down the voltage of the battery. The battery is a secondary battery, such as a lithium ion battery and a nickel metal hydride battery. A capacitor may be used instead of the battery.

[0060] An on-off valve **37** that is able to open or close the refrigerant line **34** is provided in the refrigerant line **34**. The on-off valve **37** switches between the open state and the closed state to thereby switch between fluid communication and interruption of the refrigerant line **34**. By so doing, the on-off valve **37** allows or prohibits flow of refrigerant through the refrigerant line **34**. The on-off valve **37** is provided in the refrigerant line **34** that is the path of refrigerant flowing out from the cooling portion **30**, and has the function of a first on-off valve that is able to open or close the refrigerant line **34**.

[0061] An on-off valve **38** that is able to open or close the refrigerant line **35** is provided in the refrigerant line **35**. The on-off valve **38** switches between the open state and the closed state to thereby switch between fluid communication and interruption of the refrigerant line **35**. By so doing, the on-off valve **38** allows or prohibits flow of refrigerant through the refrigerant line **35**. The on-off valve **38** is provided in the refrigerant line **35** that is the path of refrigerant flowing out from the cooling portion **30**, and has the function of a second on-off valve that is able to open or close the refrigerant line **35**.

[0062] The on-off valve **37** and the on-off valve **38** constitute a selector valve **36** that serves as a second selector valve. The selector valve **36** switches between flow of refrigerant from the cooling portion **30** toward the heat exchanger **14** via the refrigerant line **34** and flow of refrigerant from the cooling portion **30** toward the heat exchanger **15** via the refrigerant line **35**. The configuration is not limited to the example in which the selector valve **36** is formed of the two on-off valves **37** and **38**. For example, it is applicable that a three-way valve connected to a branching point between the refrigerant lines **34** and **35** is provided and then the three-way valve switches between the open state and the closed state to thereby function as the selector valve **36**.

[0063] The flow regulating valve **42** is provided in the refrigerant line **23** that forms one of the refrigerant paths, which does not pass through the cooling portion **30**, between the refrigerant paths connected in parallel between the heat exchanger **14** and the gas-liquid separator **80**. The flow regulating valve **42** changes its valve opening degree to increase or reduce the pressure loss of refrigerant flowing through the flow regulating valve **42**. By so doing, the flow regulating valve **42** selectively adjusts the flow rate of refrigerant directly flowing between the gas-liquid separator **80** and the heat exchanger **14** without passing through the cooling portion **30** and the flow rate of refrigerant flowing via the cooling system for cooling the EV device **31**, including the cooling line **32**.

[0064] When the valve opening degree of the flow regulating valve **42** is increased, the flow rate of refrigerant that flows directly to the heat exchanger **14** via the refrigerant line **23** increases and the flow rate of refrigerant that flows to the cooling line **32** via the refrigerant line **33** to cool the EV device **31** reduces within refrigerant that flows from the gas-liquid separator **80** to the heat exchanger **14**. When the valve opening degree of the flow regulating valve **42** is reduced, the flow rate of refrigerant that directly flows to the heat exchanger **14** via the refrigerant line **23** reduces and the flow rate of refrigerant that flows to the cooling line **32** to cool the

EV device **31** increases within refrigerant that flows from the gas-liquid separator **80** to the heat exchanger **14**.

[0065] The flow regulating valve **43** is provided in the refrigerant line **24** that forms one of the refrigerant path, which does not pass through the cooling portion **30**, between the refrigerant paths connected in parallel between the gas-liquid separator **80** and the heat exchanger **15**. The flow regulating valve **43** changes its valve opening degree to increase or reduce the pressure loss of refrigerant flowing through the flow regulating valve **43**. By so doing, the flow regulating valve **43** selectively adjusts the flow rate of refrigerant directly flowing between the gas-liquid separator **80** and the heat exchanger **15** without passing through the cooling portion **30** and the flow rate of refrigerant flowing via the cooling system for cooling the EV device **31**, including the cooling line **32**.

[0066] When the valve opening degree of the flow regulating valve **43** is increased, the flow rate of refrigerant that flows directly to the heat exchanger **15** via the refrigerant line **24** increases and the flow rate of refrigerant that flows to the cooling line **32** via the refrigerant line **33** to cool the EV device **31** reduces within refrigerant that flows from the gas-liquid separator **80** to the heat exchanger **15**. When the valve opening degree of the flow regulating valve **43** is reduced, the flow rate of refrigerant that directly flows to the heat exchanger **15** via the refrigerant line **24** reduces and the flow rate of refrigerant that flows to the cooling line **32** to cool the EV device **31** increases within refrigerant that flows from the gas-liquid separator **80** to the heat exchanger **15**.

[0067] As the valve opening degrees of the flow regulating valves **42** and **43** are increased, the flow rate of refrigerant that cools the EV device **31** reduces, so cooling performance for cooling the EV device **31** decreases. As the valve opening degrees of the flow regulating valves **42** and **43** reduce, the flow rate of refrigerant that cools the EV device **31** increases, so cooling performance for cooling the EV device **31** improves. The flow regulating valves **42** and **43** are used to make it possible to optimally adjust the amount of refrigerant flowing to the EV device **31**, so it is possible to appropriately control the temperature of the EV device **31** and, therefore, it is possible to reliably prevent excessive heating and excessive cooling of the EV device **31**. In addition, it is possible to reliably reduce pressure loss associated with flow of refrigerant in the cooling system for cooling the EV device **31** and the power consumption of the compressor **12** for circulating refrigerant.

[0068] The heat exchangers **13** and **18** are arranged inside the duct **90** through which air-conditioning air flows. The duct **90** has a duct inlet **91** and a duct outlet **92**. The duct inlet **91** is an inlet through which air-conditioning air flows into the duct **90**. The duct outlet **92** is an outlet through which air-conditioning air flows out from the duct **90**. A fan **93** is arranged near the duct inlet **91** inside the duct **90**.

[0069] By driving the fan **93**, flow of air is generated inside the duct **90**. As the fan **93** operates, air-conditioning air flows into the duct **90** via the duct inlet **91**. The heat exchanger **18** is arranged at the upstream side of flow of air-conditioning air inside the duct **90**, and the heat exchanger **13** is arranged at the downstream side of flow of air-conditioning air inside the duct **90**. Air flowing into the duct **90** may be outside air or may be air in the cabin of the vehicle. The arrow **97** in FIG. **1** indicates flow of air-conditioning air that flows via the heat exchanger **18**. The arrow **98** indicates flow of air-conditioning air that flows out from the duct **90** via the duct outlet **92**.

[0070] A partition wall **94** is arranged inside the duct **90**. The partition wall **94** partitions the internal space of the duct **90** into two spaces. The partition wall **94** extends in a direction in which air flows inside the duct **90**, and separates flow of air-conditioning air flowing inside the duct **90** into two flows. The heat exchanger **18** is arranged at the upstream side of flow of air-conditioning air with respect to the partition wall **94**. The heat exchanger **13** is arranged in one of the two spaces partitioned by the partition wall **94**.

[0071] A damper **96** is provided on the upstream side of the partition wall **94**. The damper **96** has the function of a flow regulating unit that adjusts the flow rate of air-conditioning air flowing to each of the two spaces partitioned by the partition wall **94**. An actuator **95** that drives the damper **96** is provided at the upstream-side end portion of the partition wall **94**. The damper **96** is supported by the actuator **95** at its one end, and is rotatable in both directions about an axis that coincides with the one end. In response to arrangement of the damper **96**, the case where air-conditioning air flows via the heat exchanger **13** and the case where air-conditioning air flows while bypassing the heat exchanger **13** are switched, and the temperature of air-conditioning air at the duct outlet **92** is adjusted.

[0072] In the arrangement of the damper **96** shown in FIG. **1**, the damper **96** blocks flow of air-conditioning air flowing toward the heat exchanger **13**. Therefore, air-conditioning air flows inside the duct **90** without passing through the heat exchanger **13**. In this case, air-conditioning air is prevented from being heated by the heat exchanger **13**, and air-conditioning air is kept at a low temperature. On the other hand, in the arrangement of the damper **96** shown in FIG. **4** (described later), the damper **96** guides flow of air-conditioning air toward the heat exchanger **13**. In, this case, heat is transferred from refrigerant adiabatically compressed in the compressor **12** to air-conditioning air at the heat exchanger **13**, and air-conditioning air is heated.

[0073] The flow regulating unit for adjusting the flow rate of air-conditioning air that passes through the heat exchanger **13** is not limited to the damper **96**. For example, it is applicable that a roll screen flow regulating unit is installed inside the duct **90** and then flow of air-conditioning air is controlled by changing the take-up amount of screen.

[0074] The cooling system **1** further includes a three-way valve **41** that serves as a first selector valve. The refrigerant line **22** that provides fluid communication between the heat exchanger **13** and the heat exchanger **14** includes a refrigerant line **22***a* and a refrigerant line **22***b*. The refrigerant line **22***a* provides fluid communication between the heat exchanger **13** and the three-way valve **41**. The refrigerant line **22***b* provides fluid communication between the three-way valve **41** and the heat exchanger **14**. The cooling system **1** further includes a refrigerant line **71**, an expansion valve **76** and refrigerant lines **72**, **73** and **74**. The refrigerant line **71** is coupled to the three-way valve **41**. The expansion valve **76** decompresses refrigerant flowing through the refrigerant line **71**. Refrigerant throttle-expanded by the expansion valve **76** flows through the refrigerant lines **72**, **73** and **74**. The three-way valve **41** that has three line connecting ports is coupled to the refrigerant line **22***a*, the refrigerant line **22***b* and the refrigerant line **71**. The refrigerant line **22***a* is connected to the first line connecting port of the three-way valve **41**. The refrigerant line **22***b* is connected to the second line connecting port of the three-way valve **41**. The refrigerant line **71** is connected to the third line connecting port of the three-way valve **41**.

