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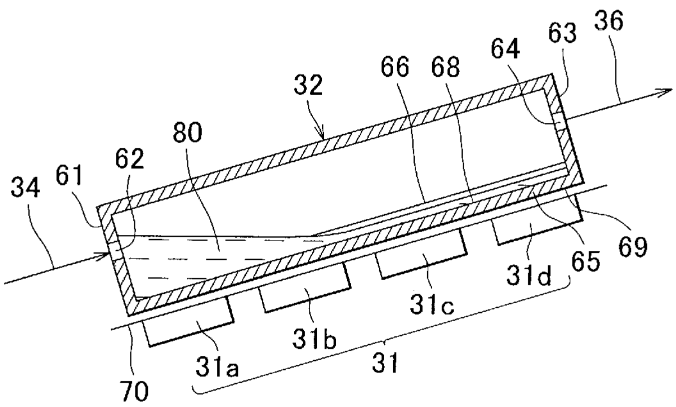
(54) Title: COOLING SYSTEM

FIG. 12



(57) Abstract: A cooling system that cools a heat generating source mounted on a vehicle includes: a compressor that circulates refrigerant; a first heat exchanger that performs heat exchange between the refrigerant and outside air; a decompressor that decompresses the refrigerant; a second heat exchanger that performs heat exchange between the refrigerant and air-conditioning air; and a cooling device that is provided on a path of the refrigerant flowing between the first heat exchanger and the decompressor and that uses the refrigerant to cool the heat generating source. A capillarity generating portion that causes the refrigerant to rise due to capillarity is provided inside the cooling device.

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COOLING SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The invention relates to a cooling system and, more particularly, to a cooling system that utilizes a vapor compression refrigeration cycle to cool a heat generating source mounted on a vehicle.

2. Description of Related Art

[0002] In recent years, hybrid vehicles, fuel cell vehicles, electric vehicles, and the like, that run using 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 has been suggested a technique that utilizes a vapor compression refrigeration cycle, which is used as a vehicle air conditioner, to cool a heat generating element.

[0003] For example, Japanese Patent Application Publication No. 2006-290254 (JP 2006-290254 A) describes a cooling system for a hybrid vehicle. The cooling system includes: a compressor that is able to introduce and compress gaseous refrigerant; a main condenser that is able to cool high-pressure gaseous refrigerant using ambient air to condense the high-pressure gaseous refrigerant; an evaporator that is able to evaporate low-temperature liquid refrigerant to cool an refrigerating object; and a decompressing unit, and a heat exchanger, which is able to absorb heat from a motor, and a second decompressing unit are connected in parallel with the decompressing unit and the evaporator.

[0004] 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 generating element are arranged in parallel with each other in a refrigerant line routed from an expansion valve to a compressor and refrigerant for an air conditioner is utilized to cool the heat generating element. Japanese Patent Application Publication No. 2001-309506 (JP 2001-309506 A) describes a cooling system that circulates refrigerant of a vehicle air-conditioning refrigeration cycle through a cooling member of an inverter circuit portion that executes drive control over a vehicle drive motor and, when cooling air-conditioning air stream is not required, cooling of air-conditioning air stream by an evaporator of the vehicle air-conditioning refrigeration cycle is suppressed.

[0005] On the other hand, as for the internal structure of a cooling system for flowing refrigerant, Japanese Patent Application Publication No. 2008-218718 (JP 2008-218718 A) describes a structure that a space inside a casing is partitioned by wall surfaces to form a plurality of accommodating portions and then coolant is accommodated in the accommodating portions to thereby keep coolant inside the accommodating portions even when the liquid surface of coolant is inclined with respect to the lower face of the casing. Japanese Patent Application Publication No. 2010-107153 (JP 2010-107153 A) describes an evaporator. The evaporator includes a refrigerant supply unit that stores refrigerant liquid flowing thereinto from a liquid tube and that supplies the refrigerant liquid and a wick that transfers refrigerant liquid by capillary force.

[0006] In cooling a heat generating source mounted on a vehicle, refrigerant liquid may be caused to flow through a cooling portion for cooling the heat generating source to cool the heat generating source through heat exchange between refrigerant and the heat generating source. While the vehicle is running on a hill, the position of the vehicle inclines and, accordingly, the position of the cooling portion inclines. Thus, the liquid surface of refrigerant liquid inside the cooling portion inclines relatively with respect to the cooling portion. There are concerns about a reduction in driving force for flowing refrigerant liquid inside the cooling portion depending on the position of the cooling portion. In this case, there is an inconvenience that refrigerant liquid does not reach all the areas in the direction in which refrigerant liquid flows inside the cooling portion and, as a result, cooling of the heat generating source is insufficient.