[0075] The refrigerant lines **73** and **74** are refrigerant paths that branch off from the refrigerant line **72**. The refrigerant line **73** that serves as a first branching line provides fluid communication between the refrigerant line **72** and the refrigerant line **25**. An on-off valve **77** that is able to open or close the refrigerant line **73** is provided in the refrigerant line **73**. The on-off valve **77** switches between the open state and the closed state to thereby switch between fluid communication and interruption of the refrigerant line **73**. By so doing, the on-off valve **77** allows or prohibits flow of refrigerant through the refrigerant line **73**. The refrigerant line **74** that serves as a second branching line provides fluid communication between the refrigerant line **72** and the refrigerant line **26**. An on-off valve **78** that is able to open or close the refrigerant line **74** is provided in the refrigerant line **74**. The on-off valve **78** switches between the open state and the closed state to thereby switch between fluid communication and interruption of the refrigerant line **74**. By so doing, the on-off valve **78** allows or prohibits flow of refrigerant through the refrigerant line **74**.

[0076] The refrigerant lines **71**, **72** and **73** provide fluid communication between the refrigerant line **22** that is the refrigerant path between the heat exchanger **13** and the heat exchanger **14** and the refrigerant line **25** that is the refrigerant path between the heat exchanger **15** and the expansion valve **16**. The refrigerant lines **71**, **72** and **74** provide fluid communication between the refrigerant line **22** and the refrigerant line **26** that is the refrigerant path between the expansion valve **16** and the heat exchanger **18**.

[0077] The three-way valve **41** switches a fluid communication state between the refrigerant line **22***a* and the refrigerant line **22***b* and switches a fluid communication state between the refrigerant line **22***a* and the refrigerant line **71**. The three-way valve **41** switches between a first state and a second state. In the first state, the refrigerant line **22***a* and the refrigerant line **22***b* are in fluid communication with each other, and the refrigerant line **22***a* and the refrigerant line **71** are not in fluid communication with each other. In the second state, the refrigerant line **22***a* and the refrigerant line **71** are in fluid communication with each other, and the refrigerant line **22***a* and the refrigerant line **22***b* are not in fluid communication with each other.

[0078] Refrigerant adiabatically compressed in the compressor **12** passes through the refrigerant line **21**, the heat exchanger **13** and the refrigerant line **22***a* and reaches the three-way valve **41**. The refrigerant flows from the three-way valve **41** to the heat exchanger **14** via the refrigerant line **22***b*. In addition, the refrigerant flows from the three-way valve **41** to the heat exchanger **15** via the refrigerant line **71**, the expansion valve **76**, the refrigerant lines **72** and **73** and the refrigerant line **25** sequentially. In addition, the refrigerant flows from the three-way valve **41** to the heat exchanger **18** via the refrigerant line **71**, the expansion valve **76**, the refrigerant lines **72** and **74** and the refrigerant line **26** sequentially. The three-way valve **41** has the function of a path selecting unit that switches between the open state and the closed state to selectively switch between flow of refrigerant from the heat exchanger **13** toward the heat exchanger **14** and flow of refrigerant from the heat exchanger **13** toward the heat exchanger **15** and/or the heat exchanger **18**.

[0079] The expansion valve **76** has the function of another decompressor different from the expansion valve **16**, and decompresses refrigerant flowing through the refrigerant line **71**. The expansion valve **76** throttle-expands refrigerant flowing through the refrigerant line **71**, and decreases the pressure of refrigerant. By so doing, in comparison with refrigerant flowing inside the refrigerant line **71**, refrigerant flowing through the refrigerant line **72** has a lower pressure. The expansion valve **76** may be an electronic expansion valve. Alternatively, the other decompressor may not have an opening degree regulating function, and a thin capillary tube may be provided instead of the expansion valve **76**.

[0080] The cooling system **1** includes a refrigerant line **61** that provides fluid communication between the refrigerant line **22***b* and the refrigerant line **28**. The refrigerant line **22***b* that serves as a sixth line constitutes a path of refrigerant that flows into or flows out from the heat exchanger **14** together with the refrigerant line **23**. An on-off valve **64** that is able to open or close the refrigerant line **61** is provided in the refrigerant line **61**. The on-off valve **64** switches between the open state and the closed state to thereby switch between fluid communication and interruption of the refrigerant line **61**. By so doing, the on-off valve **64** allows or prohibits flow of refrigerant through the refrigerant line **61**.

[0081] A check valve **66** is further provided in the refrigerant line **61**. The check valve **66** is provided in the refrigerant line **61** at a location closer to the refrigerant line **28** than the on-off valve **64**. The check valve **66** prohibits flow of refrigerant from the refrigerant line **28** toward the on-off valve **64**. The check valve **66** is provided in order to prevent refrigerant flowing from the heat exchanger **18** via the refrigerant lines **27** and **28** from flowing into the refrigerant line **61** and to reliably flow refrigerant from the refrigerant line **28** to the accumulator **85**.

[0082] The cooling system **1** further includes a communication line **51**. The communication line **51** provides fluid communication between the refrigerant line **22***b* and the outlet side of the cooling portion **30**. The refrigerant line **22***b* provides fluid communication between the three-way valve **41** and the heat exchanger **14**. An on-off valve **52** that is able to open or close the communication line **51** is provided in the communication line **51**. The on-off valve **52** switches between the open state and the closed state to thereby switch between fluid communication and interruption of the communication line **51**. By so doing, the on-off valve **52** allows or prohibits flow of refrigerant through the communication line **51**.

[0083] By opening or closing the on-off valve **52** to switch the path of refrigerant flowing out from the cooling portion **30**, it is possible to cause refrigerant after cooling the EV device **31** to flow to the heat exchanger **14** via the communication line **51** and the refrigerant line **22***b*. That is, refrigerant flowing out from the cooling portion **30** is able to flow to the heat exchanger **14** via the refrigerant lines **34** and **23***a*; and is able to flow to the heat exchanger **15** via the refrigerant lines **35** and **24***b*, and is able to further flow to the heat exchanger **14** via the communication line **51** and the refrigerant line **22***b*.

[0084] Instead of the configuration that the on-off valve **52** is provided in the communication line **51**, a four-way valve that has four line connecting ports may be provided at a branching point among the refrigerant lines **34** and **35** and the communication line **51**. In this case, the refrigerant lines **34** and **35** and the communication line **51** are respectively connected to the line connecting ports of the four-way valve, and, by switching the settings of open/close states of the four-way valve, it is possible to select any one of the refrigerant line **34**, the refrigerant line **35** and the communication line **51** as the path of refrigerant that flows out from the cooling portion **30**.

[0085] The flow regulating valves **42** and **43** each are configured to be able to adjust its opening degree, and each may be, for example, an electric valve. The on-off valves **37**, **38**, **44**, **52**, **64**, **77** and **78** each just need to be configured to be able to switch between a fully open state and a fully closed state, and each may be, for example, an electromagnetic valve.

First Operation Mode

[0086] The cooling system **1** according to the present embodiment is able to cool the EV device **31** that serves as the heat generating source in five first to fifth operation modes. FIG. **1** shows a state where the cooling system **1** is set in the first operation mode. FIGS. **2**A and **2**B are views that show settings of the compressor and valves in each operation mode of the cooling system **1**.

[0087] FIGS. **2**A and **2**B show the operation status of the compressor **12** and settings of the opening degrees of the flow regulating valves **42** and **43**, the three-way valve **41** and the on-off valves **37**, **38**, **44**, **52**, **64**, **77** and **78** in each operation mode in the case where the cooling system **1** is operated in any one of the different five operation modes. FIG. **2**B further shows the temperature regulating action of the EV device **31** and the state of air conditioning inside the vehicle cabin using an air conditioner in each operation mode of the cooling system **1**.

[0088] Among the operation modes shown in FIGS. **2**A and **2**B, the first operation mode is an operation mode in which the vehicle cabin is cooled and dehumidified during operation of the air conditioner for cooling the cabin of the vehicle. Note that in FIG. **1** and FIG. **4**, FIG. **6**, FIG. **8** and FIG. **11** (described later), refrigerant flows through the refrigerant path indicated by the solid line, and refrigerant does not flow through the refrigerant path indicated by the dotted line.

[0089] In the first operation mode, refrigerant is required to flow through a path that includes the expansion valve **16** and the heat exchanger **18** in order to cool the vehicle cabin, so the compressor **12** is in an operating state. The flow regulating valve **42** is fully open so as to minimize the pressure loss of refrigerant flowing through the refrigerant line **23**. The flow regulating valve **43** adjusts the flow rate of refrigerant flowing through the cooling portion **30**, and the valve opening degree of the flow regulating valve **43** is adjusted such that a sufficient amount of refrigerant flows to the cooling portion **30** in order to cool the EV device **31**. The open/close state of the three-way valve **41** is switched such that the refrigerant line **22***a* and the refrigerant line **22***b* are in fluid communication with each other and the refrigerant line **71** is not in fluid communication with both the refrigerant lines **22***a* and **22***b*.

[0090] The on-off valve **37** is closed, and the refrigerant line **34** is interrupted. The on-off valve **38** is opened, and the refrigerant line **35** is set in a fluid communication state. The on-off valve **52** is closed, and the communication line **51** is interrupted. The open/close states of the selector valve **36** and on-off valve **52** are switched such that refrigerant flowing out from the cooling portion **30** flows to the refrigerant line **35** and does not flow to the refrigerant line **34** and the communication line **51**. The on-off valve **44** is opened, and the refrigerant line **25** is set in a fluid communication state. The on-off valves **64**, **77** and **78** each are closed, and the refrigerant lines **61**, **73** and **74** are interrupted.

[0091] Refrigerant passes through a refrigerant circulation path that is formed by sequentially connecting the compressor **12**, the heat exchangers **14** and **15**, the expansion valve **16** and the heat exchanger **18** by the refrigerant lines **21** to **29** to circulate in the vapor compression refrigeration cycle **10**.

[0092] During cooling operation shown in FIG. **1**, it is required to keep the temperature of air-conditioning air flowing out from the duct **90** low. Therefore, by operating the damper **96**, the path of air-conditioning air inside the duct **90** is set such that air-conditioning air does not pass through the heat exchanger **13**. By so doing, it is possible to suppress a decrease in cooling performance due to heating of air-conditioning air by the heat exchanger **13**, so it is possible to efficiently cool the cabin of the vehicle, and, therefore, it is possible to ensure cooling performance.

[0093] FIG. **3** is a Mollier chart that shows the state of refrigerant in the vapor compression refrigeration cycle **10** in the first operation mode. In FIG. **3**, the abscissa axis represents the specific enthalpy of refrigerant, and the ordinate axis represents the absolute pressure of refrigerant. The unit of the specific enthalpy is kJ/kg, and the unit of the absolute pressure is MPa. The curve in the chart is the saturation vapor line and saturation liquid line of refrigerant.

[0094] FIG. **3** shows the thermodynamic state of refrigerant at points in the vapor compression refrigeration cycle **10** when refrigerant flows from the refrigerant line **23** at the outlet of the heat exchanger **14** to the refrigerant line **33** via the gas-liquid separator **80**, flows into the cooling portion **30** to cool the EV device **31** and returns from the cooling portion **30** to the refrigerant line **24***b* at the inlet of the heat exchanger **15** via the refrigerant line **35**.

[0095] As shown in FIG. **3**, refrigerant in a saturated steam state is introduced from the accumulator **85** into the compressor **12**, and the refrigerant is adiabatically compressed in the compressor **12** along a constant specific entropy line. As refrigerant is compressed in the compressor. **12**, the refrigerant increases in pressure and temperature into high-temperature and high-pressure superheated steam having a high degree of superheat at the outlet of the compressor **12**.

[0096] High-temperature and high-pressure refrigerant in a superheated steam state, adiabatically compressed in the compressor **12**, flows to the heat exchanger **14** and is cooled in the heat exchanger **14**. High-pressure gaseous refrigerant discharged from the compressor **12** releases heat to the surroundings to be cooled in the heat exchanger **14** to thereby condense (liquefy). Through heat exchange with outside air in the heat exchanger **14**, the temperature of refrigerant decreases, and refrigerant liquefies. High-pressure refrigerant steam in the heat exchanger **14** becomes dry saturated steam from superheated steam with a constant pressure in the heat exchanger **14**, and releases latent heat of condensation to gradually liquefy into wet steam in a gas-liquid mixing state.

[0097] In the gas-liquid separator **80**, refrigerant in a gas-liquid two-phase state is separated into refrigerant steam in a saturated steam state and refrigerant liquid in a saturated liquid state. Refrigerant in a saturated liquid state flows out from the gas-liquid separator **80**, flows to the cooling line **32** of the cooling portion **30** via the refrigerant line **33**, and cools the EV device **31**. In the cooling portion **30**, heat is released to liquid refrigerant in a saturated liquid state, which is condensed in the heat exchanger **14** and is separated in the gas-liquid separator **80**, to thereby cool the EV device **31**. Refrigerant is heated by exchanging heat with the EV device **31**, and the dryness of the refrigerant increases. Refrigerant receives latent heat from the EV device **31** to partially vaporize into wet steam in a gas-liquid two-phase state, which mixedly contains saturated liquid and saturated steam at the outlet of the cooling portion **30**.

[0098] Refrigerant flowing out from the cooling portion **30** flows into the heat exchanger **15** via the refrigerant lines **35** and **24***b*. Wet steam of refrigerant releases heat to surroundings to exchange heat with outside air in the heat exchanger **15** to be cooled to thereby condense again, becomes saturated liquid as the entire refrigerant condenses, and further releases sensible heat to become supercooled liquid. Refrigerant is cooled to below a saturated temperature in the heat exchanger **15**. After that, the refrigerant flows into the expansion valve **16** via the refrigerant line **25**. In the expansion valve **16**, refrigerant in a supercooled liquid state is throttle-expanded, and the refrigerant decreases in temperature and pressure with the specific enthalpy unchanged to become low-temperature and low-pressure wet steam in a gas-liquid mixing state.

[0099] Refrigerant in a wet steam state from the expansion valve **16** flows into the heat exchanger **18** via the refrigerant line **26**. Refrigerant in a wet steam state flows into the tubes of the heat exchanger **18**. Atomized refrigerant flowing inside the heat exchanger **18** vaporizes to absorb heat of air-conditioning air that is introduced so as to contact with the heat exchanger **18**. The heat exchanger **18** uses low-temperature and low-pressure refrigerant decompressed by the expansion valve **16** to absorb heat of vaporization, which is required at the time when wet steam of refrigerant evaporates into refrigerant gas, from air-conditioning air flowing to the cabin of the vehicle to thereby cool the cabin of the vehicle. Air-conditioning air of which heat is absorbed by the heat exchanger **18** to decrease in temperature flows into the cabin of the vehicle to cool the cabin of the vehicle.

[0100] When refrigerant flows through the tubes of the heat exchanger **18**, the refrigerant absorbs heat of air-conditioning air as latent heat of vaporization via the fins to be heated and evaporate with a constant pressure. During cooling operation, air-conditioning air is cooled in the heat exchanger **18** through heat exchange between high-temperature air-conditioning air and refrigerant, the temperature of air-conditioning air decreases, and refrigerant receives heat transferred from air-conditioning air to be heated.

[0101] In response to cooling performance required to cool the vehicle cabin, the amount of heat that is exchanged between refrigerant and air-conditioning air in the heat exchanger **18** changes. In the heat exchanger **18**, refrigerant may be heated until all the refrigerant becomes superheated steam, refrigerant may be heated until all the refrigerant becomes dry saturated steam or refrigerant may be in a wet saturated steam state at the outlet of the heat exchanger **18**. When refrigerant flowing out from the heat exchanger **18** contains liquid refrigerant, refrigerant liquid is stored in the accumulator **85**, and only gaseous refrigerant steam is introduced into the compressor **12**. By so doing, refrigerant liquid is prevented from flowing into the compressor **12**. FIG. **3** shows the state of refrigerant when refrigerant in a wet saturated steam state is separated into gas and liquid in the accumulator **85** and refrigerant in a dry saturated steam state flows out from the accumulator **85** to the compressor **12** via the refrigerant line **29**.

[0102] Refrigerant continuously repeats changes among the compressed state, the condensed state, the throttle-expanded state and the evaporated state in accordance with the above-described cycle. Note that, in the above description of the vapor compression refrigeration cycle, a theoretical refrigeration cycle is described; however, in the actual vapor compression refrigeration cycle **10**, it is, of course, necessary to consider a loss in the compressor **12**, a pressure loss of refrigerant and a heat loss.

[0103] During operation of the vapor compression refrigeration cycle **10**, refrigerant absorbs heat of vaporization from air in the cabin of the vehicle at the time when the refrigerant evaporates in the heat exchanger **18** that serves as an evaporator to thereby cool the cabin. In addition, high-pressure liquid refrigerant condensed in the heat exchanger **14** and separated by the gas-liquid separator **80** flows to the cooling portion **30** and exchanges heat with the EV device **31** to thereby cool the EV device **31**. The cooling system **1** cools the EV device **31**, which is the heat generating source mounted on the vehicle, by utilizing the vapor compression refrigeration cycle **10** for air-conditioning the cabin of the vehicle. Note that the temperature required to cool the EV device **31** is desirably at least lower than the upper limit of a target temperature range of the EV device **31**.

[0104] The vapor compression refrigeration cycle **10** that is provided in order to cool a cooled portion in the heat exchanger **18** is utilized to cool the EV device **31**, so it is not necessary to provide a device, such as an exclusive water circulation pump and a cooling fan, in order to cool the EV device **31**. Therefore, components required for the cooling system **1** to cool the EV device **31** may be reduced to make it possible to simplify the system configuration, so the manufacturing cost of the cooling system **1** may be reduced. In addition, it is not necessary to operate a power source, such as a pump and a cooling fan, in order to cool the EV device **31**, and power consumption for operating the power source is not required. Thus, it is possible to reduce power consumption for cooling the EV device **31**, so it is possible to cool the EV device **31** at a low power.

[0105] In the heat exchanger **14**, refrigerant just needs to be cooled into a wet saturated steam state. Refrigerant in a saturated liquid state, which is separated by the gas-liquid separator **80**, is supplied to the cooling portion **30**. Refrigerant in a wet steam state, which receives latent heat of vaporization from the EV device **31** to be partially vaporized, is cooled again in the heat exchanger **15**. Refrigerant changes in state at a constant temperature until the refrigerant in a wet steam state completely condenses into saturated liquid. The heat exchanger **15** further supercools liquid refrigerant to a degree of supercooling required to cool the cabin of the vehicle. A degree of supercooling of refrigerant does not need to be excessively increased, so the capacity of each of the heat exchangers **14** and **15** may be reduced. Thus, the cooling performance for cooling the cabin may be ensured, and the size of each of the heat exchangers **14** and **15** may be reduced, so it is possible to obtain the cooling system **1** that is reduced in size and that is advantageous in installation on the vehicle.