SUMMARY OF THE INVENTION

[0007] The invention provides a cooling system that is able to reliably cool a heat generating source irrespective of the position of a vehicle.

[0008] An aspect of the invention relates to a cooling system that cools a heat generating source. The cooling system includes: a compressor that circulates refrigerant; a first heat exchanger that performs heat exchange between the refrigerant and outside air; a decompressor that decompresses the refrigerant; a second heat exchanger that performs heat exchange between the refrigerant and air-conditioning air; and a cooling device that is provided on a path of the refrigerant flowing between the first heat exchanger and the decompressor and that uses the refrigerant to cool the heat generating source. A capillarity generating portion that causes the refrigerant to rise due to capillarity is provided inside the cooling device.

[0009] In the above cooling system, the capillarity generating portion may be formed by subjecting an inner face of a bottom portion of the cooling device to surface processing.

[0010] In the above cooling system, the capillarity generating portion may extend in a flow direction of the refrigerant flowing through the cooling device.

[0011] In the above cooling system, the heat generating source may be in thermal contact with an outer face of a bottom portion of the cooling device. The above cooling system may further include: a first line through which the refrigerant flows between the compressor and the first heat exchanger; a second line through which the refrigerant flows between the cooling device and the decompressor; and a communication line that provides fluid communication between the first line and the second line.

[0012] With the cooling system according to the aspect of the invention, it is possible to reliably cool a heat generating source mounted on a vehicle irrespective of the position of the vehicle.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] 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:

FIG. 1 is a schematic view that shows the configuration of a cooling system according to an embodiment;

FIG. 2 is a Mollier chart that shows the state of refrigerant in a vapor compression refrigeration cycle;

FIG. 3 is a schematic view that shows the flow of refrigerant that cools an HV device during operation of the vapor compression refrigeration cycle;

FIG. 4 is a schematic view that shows the flow of refrigerant that cools the HV device during a stop of the vapor compression refrigeration cycle;

FIG. 5 is a partially cross-sectional view of a cooling device;

FIG. 6 is a partially enlarged perspective view of the inner face of the bottom portion of a cooling passage;

FIG. 7 is a schematic view that shows a vehicle that is running on a flat road;

FIG. 8 is a cross-sectional view that shows the state of refrigerant liquid inside the cooling passage while the vehicle is running on the flat road;

FIG. 9 is a schematic view that shows the vehicle that is running on an uphill;

FIG. 10 is a cross-sectional view that shows the state of refrigerant liquid inside the cooling passage while the vehicle is running on the uphill;

FIG. 11 is a schematic view that shows the vehicle that is running on a downhill; and

FIG. 12 is a cross-sectional view that shows the state of refrigerant liquid inside the cooling passage while the vehicle is running on the downhill.

DETAILED DESCRIPTION OF EMBODIMENTS

[0014] Hereinafter, an embodiment of the invention will be described with reference to the accompanying drawings. Note that, in the following drawings, like reference numerals denote the same or corresponding portions and the description thereof is not repeated.

[0015] FIG. 1 is a schematic view that shows the configuration of a cooling system 1 according to the present embodiment. 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 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.

[0016] 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, an expansion valve 16 that is an example of a decompressor, and a heat exchanger 18 that serves as a second heat exchanger. The vapor compression refrigeration cycle 10 further includes a gas-liquid separator 40. The gas-liquid separator 40 is arranged on a path of refrigerant between the heat exchanger 14 and the heat exchanger 15.

[0017] 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 from the heat exchanger 18 during operation of the vapor compression refrigeration cycle 10, and discharges high-temperature and high-pressure gaseous refrigerant to a refrigerant line 21. The compressor 12 discharges refrigerant to the refrigerant line 21 to thereby circulate refrigerant in the vapor compression refrigeration cycle 10.

[0018] The heat exchangers 14 and 15 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. High-pressure gaseous refrigerant discharged from the compressor 12 releases heat to the surroundings to be cooled in the heat exchangers 14 and 15 to thereby condense (liquefy). 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. Each of the heat exchangers 14 and 15 exchanges heat between refrigerant and natural draft generated as the vehicle runs or cooling air supplied by forced draft from a cooling fan, such as an engine cooling radiator fan. Due to heat exchange in the heat exchangers 14 and 15, the temperature of refrigerant decreases, and refrigerant liquefies.