[0106] At the time when the specifications of each of the heat exchangers **14** and **15** are determined in the design step of the cooling system **1**, the maximum heat generation amount of the EV device **31** is used as a designed value. During normal heat generation in which the EV device **31** generates the amount of heat smaller than the maximum heat generation amount, there is an allowance for the performance of each of the heat exchangers **14** and **15**. Therefore, once in a state where not the EV device **31** that generates the maximum heat generation amount is cooled, refrigerant is able to exchange heat with a larger amount of air in each of the heat exchangers **14** and **15**. This may be understood that the heat exchangers **14** and **15** each apparently increase in size and the temperature efficiency ϕc of each of the heat exchangers **14** and **15** becomes higher.

[0107] An air-side heat radiation performance Qca in each of the heat exchangers **14** and **15** is directly proportional to the temperature efficiency ϕc of the heat exchanger, an air specific heat Ca, an air volume by weight Gea and a difference (Ter−Tea) obtained by subtracting an intake air temperature Tea from a refrigerant temperature Ter. The required heat radiation performance Qca is unchanged, and the air specific heat Ca, the air volume by weight Gea and the intake air temperature Tea are determined in accordance with an outside air temperature and a vehicle speed, so the refrigerant temperature Ter decreases by the amount of increase in the temperature efficiency ϕc. Referring to the Mollier chart, when refrigerant is in a gas-liquid two-phase state, the temperature and pressure of refrigerant linearly correlate with each other, and the temperature of refrigerant varies with a variation in the pressure of refrigerant. That is, a decrease in the refrigerant temperature Ter in the heat exchangers **14** and **15** means a decrease in the pressure of refrigerant flowing through the heat exchangers **14** and **15**.

[0108] The pressure of refrigerant in the heat exchangers **14** and **15** decreases, and the high pressure of the vapor compression refrigeration cycle **10** decreases. As a result, the pressure of refrigerant at the outlet of the compressor **12** may be relatively low. Therefore, it is possible to reduce power for adiabatically compressing refrigerant in the compressor **12**, so it is possible to achieve further power saving. Thus, it is possible to improve the fuel consumption of the vehicle. Particularly, in an electric vehicle, it is possible to directly improve electric power consumption through power saving.

[0109] The refrigerant line **24** that forms a refrigerant path not passing through the cooling portion **30** and the refrigerant lines **33** and **35** and cooling line **32** that form a refrigerant path passing through the cooling portion **30** to cool the EV device **31** are provided in parallel with each other as the paths of refrigerant flowing from the gas-liquid separator **80** toward the heat exchanger **15**. The cooling system for cooling the EV device **31**, including the refrigerant lines **33** and **35**, is connected in parallel with the refrigerant line **24**. Therefore, only part of refrigerant flowing out from the gas-liquid separator **80** flows to the cooling portion **30**. By adjusting the opening degree of the flow regulating valve **43** provided in the refrigerant line **24**, the flow rate of refrigerant flowing from the gas-liquid separator **80** to the refrigerant line **24** and the flow rate of refrigerant flowing through the cooling portion **30** are appropriately adjusted. Through the flow rate adjustment, an amount of refrigerant required to cool the EV device **31** flows to the cooling portion **30**, and the EV device **31** is appropriately cooled.

[0110] The path of refrigerant that flows from the heat exchanger **14** to the heat exchanger **15** without passing through the cooling portion **30** and the path of refrigerant that flows from the heat exchanger **14** to the heat exchanger **15** via the cooling portion **30** are provided in parallel with each other, and only part of refrigerant is caused to flow to the refrigerant lines **33** and **35**. By so doing, it is possible to reduce the pressure loss at the time when refrigerant flows through the cooling system for cooling the EV device **31**. Not the entire refrigerant flows to the cooling portion **30**. Therefore, it is possible to reduce the pressure loss associated with flow of refrigerant via the cooling portion **30**, and, accordingly, it is possible to reduce power consumption required to operate the compressor **12** for circulating refrigerant.

[0111] When low-temperature and low-pressure refrigerant after passing through the expansion valve **16** is used to cool the EV device **31**, the cooling performance of air in the cabin in the heat exchanger **18** reduces and the cooling performance for cooling the cabin decreases In contrast to this, in the cooling system **1** according to the present embodiment, in the vapor compression refrigeration cycle **10**, high-pressure refrigerant discharged from the compressor **12** is condensed by both the heat exchanger **14** that serves as a first condenser and the heat exchanger **15** that serves as a second condenser. The two-stage heat exchangers **14** and **15** are arranged between the compressor **12** and the expansion valve **16**, and the cooling portion **30** for cooling the EV device **31** is provided between the heat exchanger **14** and the heat exchanger **15**. The heat exchanger **15** is provided in the path of refrigerant flowing from the cooling, portion **30** toward the expansion valve **16**.

[0112] By sufficiently cooling refrigerant, which receives latent heat of vaporization from the EV device **31** to be heated, in the heat exchanger **15**, the refrigerant has a temperature and a pressure that are originally required to cool the cabin of the vehicle at the outlet of the expansion valve **16**. Therefore, it is possible to sufficiently increase the amount of heat externally received when refrigerant evaporates in the heat exchanger **18**, so it is possible to sufficiently cool air-conditioning air that passes through the heat, exchanger **18**. In this way, by setting the heat radiation performance for the heat exchanger **15** such that the heat exchanger **15** is able to sufficiently cool refrigerant, the EV device **31** may be cooled without any influence on the cooling performance for cooling the cabin. Thus, both the cooling performance for cooling the EV device **31** and the cooling performance for cooling the cabin may be reliably ensured.

[0113] When refrigerant flowing from the heat exchanger **14** to the cooling portion **30** cools the EV device **31**, the refrigerant receives heat from the EV device **31** to be heated. As refrigerant is heated to a saturated steam temperature or above and the entire amount of the refrigerant vaporizes in the cooling portion **30**, the amount of heat exchanged between the refrigerant and the EV device **31** reduces, and the EV device **31** cannot be efficiently cooled, and, in addition, pressure loss at the time when the refrigerant flows in the line increases. Therefore, it is desirable to sufficiently cool refrigerant in the heat exchanger **14** such that the entire amount of refrigerant does not vaporize after cooling the EV device **31** and to supply a sufficient amount of liquid refrigerant to the gas-liquid separator **80**.

[0114] Specifically, the state of refrigerant at the outlet of the heat exchanger **14** is brought close to saturated liquid, and, typically, refrigerant is placed in a state on the saturated liquid line at the outlet of the heat exchanger **14**. Because the heat exchanger **14** is capable of sufficiently cooling refrigerant in this way, the heat radiation performance of the heat exchanger **14** for causing refrigerant to release heat is higher than the heat radiation performance of the heat exchanger **15**. By sufficiently cooling refrigerant in the heat exchanger **14** having relatively high heat radiation performance, refrigerant that has received heat from the EV device **31** may be maintained in a wet steam state, and a reduction in the amount of heat exchanged between refrigerant and the EV device **31** may be avoided, so it is possible to sufficiently cool the EV device **31**. Refrigerant in a wet steam state after cooling the

EV device **31** is efficiently cooled again in the heat exchanger **15**, and is cooled into a supercooled liquid state below a saturated temperature. Thus, it is possible to provide the cooling system **1** that ensures both the cooling performance for cooling the cabin and the cooling performance for cooing the EV device **31**.

[0115] Refrigerant is caused to circulate in the vapor compression refrigeration cycle **10**, and heat is taken from the EV device **31** due to latent heat of vaporization of refrigerant in a saturated liquid state, flowing to the cooling portion **30**, so it is possible to efficiently cool the EV device **31**. In addition, it is possible to cool air-conditioning air by supplying the heat exchanger **18** with refrigerant adjusted into a low-temperature and low-pressure atomized state by the expansion valve **16**, so it is possible to ensure cooling performance for cooling the vehicle cabin and dehumidifying performance for dehumidifying the vehicle cabin.

Second Operation Mode

[0116] FIG. **4** is a schematic view that shows the operation of the cooling system **1** in the second operation mode. As shown in FIG. **2**A, FIG. **2**B and FIG. **4**, the second operation mode is an operation mode in which heating performance for heating the vehicle cabin is increased while the vehicle cabin is not dehumidified during operation of the air conditioner for heating the cabin of the vehicle.

[0117] In the second operation mode, refrigerant is required to flow through a path that includes the heat exchanger **13** in order to heat the vehicle cabin, so the compressor **12** is in an operating state. The flow regulating valve **42** adjusts the flow rate of refrigerant flowing through the cooling portion **30**, and the valve opening degree of the flow regulating valve **42** is adjusted such that a sufficient amount of refrigerant flows to the cooling portion **30** in order to cool the EV device **31**. The flow regulating valve **43** is fully opened so as to minimize the pressure loss of refrigerant flowing through the refrigerant line **24**. The open/close state of the three-way valve **41** is switched such that the refrigerant line **22***a* and the refrigerant line **71** are in fluid communication with each other and the refrigerant line **22***b* is not in fluid communication with both the refrigerant lines **22***a* and **71**.

[0118] The on-off valve **37** is opened, and the refrigerant line **34** is set in a fluid communication state. The on-off valve **38** is closed, and the refrigerant line **35** is interrupted. The on-off valve **52** is closed, and the communication line **51** is interrupted. The open/close states of the selector valve **36** and on-off valve **52** are switched such that refrigerant flowing out from the cooling portion **30** flows to the refrigerant line **34** and does not flow to the refrigerant line **35** and the communication line **51**. The on-off valves **64** and **77** are opened, and the refrigerant lines **61** and **73** are set in a fluid communication state. The on-off valves **44** and **78** are closed, and the refrigerant lines **25** and **74** are interrupted.

[0119] Refrigerant passes through a refrigerant circulation path that is formed by sequentially connecting the compressor **12**, the heat exchanger **13**, the expansion valve **76** and the heat exchangers **15** and **14** by the refrigerant lines **21**, **22***a*, **71**, **72**, **73**, **25**, **24**, **23**, **22***b*, **61** and **29** to circulate in the vapor compression refrigeration cycle **10**.

[0120] During heating operation, it is required to increase the temperature of air-conditioning air flowing out from the duct **90**. Therefore, as shown in FIG. **4**, by operating the damper **96**, the path of air-conditioning air inside the duct **90** is set such that air-conditioning air passes through the heat exchanger **13**. By so doing, it is possible to heat air-conditioning air through heat exchange between high-temperature and high-pressure refrigerant adiabatically compressed in the compressor **12** and air-conditioning air, so it is possible to efficiently heat the cabin of the vehicle, and, therefore, it is possible to ensure heating performance for heating the vehicle cabin.

[0121] FIG. **5** is a Mollier chart that shows the state of refrigerant in the vapor compression refrigeration cycle **10** in the second operation mode. In FIG. **5**, the abscissa axis represents the specific enthalpy of refrigerant, and the ordinate axis represents the absolute pressure of refrigerant. The unit of the specific enthalpy is kJ/kg, and the unit of the absolute pressure is MPa. The curve in the chart is the saturation vapor line and saturation liquid line of refrigerant.

[0122] FIG. **5** shows the thermodynamic state of refrigerant at points in the vapor compression refrigeration cycle **10** when refrigerant flows from the refrigerant line **24** at the outlet of the heat exchanger **15** to the refrigerant line **33** via the gas-liquid separator **80**, flows into the cooling portion **30** to cool the EV device **31** and returns from the cooling portion **30** to the refrigerant line **23***a* at the inlet of the heat exchanger **14** via the refrigerant line **34**.

[0123] As shown in FIG. **5**, refrigerant in a saturated steam state is introduced from the accumulator **85** into the compressor **12**, and the refrigerant is adiabatically compressed in the compressor **12** along a constant specific entropy line. As refrigerant is compressed in the compressor **12**, the refrigerant increases in pressure and temperature into high-temperature and high-pressure superheated steam having a high degree of superheat at the outlet of the compressor **12**, and flows to the heat exchanger **13**.

[0124] High-pressure refrigerant steam in the heat exchanger **13** is cooled in the heat exchanger **13**, becomes dry saturated steam from superheated steam with a constant pressure, releases latent heat of condensation to gradually liquefy into wet steam in a gas-liquid mixing state, becomes saturated liquid as the entire refrigerant condenses, and further releases sensible heat to become supercooled liquid. The heat exchanger **13** causes superheated refrigerant gas, compressed in the compressor **12**, to release heat to air-conditioning air with a constant pressure and to become refrigerant liquid. Gaseous refrigerant discharged from the compressor **12** releases heat to air-conditioning air to be cooled in the heat exchanger **13** to thereby condense (liquefy). Owing to heat exchange in the heat exchanger **13**, the temperature of refrigerant decreases, and refrigerant liquefies. During heating operation, low-temperature air-conditioning air and refrigerant exchange heat with each other in the heat exchanger **13**, heat is transferred from refrigerant to air-conditioning air to heat the air-conditioning air, the temperature of the air-conditioning air increases, and refrigerant releases heat to air-conditioning air to be cooled.

[0125] High-pressure liquid refrigerant liquefied in the heat exchanger **13** flows into the expansion valve **76** via the refrigerant lines **22***a* and **71**. In the expansion valve **76**, refrigerant in a supercooled liquid state is throttle-expanded, and the refrigerant decreases in temperature and pressure with the specific enthalpy of the refrigerant unchanged to become low-temperature and low-pressure wet steam in a gas-liquid mixing state.

[0126] Refrigerant of which the temperature is decreased in the expansion valve **76** flows to the heat exchanger **15** via the refrigerant lines **72** and **73**. Refrigerant in a wet steam state flows into the tubes of the heat exchanger **15**. When refrigerant flows through the tubes, the refrigerant absorbs heat of outside air via the fins as latent heat of vaporization to evaporate with a constant pressure. Refrigerant exchanges heat with outside air in the heat exchanger **15** to be heated, and the dryness of the refrigerant increases. Part of refrigerant receives latent heat in the heat exchanger **15** to vaporize, so the percentage of saturated steam contained in the refrigerant in a wet steam state increases.

[0127] In the gas-liquid separator **80**, refrigerant in a gas-liquid two-phase state is separated into refrigerant steam in a saturated steam state and refrigerant liquid in a saturated liquid state. Refrigerant in a saturated liquid state flows out from the gas-liquid separator **80**, flows to the cooling line **32** of the cooling portion **30** via the refrigerant line **33**, and cools the EV device **31**. In the cooling portion **30**, heat is released to liquid refrigerant in a saturated liquid state, which is separated in the gas-liquid separator **80**, to cool the EV device **31**. Refrigerant is heated by exchanging heat with the EV device **31**, and the dryness of the refrigerant increases. Refrigerant receives latent heat from the EV device **31** to partially vaporize into wet steam in a gas-liquid two-phase state, which mixedly contains saturated liquid and saturated steam at the outlet of the cooling portion **30**.

[0128] Refrigerant in a wet steam state, flowing out from the cooling portion **30**, flows into the heat exchanger **14** via the refrigerant lines **34** and **23***a*. Refrigerant in a wet steam state flows into the tubes of the heat exchanger **14**. When refrigerant flows through the tubes, the refrigerant absorbs heat of outside, air via the fins as latent heat of vaporization to evaporate with a constant pressure, so the percentage of saturated steam contained in the refrigerant in a wet steam state increases.

[0129] In the heat exchanger **14**, refrigerant may be heated until all the refrigerant becomes superheated steam, refrigerant may be heated until all the refrigerant becomes dry saturated steam or refrigerant may be in a wet saturated steam state at the outlet of the heat exchanger **14**. When refrigerant flowing out from the heat exchanger **14** contains liquid refrigerant, refrigerant liquid is stored in the accumulator **85**, and only gaseous refrigerant steam is introduced into the compressor **12**. By so doing, refrigerant liquid is prevented from flowing into the compressor **12**. FIG. **5** shows the state of refrigerant when refrigerant in a wet saturated steam state is separated into gas and liquid in the accumulator **85** and refrigerant in a dry saturated steam state flows out from the accumulator **85** to the compressor **12** via the refrigerant line **29**. Refrigerant continuously repeats changes among the compressed state, the condensed state, the throttle-expanded state and the evaporated state in accordance with the above-described cycle.

[0130] The cooling system **1** according to the present embodiment includes the three-way valve **41** that switches flow of refrigerant in the vapor compression refrigeration cycle **10** between cooling operation and heating operation. During heating operation, refrigerant steam flowing inside the heat exchanger **13** condenses to release heat to air-conditioning air introduced so as to contact with the heat exchanger **13**. The heat exchanger **13** uses high-temperature and high-pressure refrigerant adiabatically compressed in the compressor **12** to release heat of condensation, which is required at the time when refrigerant gas condenses into wet steam of refrigerant, to air-conditioning air flowing to the cabin of the vehicle to thereby heat the cabin of the vehicle. Air-conditioning air that receives heat from the heat exchanger **13** to increase its temperature flows into the cabin of the vehicle to thereby heat the cabin of the vehicle.

[0131] The cooling system **1** is able to appropriately adjust the temperature of air-conditioning air flowing to the cabin of the vehicle in the case of both cooling operation and heating operation. Therefore, it is possible to reduce the cost of the cooling system **1**, and, in addition, it is possible to reduce the size of the cooling system **1**. In addition, during heating operation, refrigerant flows to the cooling portion **30**, and exchanges heat with the EV device **31** to cool the EV device **31**. The cooling system **1** cools the EV device **31**, which is the heat generating source mounted on the vehicle, by utilizing the vapor compression refrigeration cycle **10** for air-conditioning the cabin of the vehicle.

[0132] Thus, it is possible to provide the cooling system **1** that is able to appropriately cool the EV device **31** while maintaining excellent heating performance for heating the cabin of the vehicle and that ensures both heating performance for heating the vehicle cabin and cooling performance for cooling the EV device **31**. In the cooling portion **30**, the EV device **31** exchanges heat with low-temperature and low-pressure refrigerant after being throttle-expanded by the expansion valve **76**, so it is possible to further improve cooling performance for cooling the EV device **31**.

[0133] During heating operation, refrigerant absorbs heat from the EV device **31** in the cooling portion **30** to be heated, and absorbs heat from outside air in the heat exchanger **14** to be further heated. By heating refrigerant in both the cooling portion **30** and the heat exchanger **14**, it is possible to effectively utilize heat waste from the EV device **31** for heating the cabin, so the coefficient of performance improves, and it is possible to reduce power consumption for adiabatically compressing refrigerant in the compressor **12** during heating operation.