[0019] The expansion valve 16 causes high-pressure liquid refrigerant, flowing through a refrigerant line 25, to be sprayed through a small hole to expand into low-temperature and low-pressure atomized refrigerant. The expansion valve 16 decompresses refrigerant liquid, condensed in the heat exchangers 14 and 15, 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 performs throttle expansion; instead, the decompressor may be a capillary tube.

[0020] Atomized refrigerant flowing inside the heat exchanger 18 vaporizes to absorb heat of ambient 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, 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 its temperature flows into the cabin of the vehicle to cool the cabin of the vehicle. Refrigerant absorbs heat from the surroundings in the heat exchanger 18 to be heated.

[0021] The heat exchanger 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 18. Refrigerant in a wet steam state flows through the tubes. When refrigerant flows through the tubes, the refrigerant absorbs heat of air in the cabin of the vehicle as latent heat of vaporization via the fins to evaporate, and further becomes superheated steam because of sensible heat. Vaporized refrigerant flows into the compressor 12 via a refrigerant line 27. The compressor 12 compresses refrigerant flowing from the heat exchanger 18.

[0022] The vapor compression refrigeration cycle 10 further includes the refrigerant line 21, refrigerant lines 22, 23 and 24, the refrigerant line 25, a refrigerant line 26 and the refrigerant line 27. The refrigerant line 21 provides fluid communication between the compressor 12 and the heat exchanger 14, and serves as a first line. The refrigerant lines 22, 23 and 24 provide fluid communication between the heat exchanger 14 and the heat exchanger 15. The refrigerant line 25 provides fluid communication between the heat exchanger 15 and the expansion valve 16. The refrigerant line 26 provides fluid communication between the expansion valve 16 and the heat exchanger 18, and serves as a third line. The refrigerant line 27 provides fluid communication between the heat exchanger 18 and the compressor 12, and serves as a fourth line.

[0023] The refrigerant line 21 is a line for flowing refrigerant from the compressor 12 to the heat exchanger 14. Refrigerant flows through the refrigerant line 21 from the outlet of the compressor 12 toward the inlet of the heat exchanger 14 between the compressor 12 and the heat exchanger 14. The refrigerant lines 22 to 25 are lines for flowing refrigerant from the heat exchanger 14 to the expansion valve 16. Refrigerant flows through the refrigerant lines 22 to 25 from the outlet of the heat exchanger 14 toward the inlet of the expansion valve 16 between the heat exchanger 14 and the expansion valve 16.

[0024] The refrigerant line 26 is a line for flowing refrigerant from the expansion valve 16 to the heat exchanger 18. Refrigerant flows through the refrigerant line 26 from the outlet of the expansion valve 16 toward the inlet of the heat exchanger 18 between the expansion valve 16 and the heat exchanger 18. The refrigerant line 27 is a line for flowing refrigerant from the heat exchanger 18 to the compressor 12. Refrigerant flows through the refrigerant line 27 from the outlet of the heat exchanger 18 toward the inlet of the compressor 12 between the heat exchanger 18 and the compressor 12.

[0025] The vapor compression refrigeration cycle 10 is formed such that the compressor 12, the heat exchangers 14 and 15, the expansion valve 16 and the heat exchanger 18 are coupled by the refrigerant lines 21 to 27. Note that refrigerant used in the vapor compression refrigeration cycle 10 may be, for example, carbon dioxide, hydrocarbon, such as propane and isobutane, ammonia, water, or the like.

[0026] The gas-liquid separator 40 separates refrigerant, flowing out from the heat exchanger 14, 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 40. The refrigerant lines 22 and 23 and the refrigerant line 34 are coupled to the gas-liquid separator 40.

[0027] Refrigerant is in a wet steam gas-liquid two-phase state, mixedly containing saturated liquid and saturated steam, on the outlet side of the heat exchanger 14. Refrigerant flowing out from the heat exchanger 14 is supplied to the gas-liquid separator 40 through the refrigerant line 22. Refrigerant in a gas-liquid two-phase state, flowing from the refrigerant line 22 into the gas-liquid separator 40, is separated into gas and liquid inside the gas-liquid separator 40. The gas-liquid separator 40 separates refrigerant, condensed by the heat exchanger 14, into liquid-state refrigerant liquid and gaseous refrigerant steam and temporarily stores them.