[0134] The cooling system **1** includes the single gas-liquid separator **80**. By using the single gas-liquid separator **80**, during both cooling operation and heating operation, refrigerant in a gas-liquid two-phase state is separated into gas and liquid, and only refrigerant liquid that is liquid refrigerant separated in the gas-liquid separator **80** is supplied to the cooling portion **30** to cool the EV device **31**. The liquid refrigerant is refrigerant in a just saturated liquid state. Therefore, by taking only liquid refrigerant from the gas-liquid separator **80** and flowing the liquid refrigerant to the cooling portion **30**, the performance of the heat exchanger **15** arranged on the upstream side of the gas-liquid separator **80** may be fully utilized to cool the EV device **31**, so it is possible to provide the cooling system **1** having improved cooling performance for cooling the EV device **31**.

[0135] Refrigerant in a saturated liquid state at the outlet of the gas-liquid separator **80** is introduced into the cooling line **32** that cools the EV device **31** to thereby make it possible to minimum gaseous refrigerant within refrigerant that flows in the cooling system for cooling the EV device **31**, including the cooling line **32**. Therefore, it is possible to suppress an increase in pressure loss due to an increase in flow rate of refrigerant steam flowing in the cooling system for cooling the EV device **31**, and the power consumption of the compressor **12** for flowing refrigerant may be reduced, so it is possible to avoid deterioration of the performance of the vapor compression refrigeration cycle **10**.

[0136] When refrigerant liquid in a predetermined amount is stored in the gas-liquid separator **80**, it is possible to maintain the flow rate of refrigerant flowing from the gas-liquid separator **80** to the cooling portion **30** at the time of switching between heating operation and cooling operation. Because the gas-liquid separator **80** has the function of storing liquid, it is possible to absorb fluctuations in refrigerant flow rate, that is, the flow rate of refrigerant flowing from the heat exchangers **14** and **15** to the gas-liquid separator **80** temporarily decreases at the time of switching between cooling operation and heating operation. Thus, it is possible to avoid a shortage of refrigerant supplied to the cooling portion **30** at the time of switching between heating operation and cooling operation, so it is possible to stabilize the cooling performance for cooling the EV device **31**.

[0137] The refrigerant line **23** that forms a refrigerant path not passing through the cooling portion **30** and the refrigerant lines **33** and **34** and cooling line **32** that form a refrigerant path passing through the cooling portion **30** to cool the EV device **31** are provided in parallel with each other as the paths of refrigerant flowing from the gas-liquid separator **80** toward the heat exchanger **14**. The cooling system for cooling the EV device **31**, including the refrigerant lines **33** and **34**, is connected in parallel with the refrigerant line **23**. Therefore, only part of refrigerant flowing out from the gas-liquid separator **80** flows to the cooling portion **30**. By adjusting the opening degree of the flow regulating valve **42** provided in the refrigerant line **23**, the flow rate of refrigerant flowing from the gas-liquid separator **80** to the refrigerant line **23** and the flow rate of refrigerant flowing through the cooling portion **30** are appropriately adjusted. Through the flow rate adjustment, an amount of refrigerant required to cool the EV device **31** flows to the cooling portion **30**, and the EV device **31** is appropriately cooled.

[0138] The path of refrigerant that flows from the heat exchanger **15** to the heat exchanger **14** without passing through the cooling portion **30** and the path of refrigerant that flows from the heat exchanger **15** to the heat exchanger **14** via the cooling portion **30** are provided in parallel with each other, and only part of refrigerant is caused to flow to the refrigerant lines **33** and **34**. By so doing, it is possible to reduce the pressure loss at the time when refrigerant flows through the cooling system for cooling the EV device **31**. Not the entire refrigerant flows to the cooling portion **30**. Therefore, it is possible to reduce the pressure loss associated with flow of refrigerant via the cooling portion **30**, and, accordingly, it is possible to reduce power consumption required to operate the compressor **12** for circulating refrigerant.

[0139] As described above, during normal heat generation in which the EV device **31** generates the amount of heat smaller than the maximum heat generation amount, it may be understood that the heat exchangers **14** and **15** each apparently increase in size and the temperature efficiency ϕc of each of the heat exchangers **14** and **15** becomes higher. An air-side cooling performance Qea in each of the heat exchangers **14** and **15** is directly proportional to the temperature efficiency ϕc of the heat exchanger, an air specific heat Ca, an air volume by weight Gea and a difference (Tea−Ter) obtained by subtracting a refrigerant temperature Ter from an intake air temperature Tea. The required cooling performance Qea is unchanged, and the air specific heat Ca, the air volume by weight Gea and the intake air temperature Tea are determined in accordance with an outside air temperature and a vehicle speed, so the refrigerant temperature Ter increases by the amount of increase in the temperature efficiency ϕc. A decrease in the refrigerant temperature Ter in the heat exchangers **14** and **15** means an increase in the pressure of refrigerant flowing through the heat exchangers **14** and **15**.

[0140] The pressure of refrigerant in the heat exchangers **14** and **15** increases, and the low pressure of the vapor compression refrigeration cycle **10** increases. As a result, the pressure of refrigerant at the inlet of the compressor **12** increases. Therefore, it is possible to reduce power for adiabatically compressing refrigerant in the compressor **12** in order to obtain a predetermined refrigerant pressure at the outlet of the compressor **12**, so it is possible to achieve further power saving. Thus, it is possible to improve the fuel consumption of the vehicle. Particularly, in an electric vehicle, it is possible to directly improve electric power consumption through power saving.

Third Operation Mode

[0141] FIG. **6** is a schematic view that shows the operation of the cooling system **1** in the third operation mode. As shown in FIG. **2**A, FIG. **2**B and FIG. **6**, the third operation mode is an operation mode in which heating performance is slightly decreased but it is possible to dehumidify the vehicle cabin during operation of the air conditioner for heating the cabin of the vehicle.

[0142] In the third operation mode, refrigerant is required to flow through a path that includes the heat exchanger **13** in order to heat the vehicle cabin, so the compressor **12** is in an operating state. The flow regulating valve **42** adjusts the flow rate of refrigerant flowing through the cooling portion **30**, and the valve opening degree of the flow regulating valve **42** is adjusted such that a sufficient amount of refrigerant flows to the cooling portion **30** in order to cool the EV device **31**. The flow regulating valve **43** is fully opened so as to minimize the pressure loss of refrigerant flowing through the refrigerant line **24**. The open/close state of the three-way valve **41** is switched such that the refrigerant line **22***a* and the refrigerant line **71** are in fluid communication with each other and the refrigerant line **22***b* is not in fluid communication with both the refrigerant lines **22***a* and **71**.

[0143] The on-off valve **37** is opened, and the refrigerant line **34** is set in a fluid communication state. The on-off valve **38** is closed, and the refrigerant line **35** is interrupted. The on-off valve **52** is closed, and the communication line **51** is interrupted. The open/close states of the selector valve **36** and on-off valve **52** are switched such that refrigerant flowing out from the cooling portion **30** flows to the refrigerant line **34** and does not flow to the refrigerant line **35** and the communication line **51**. The on-off valves **64**, **77** and **78** each are opened, and the refrigerant lines **61**, **73** and **74** are set in a fluid communication state. The on-off valve **44** is closed, and the refrigerant line **25** is interrupted.

[0144] Refrigerant passes through a refrigerant circulation path that is formed by sequentially connecting the compressor **12**, the heat exchanger **13**, the expansion valve **76** and the heat exchangers **15** and **14** by the refrigerant lines **21**, **22***a*, **71**, **72**, **73**, **25**, **24**, **23**, **22***b*, **61** and **29** to circulate in the vapor compression refrigeration cycle **10**. Refrigerant also passes through a refrigerant circulation path that is formed by sequentially connecting the compressor **12**, the heat exchanger **13**, the expansion valve **76** and the heat exchanger **18** by the refrigerant lines **21**, **22***a*, **71**, **72**, **74**, and **26** to **29** to circulate in the vapor compression refrigeration cycle **10**. Refrigerant passing through the expansion valve **76** flows to the heat exchangers **15** and **14** and the heat exchanger **18** in parallel.

[0145] FIG. **7** is a Mollier chart that shows the state of refrigerant in the vapor compression refrigeration cycle **10** in the third operation mode. In FIG. **7**, the abscissa axis represents the specific enthalpy of refrigerant, and the ordinate axis represents the absolute pressure of refrigerant. The unit of the specific enthalpy is kJ/kg, and the unit of the absolute pressure is MPa. The curve in the chart is the saturation vapor line and saturation liquid line of refrigerant.

[0146] FIG. **7** shows the thermodynamic state of refrigerant at points in the vapor compression refrigeration cycle **10** when refrigerant is adiabatically compressed in the compressor **12**, is condensed in the heat exchanger **13**, is throttle-expanded by the expansion valve **76** and evaporates in the heat exchanger **18** in addition to the thermodynamic state of refrigerant that flows into the cooling portion **30** to cool the EV device **31** as shown in FIG. **5**. The state of refrigerant that cools the EV device **31** and the state of refrigerant that reaches from the compressor **12** to the expansion valve **76** are the same as those of the second operation mode, so the description thereof is not repeated. Hereinafter, the state of refrigerant that flows from the expansion valve **76** toward the heat exchanger **18**, which is characteristic to the third operation mode, will be described.

[0147] Refrigerant that is decompressed in the expansion valve **76** and is decreased in temperature flows to the refrigerant line **72**. Refrigerant branches off from the refrigerant line **72** to the refrigerant lines **73** and **74**, and part of refrigerant flows to the heat exchanger **18** via the refrigerant lines **74** and **26**. Part of refrigerant that circulates in the vapor compression refrigeration cycle **10** branches off and flows to the heat exchanger **18**, and refrigerant in a wet steam state, which is lower in temperature than a dew point temperature of air-conditioning air, flows into the tubes of the heat exchanger **18**. The heat exchanger **18** absorbs heat of air-conditioning air introduced so as to contact with the heat exchanger **18** by vaporization of atomized refrigerant flowing inside the heat exchanger **18** to thereby decrease the temperature of the air-conditioning air. When refrigerant flows through the tubes of the heat exchanger **18**, the refrigerant absorbs heat of air-conditioning air via the fins as latent heat of vaporization to be heated and evaporate with a constant pressure. Thus, the dryness of refrigerant increases.

[0148] Refrigerant is in a wet saturated steam state at the outlet of the heat exchanger **18**. After that, refrigerant flows to the accumulator **85**. Refrigerant liquid is stored in the accumulator **85**, and only gaseous refrigerant steam is introduced into the compressor **12**. By so doing, refrigerant liquid is prevented from flowing into the compressor **12**.

[0149] In the thus described third operation mode, air-conditioning air that flows through the duct **90** is cooled by releasing heat to refrigerant in the heat exchanger **18**. When the temperature of air-conditioning air is decreased to below the dew point temperature, water vapor contained in air-conditioning air condensates, and the amount of water vapor contained in air-conditioning air reduces. After that, air-conditioning air receives heat from refrigerant in the heat exchanger **13** to be heated. Air-conditioning air after being cooled in the heat exchanger **18** is heated in the heat exchanger **13**. By so doing, the humidity of air-conditioning air decreases. In this way, dried air-conditioning air is introduced into the cabin of the vehicle, so it is possible to dehumidify the vehicle cabin in addition to heating operation.

[0150] In the third operation mode, the temperature of air-conditioning air is once decreased in the heat exchanger **18**, so heating performance decreases as compared with the second operation mode, but it is advantageously possible to dehumidify the vehicle cabin. In the case of the cooling system **1** that is mounted on the vehicle, a dehumidifying function for, for example, removing fogging of a vehicle window is indispensable. According to the present embodiment, it is possible to implement the cooling system **1** that includes the dehumidifying function in addition to the heating and cooling function and that is able to further appropriately cool the EV device **31** with a simple configuration.

Fourth Operation Mode

[0151] FIG. **8** is a schematic view that shows the operation of the cooling system **1** in the fourth operation mode. As shown in FIG. **2**A, FIG. **2**B and FIG. **8**, the fourth operation mode is an operation mode in which dehumidifying performance for dehumidifying the vehicle cabin is further increased during operation of the air conditioner for heating the cabin of the vehicle.

[0152] In the fourth operation mode, refrigerant is required to flow through a path that includes the heat exchanger **13** in order to heat the vehicle cabin, so the compressor **12** is in an operating state. The flow regulating valve **42** is fully opened so as to minimize the pressure loss of refrigerant flowing through the refrigerant line **23**. The flow regulating valve **43** is fully closed, and the refrigerant line **24** is interrupted. The open/close state of the three-way valve **41** is switched such that the refrigerant line **22***a* and the refrigerant line **71** are in fluid communication with each other and the refrigerant line **22***b* is, not in fluid communication with both the refrigerant lines **22***a* and **71**.

[0153] The on-off valves **37** and **38** are closed, and the refrigerant lines **34** and **35** are interrupted. The on-off valve **52** is opened, and the communication line **51** is set in a fluid communication state. The open/close states of the selector valve **36** and on-off valve **52** are switched such that refrigerant flowing out from the cooling portion **30** flows to the communication line **51** and does not flow to the refrigerant line **34** and the refrigerant line **35**. The on-off valve **78** is opened, and the refrigerant line **74** is set in a fluid communication state. The on-off valves **44**, **64** and **77** each are closed, and the refrigerant lines **25**, **61** and **73** are interrupted.

[0154] Refrigerant passes through a refrigerant circulation path that is formed by sequentially connecting the compressor **12**, the heat exchanger **13**, the expansion valve **76** and the heat exchanger **18** by the refrigerant lines **21**, **22***a*, **71**, **72**, **74**, and **26** to **29** to circulate in the vapor compression refrigeration cycle **10**. Refrigerant also passes through a refrigerant circulation path that is formed by connecting the cooling portion **30** to the heat exchanger **14** by the refrigerant line **23**, the gas-liquid separator **80**, the refrigerant line **33**, the communication line **51** and the refrigerant line **22***b*.

[0155] FIG. **9** is a schematic view that shows the configuration of part of the cooling system **1** shown in FIG. **8**. With the above-described settings of the open/close states of the three-way valve **41**, the flow regulating valves **42** and **43** and the on-off valves **37**, **38**, **52** and **64**, flow of refrigerant that circulates between the cooling portion **30** and the heat exchanger **14** occurs. That is, a closed annular path that is routed from the heat exchanger **14** to the cooling portion **30** via the refrigerant line **23**, the gas-liquid separator **80** and the refrigerant line **33** sequentially, and further passes through the communication line **51** and the refrigerant line **22** sequentially and returns to the heat exchanger **14**. It is possible to circulate refrigerant between the heat exchanger **14** and the cooling portion **30** via the annular path.

[0156] When refrigerant cools the EV device **31**, the refrigerant receives latent heat of vaporization from the EV device **31** to evaporate. Refrigerant steam vaporized by exchanging heat with the EV device **31** flows to the heat exchanger **14** via the communication line **51** and the refrigerant line **22** sequentially. In the heat exchanger **14**, refrigerant steam is cooled to condense by running wind of the vehicle or draft from a cooling fan. Refrigerant liquid liquefied in the heat exchanger **14** flows to the gas-liquid separator **80** via the refrigerant line **23**. Liquid refrigerant separated in the gas-liquid separator **80** returns to the cooling portion **30** via the refrigerant line **33**.

[0157] In this way, a heat pipe in which the EV device **31** serves as a heating portion and the heat exchanger **14** serves as a cooling portion is formed by the annular path that passes through the cooling portion **30** and the heat exchanger **14**. Thus, it is possible to supply refrigerant to the cooling portion **30** without the necessity of the power of the compressor **12**, so it is possible to reliably cool the EV device **31**.

[0158] FIG. **9** shows a ground **100**. The cooling portion **30** for cooling the EV device **31** is arranged below the heat exchanger **14** in the vertical direction perpendicular to the ground **100**. In the annular path that circulates refrigerant between the heat exchanger **14** and the cooling portion **30**, the cooling portion **30** is arranged below, and the heat exchanger **14** is arranged above. The heat exchanger **14** is arranged at the level higher than the cooling portion **30**.

[0159] In this case, refrigerant steam heated and vaporized in the cooling portion **30** goes up in the annular path, reaches the heat exchanger **14**, is cooled in the heat exchanger **14**, condenses into liquid refrigerant, goes down in the annular path by the action of gravity and returns to the cooling portion **30**. That is, a thermo-siphon heat pipe is formed of the cooling portion **30**, the heat exchanger **14** and the refrigerant paths that connect them. During heat pipe operation, the potential head of refrigerant liquefied in the heat exchanger **14** influences the circulation amount of refrigerant, so, by arranging the heat exchanger **14** at a level higher than the cooling portion **30**, it is possible to improve the heat-transfer efficiency from the EV device **31** to the heat exchanger **14**, and it is possible to further improve cooling performance for cooling the EV device **31**. Thus, even when the vapor compression refrigeration cycle **10** is stopped, it is possible to further efficiently cool the EV device **31** without adding power.

[0160] FIG. **10** is a Mollier chart that shows the state of refrigerant in the vapor compression refrigeration cycle **10** in the fourth operation mode. In FIG. **10**, the abscissa axis represents the specific enthalpy of refrigerant, and the ordinate axis represents the absolute pressure of refrigerant. The unit of the specific enthalpy is kJ/kg, and the unit of the absolute pressure is MPa. The curve in the chart is the saturation vapor line and saturation liquid line of refrigerant.

[0161] FIG. **10** shows the thermodynamic state of refrigerant that flows from the expansion valve **76** toward the heat exchanger **18** by the solid line, which is also shown in FIG. **7**, and further shows the thermodynamic state of refrigerant that circulates in a closed loop that is formed of a refrigerant path that connects the heat exchanger **14**, the gas-liquid separator **80** and the cooling portion **30** by the dotted line. The state of refrigerant that heats and dehumidifies air-conditioning air is the same as that of the third operation mode, so the description thereof is not repeated. Hereinafter, the state of refrigerant that circulates between the heat exchanger **14** and the cooling portion **30**, which is characteristic to the fourth operation mode, will be described.

[0162] Refrigerant flowing into the heat exchanger **14** releases heat to surroundings to be cooled at the time of flowing through the tubes of the heat exchanger **14** due to running wind of the vehicle or draft from the cooling fan to thereby condense (liquefy). Through heat exchange with outside air in the heat exchanger **14**, the temperature of refrigerant decreases, and refrigerant liquefies. In the heat exchanger **14**, refrigerant releases latent heat of condensation to gradually liquefy with a constant pressure into wet steam in a gas-liquid mixing state. Refrigerant in a gas-liquid two-phase state flows to the gas-liquid separator **80** via the refrigerant line **23**, and is separated into refrigerant steam in a saturated steam state and refrigerant liquid in a saturated liquid state in the gas-liquid separator **80**.

[0163] Refrigerant in a saturated liquid state flows out from the gas-liquid separator **80**, flows to the cooling line **32** of the cooling portion **30** via the refrigerant line **33**, and cools the EV device **31**. In the cooling portion **30**, heat is released to liquid refrigerant in a saturated liquid state, which is condensed in the heat exchanger **14** and is separated in the gas-liquid separator **80**, to thereby cool the EV device **31**. Refrigerant is heated by exchanging heat with the EV device **31**, gradually evaporates with a constant pressure, and the dryness of the refrigerant increases. Typically, in the cooling portion **30**, heat is exchanged between refrigerant and the EV device **31** until all the refrigerant becomes dry saturated steam. Refrigerant of which part or all is vaporized through heat exchange with the EV device **31** flows out from the cooling portion **30** and returns to the heat exchanger **14** via the communication line **51** and the refrigerant line **22** sequentially.