[0028] The separated refrigerant liquid flows out to the outside of the gas-liquid separator 40 via the refrigerant line 34. The end portion of the refrigerant line 34 arranged in liquid inside the gas-liquid separator 40 forms an outlet port through which liquid refrigerant flows out from the gas-liquid separator 40. The separated refrigerant steam flows out to the outside of the gas-liquid separator 40 via the refrigerant line 23. The end portion of the refrigerant line 23 arranged in gas inside the gas-liquid separator 40 forms an outlet port through which gaseous refrigerant flows out from the gas-liquid separator 40. Gaseous refrigerant steam delivered from the gas-liquid separator 40 radiates heat to the surroundings in the heat exchanger 15 that serves as a third heat exchanger to be cooled to thereby condense.

[0029] Inside the gas-liquid separator 40, the refrigerant liquid accumulates at the lower side and the refrigerant steam accumulates at the upper side. The end portion of the refrigerant line 34 that delivers refrigerant liquid from the gas-liquid separator 40 is coupled to the bottom portion of the gas-liquid separator 40. Only refrigerant liquid is delivered from the bottom side of the gas-liquid separator 40 to the outside of the gas-liquid separator 40 via the refrigerant line 34. The end portion of the refrigerant line 23 that delivers refrigerant steam from the gas-liquid separator 40 is coupled to the ceiling portion of the gas-liquid separator 40. Only refrigerant steam is delivered from the ceiling side of the gas-liquid separator 40 to the outside of the gas-liquid separator 40 via the refrigerant line 23. By so doing, the gas-liquid separator 40 is able to reliably separate gaseous refrigerant and liquid refrigerant from each other.

[0030] The path through which refrigerant flows from the outlet of the heat exchanger 14 toward the inlet of the expansion valve 16 includes the refrigerant line 22, the refrigerant line 23, the refrigerant line 24 and the refrigerant line 25. The refrigerant line 22 is routed from the outlet side of the heat exchanger 14 to the gas-liquid separator 40. The refrigerant line 23 flows out refrigerant steam from the gas-liquid separator 40, and passes through a flow regulating valve 28 (described later). The refrigerant line 24 is coupled to the inlet side of the heat exchanger 15. The refrigerant line 25 flows refrigerant from the outlet side of the heat exchanger 15 to the expansion valve 16.

[0031] The path of refrigerant that flows between the heat exchanger 14 and the heat exchanger 15 includes the refrigerant line 34 and a refrigerant line 36. The refrigerant line 34 provides fluid communication between the gas-liquid separator 40 and the cooling device 30. The refrigerant line 36 serves as a second line, and provides fluid communication between the cooling device 30 and the refrigerant line 24. Refrigerant liquid flows from the gas-liquid separator 40 to the cooling device 30 via the refrigerant line 34. Refrigerant passing through the cooling device 30 returns to the refrigerant line 24 via the refrigerant line 36. The cooling device 30 is provided on the path of refrigerant flowing from the heat exchanger 14 toward the heat exchanger 15.

[0032] Point D shown in FIG. 1 indicates a coupling point among the refrigerant line 23, the refrigerant line 24 and the refrigerant line 36. That is, point D indicates the downstream-side (side closer to the heat exchanger 15) end portion of the refrigerant line 23, the upstream-side (side closer to the heat exchanger 14) end portion of the refrigerant line 24 and the downstream-side end portion of the refrigerant line 36. The refrigerant line 23 forms part of the path routed from the gas-liquid separator 40 to point D within the path of refrigerant flowing from the gas-liquid separator 40 toward the expansion valve 16.

[0033] The cooling system 1 further includes a path of refrigerant arranged in parallel with the refrigerant line 23. The cooling device 30 is provided in that path of refrigerant. The cooling device 30 includes a hybrid vehicle (HV) device 31 and a cooling passage 32. The HV device 31 is an electrical device mounted on the vehicle. The cooling passage 32 is a line through which refrigerant flows. The HV device 31 is an example of a heat generating source. One end portion of the cooling passage 32 is connected to the refrigerant line 34. The other end portion of the cooling passage 32 is connected to the refrigerant line 36.