[0164] In the third operation mode shown in FIG. **6**, only part of low-temperature and low-pressure refrigerant decompressed by the expansion valve **76** flows to the heat exchanger **18**. In contrast to this, in the fourth operation mode, all the low-temperature and low-pressure refrigerant decompressed by the expansion valve **76** flows to the heat exchanger **18**. Because of an increase in the amount of refrigerant that flows to the heat exchanger **18**, heating performance further decreases as compared with the third operation mode; however, it is possible to further cool air-conditioning air in the heat exchanger **18**, so dehumidifying performance for dehumidifying air-conditioning air improves. By operating the cooling system **1** in the fourth operation mode, it is possible to further dehumidify air inside the vehicle cabin, so it is possible to quickly and reliably carry out dehumidification.

[0165] Refrigerant that is driven by the compressor **12** does not flow to the cooling portion **30**; however, a loop heat pipe that uses the heat exchanger **14** as a condenser and uses the cooling portion **30** as an evaporator operates to reliably cool the EV device **31**. The power of the compressor **12** is not required to cool the EV device **31**, and it is possible to cool the EV device **31** with no power.

[0166] Thus, it is possible to implement the cooling system **1** that includes the further excellent dehumidifying function and that is able to further appropriately cool the EV device **31** with a simple configuration. It is possible to cool the EV device **31** with no power, so it is possible to further improve power saving and comfort by reducing the power consumption of the compressor **12**.

Fifth Operation Mode

[0167] FIG. **11** is a schematic view that shows the operation of the cooling system **1** in the fifth operation mode. As shown in FIG. **2**A, FIG. **2**B and FIG. **11**, the fifth operation mode is an operation mode in which the EV device **31** is cooled with no power during a stop of the air conditioner for heating the cabin of the vehicle.

[0168] In the fifth operation mode, the air conditioner in the vehicle cabin is stopped, and it is not required to heat or cool air-conditioning air, so the compressor **12** is in a stopped state. The flow regulating valve **42** is fully opened so as to minimize the pressure loss of refrigerant flowing through the refrigerant line **23**. The flow regulating valve **43** is fully closed, and the refrigerant line **24** is interrupted. The open/close state of the three-way valve **41** is switched such that the refrigerant line **22***a* and the refrigerant line **71** are in fluid communication with each other and the refrigerant line **22***b* is not in fluid communication with both the refrigerant lines **22***a* and **71**.

[0169] The on-off valves **37** and **38** are closed, and the refrigerant lines **34** and **35** are interrupted. The on-off valve **52** is opened, and the communication line **51** is set in a fluid communication state. The open/close states of the selector valve **36** and on-off valve **52** are switched such that refrigerant flowing out from the cooling portion **30** flows to the communication line **51** and does not flow to the refrigerant line **34** and the refrigerant line **35**. The on-off valve **64** is closed, and the refrigerant line **61** is interrupted. The open/close states of the other on-off valves **44**, **77** and **78** are arbitrarily selected.

[0170] Refrigerant passes through a refrigerant circulation path that is formed by connecting the cooling portion **30** to the heat exchanger **14** by the refrigerant line **23**, the gas-liquid separator **80**, the refrigerant line **33**, the communication line **51** and the refrigerant line **22***b*.

[0171] As in the case of the fourth operation mode, a heat pipe in which the EV device **31** serves as a heating portion and the heat exchanger **14** serves as a cooling portion is formed by the annular path that passes through the cooling portion **30** and the heat exchanger **14**. It is possible to circulate refrigerant between the heat exchanger **14** and the cooling portion **30** via the annular path without operating the compressor **12**.

[0172] Therefore, even when the vapor compression refrigeration cycle **10** is stopped, that is, even when cooling for the vehicle is stopped, it is possible to reliably cool the EV device **31** without the necessity of a start-up of the compressor **12**. It is possible to cool the EV device **31** with no power, and the compressor **12** is not required to constantly operate in order to cool the EV device **31**. By so doing, it is possible to improve further power saving and comfort by reducing the power consumption of the compressor **12**, and, in addition, it is possible to improve the reliability of the compressor **12** because the life of the compressor **12** is extended.

[0173] During operation of the cooling system **1** in the fourth or fifth operation mode, when it is not possible to sufficiently ensure the potential head of refrigerant because of a shortage of the amount of refrigerant inside the closed loop refrigerant path, the compressor **12** is operated in a forced operation so as to operate in only a short period of time in a state where the three-way valve **41** is switched so as to provide fluid communication between the refrigerant line **22***a* and the refrigerant line **22***b*. Through the forced operation, refrigerant accumulating in the heat exchangers **13** and **18** is drawn up and is supplied to the closed loop path, the amount of refrigerant in the closed loop is increased, thus ensuring the amount of refrigerant in the heat pipe. As a result, it is possible to ensure the potential head of refrigerant at which it is possible to ensure cooling performance required to cool the EV device **31**, so it is possible to increase the amount of heat exchanged in the heat pipe, and it is possible to avoid a situation that cooling the EV device **31** is insufficient due to a shortage of the amount of refrigerant.

[0174] Note that, in the above-described embodiment, the cooling system **1** that cools an electrical device mounted on the vehicle is described using the EV device **31** as an example. The electrical device is not limited to the illustrated electrical devices, such as an inverter and a motor generator. The electrical device may be any electrical device as long as it generates heat when it is operated. In the case where there are a plurality of electrical devices to be cooled, the plurality of electrical devices desirably have a common cooling target temperature range. The cooling target temperature range is an appropriate temperature range within which the electrical device is operated.

[0175] Furthermore, the heat generating source cooled by the cooling system **1** according to the embodiment of the invention is not limited to the electrical device mounted on the vehicle; instead, it may be any device that generates heat or may be a heat generating portion of any device.

[0176] The embodiment according to the invention is described above; however, the embodiment described above should be regarded as only illustrative in every respect and not restrictive. The scope of the invention is indicated not by the above description but by the appended claims, and is intended to include all modifications within the meaning and scope equivalent to the scope of the appended claims.

[0177] The cooling system according to the invention may be particularly advantageously applied to cooling of an electrical device, such as a motor generator and an inverter, using a vapor compression refrigeration cycle for cooling a cabin, in a vehicle, such as a hybrid vehicle, a fuel-cell vehicle and an electric vehicle, equipped with the electrical device.

1. A cooling system cooling a heat generating source, comprising:

a compressor configured to compress refrigerant circulating in the cooling system; a first heat exchanger configured to exchange heat between the refrigerant and outside air;

a second heat exchanger configured to exchange heat between the refrigerant and outside air;

a first decompressor configured to decompress the refrigerant;

a third heat exchanger configured to exchange heat between the refrigerant and air-conditioning air;

a reservoir configured to store the refrigerant in a liquid phase, the refrigerant being condensed in the first heat exchanger or the second heat exchanger;

a cooling portion configured to cool the heat generating source using the refrigerant in a liquid phase;

a first selector valve configured to switch between flow of the refrigerant from the first heat exchanger toward the cooling portion via the reservoir and flow of the refrigerant from the second heat exchanger toward the cooling portion via the reservoir; a first line providing fluid communication between the first heat exchanger and the reservoir;

a second line providing fluid communication between the second heat exchanger and the reservoir;

a third line, the refrigerant in a liquid phase flowing from the reservoir toward the cooling portion through the third line;

a first flow regulating valve provided in the first line, the first flow regulating valve being configured to adjust a flow rate of the refrigerant flowing through the cooling portion;

a second flow regulating valve provided in the second line, the second flow regulating valve being configured to adjust the flow rate of the refrigerant flowing through the cooling portion;

a fourth line providing fluid communication between an outlet side of the cooling portion and the first line between the first heat exchanger and the first flow regulating valve;

a fifth line providing fluid communication between the outlet side of the cooling portion and the second line between the second heat exchanger and the second flow regulating valve; and

a second selector valve configured to switch between flow of the refrigerant from the cooling portion toward the first heat exchanger via the fourth line and flow of the refrigerant from the cooling portion toward the second heat exchanger via the fifth line.

2. The cooling system according to claim **1**, further comprising:

a sixth line constituting a path of the refrigerant flowing into or flowing out from the first heat exchanger together with the first line;

a communication line providing fluid communication between the outlet side of the cooling portion and the sixth line; and

an on-off valve configured to open or close the communication line.

3. The cooling system according to claim **2**, wherein

the heat generating source is arranged below the first heat exchanger.

4. The cooling system according claim **1**, wherein the first heat exchanger has a higher heat radiation performance for releasing heat from the refrigerant than the second heat exchanger.

5. The cooling system according to claim **1**, further comprising:

an interior condenser arranged on a downstream side of flow of the air-conditioning air with respect to the third heat exchanger, the interior condenser being configured to transfer heat from the refrigerant compressed in the compressor to the air-conditioning air to heat the air-conditioning air.

6. The cooling system according to claim **1**, further comprising:

a second decompressor provided in a path of the refrigerant flowing from the compressor to the second heat exchanger via the first selector valve, the second decompressor being configured to decompress the refrigerant; and

a branching line configured to branch part of the refrigerant decompressed in the second decompressor, the branching line flowing the part of the refrigerant to the third heat exchanger.

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