[0034] The path of refrigerant, connected in parallel with the refrigerant line 23 between the gas-liquid separator 40 and point D shown in FIG. 1, includes the refrigerant line 34 on the upstream side (side closer to the gas-liquid separator 40) of the cooling device 30, the cooling passage 32 included in the cooling device 30, and the refrigerant line 36 on the downstream side (side closer to the heat exchanger 15) of the cooling device 30. The refrigerant line 34 is a line for flowing liquid refrigerant from the gas-liquid separator 40 to the cooling device 30. The refrigerant line 36 is a line for flowing refrigerant from the cooling device 30 to point D. Point D is a branching portion between the refrigerant lines 23 and 24 and the refrigerant line 36.

[0035] Refrigerant liquid flowing out from the gas-liquid separator 40 flows toward the cooling device 30 via the refrigerant line 34. Refrigerant that flows to the cooling device 30 and that flows via the cooling passage 32 takes heat from the HV device 31 that serves as the heat generating source to cool the HV device 31. The cooling device 30 uses liquid refrigerant separated in the gas-liquid separator 40 to cool the HV device 31. Refrigerant flowing through the cooling passage 32 exchanges heat with the HV device 31 in the cooling device 30 to cool the HV device 31, and the refrigerant is heated. Refrigerant further flows from the cooling device 30 toward point D via the refrigerant line 36, and reaches the heat exchanger 15 via the refrigerant line 24.

[0036] The cooling device 30 is configured to be able to exchange heat between the HV device 31 and refrigerant in the cooling passage 32. In the present embodiment, the cooling device 30, for example, has the cooling passage 32 that is formed such that the outer peripheral surface of the cooling passage 32 is in direct contact with the casing of the HV device 31. The cooling passage 32 has a portion adjacent to the casing of the HV device 31. At that portion, heat is exchangeable between refrigerant, flowing through the cooling passage 32, and the HV device 31.

[0037] The HV device 31 is directly connected to the outer peripheral surface of the cooling passage 32 that forms part of the path of refrigerant, routed from the heat exchanger 14 to the heat exchanger 15 in the vapor compression refrigeration cycle 10, and is cooled. The HV device 31 is arranged on the outside of the cooling passage 32, so the HV device 31 does not interfere with flow of refrigerant flowing inside the cooling passage 32. Therefore, the pressure loss of the vapor compression refrigeration cycle 10 does not increase, so the HV device 31 may be cooled without increasing the power of the compressor 12.

[0038] Alternatively, the cooling device 30 may include a selected known heat pipe that is interposed between the HV device 31 and the cooling passage 32. In this case, the HV device 31 is connected to the outer peripheral surface of the cooling passage 32 via the heat pipe, and heat is transferred from the HV device 31 to the cooling passage 32 via the heat pipe to thereby cool the HV device 31. The HV device 31 serves as a heating portion for heating the heat pipe, and the cooling passage 32 serves as a cooling device for cooling the heat pipe to thereby increase the heat-transfer efficiency between the cooling passage 32 and the HV device 31, so the cooling efficiency of the HV device 31 may be improved. For example, a Wick heat pipe may be used.

[0039] Heat may be reliably transferred from the HV device 31 to the cooling passage 32 by the heat pipe, so there may be a distance between the HV device 31 and the cooling passage 32, and complex arrangement of the cooling passage 32 is not required to bring the cooling passage 32 into contact with the HV device 31. As a result, it is possible to improve the flexibility of arrangement of the HV device 31.

[0040] The HV 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 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.

[0041] The heat exchanger 18 is arranged inside a duct 90 through which air flows. The heat exchanger 18 exchanges heat between refrigerant and air-conditioning air flowing through the duct 90 to adjust the temperature of air-conditioning air. 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.

[0042] As the fan 93 is driven, air flows through the duct 90. As the fan 93 operates, air-conditioning air flows into the duct 90 via the duct inlet 91. Air flowing into the duct 90 may be outside air or may be air in the cabin of the vehicle. The arrow 95 in FIG. 1 indicates flow of air-conditioning air that flows via the heat exchanger 18 and exchanges heat with refrigerant in the vapor compression refrigeration cycle 10. During cooling operation, air-conditioning air is cooled in the heat exchanger 18, and refrigerant receives heat transferred from air-conditioning air to be heated. The arrow 96 indicates flow of air-conditioning air that is adjusted in temperature by the heat exchanger 18 and that flows out from the duct 90 via the duct outlet 92.

[0043] 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 27 to circulate in the vapor compression refrigeration cycle 10. Refrigerant flows in the vapor compression refrigeration cycle 10 so as to sequentially pass through points A, B, C, D, E and F shown in FIG. 1, and refrigerant circulates among the compressor 12, the heat exchangers 14 and 15, the expansion valve 16 and the heat exchanger 18.

[0044] FIG. 2 is a Mollier chart that shows the state of refrigerant in the vapor compression refrigeration cycle 10. In FIG. 2, the abscissa axis represents the specific enthalpy (unit: kJ/kg) of refrigerant, and the ordinate axis represents the absolute pressure (unit: MPa) of refrigerant. The curve in the chart is the saturation vapor line and saturation liquid line of refrigerant. FIG. 2 shows the thermodynamic state of refrigerant at points (that is, points A, B, C, D, E and F) in the vapor compression refrigeration cycle 10 when refrigerant heat flows from the refrigerant line 22 at the outlet of the exchanger 14 into the refrigerant line 34 via the gas-liquid separator 40, cools the HV device 31 and returns from the refrigerant line 36 to the refrigerant line 24 at the inlet of the heat exchanger 15 via point D.

[0045] As shown in FIG. 2, refrigerant (point A) in a superheated steam state, introduced into the compressor 12, is adiabatically compressed in the compressor 12 along a constant specific entropy line. As refrigerant is compressed, the refrigerant increases in pressure and temperature into high-temperature and high-pressure superheated steam having a high degree of superheat (point B), and then the refrigerant flows to the heat exchanger 14. Gaseous refrigerant discharged from the compressor 12 releases heat to the surroundings to be cooled in the heat exchanger 14 to thereby condense (liquefy). Due to heat exchange 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. Condensed refrigerant within refrigerant in a gas-liquid two-phase state is in the state of saturated liquid (point C).

[0046] Refrigerant is separated in the gas-liquid separator 40 into gaseous refrigerant and liquid refrigerant. Refrigerant liquid in a liquid phase within refrigerant separated into gas and liquid flows from the gas-liquid separator 40 to the cooling passage 32 of the cooling device 30 via the refrigerant line 34 to cool the HV device 31. In the cooling device 30, heat is released to liquid refrigerant in a saturated liquid state, which is condensed as it passes through the heat exchanger 14, to thereby cool the HV device 31. Refrigerant is heated by exchanging heat with the HV device 31, and the dryness of the refrigerant increases. Refrigerant receives latent heat from the HV device 31 to partially vaporize into wet steam that mixedly contains saturated liquid and saturated steam (point D).

[0047] After that, refrigerant flows into the heat exchanger 15. Wet steam of refrigerant exchanges 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 (point E). After that, 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 (point F).

[0048] 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. When refrigerant flows through the tubes of the heat exchanger 18, the refrigerant absorbs heat of air in the cabin of the vehicle as latent heat of vaporization via the fins to evaporate with a constant pressure. As the entire refrigerant becomes dry saturated steam, the refrigerant steam further increases in temperature by sensible heat to become superheated steam (point A). After that, refrigerant is introduced into the compressor 12 via the refrigerant line 27. The compressor 12 compresses refrigerant flowing from the heat exchanger 18.

[0049] 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.

[0050] 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 flowing out from the heat exchanger 14 and separated by the gas-liquid separator 40 into gas and liquid flows to the cooling device 30 and exchanges heat with the HV device 31 to thereby cool the HV device 31. The cooling system 1 cools the HV 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 HV device 31 is desirably at least lower than the upper limit of a target temperature range of the HV device 31.

[0051] 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 HV 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 HV device 31. Therefore, components required for the cooling system 1 to cool the HV 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 HV device 31, and power consumption for operating the power source is not required. Thus, it is possible to reduce power consumption for cooling the HV device 31.

[0052] In the heat exchanger 14, refrigerant just needs to be cooled into a wet steam state. Refrigerant in a gas-liquid mixing state is separated by the gas-liquid separator 40, and only refrigerant liquid in a saturated liquid state is supplied to the cooling device 30. Refrigerant in a wet steam state, which receives latent heat of vaporization from the HV 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.

[0053] The refrigerant line 23 that forms part of the path of refrigerant from the outlet of the heat exchanger 14 toward the inlet of the expansion valve 16 is provided between the heat exchanger 14 and the heat exchanger 15. The refrigerant line 23 that does not pass through the cooling device 30 and the refrigerant lines 34 and 36 and cooling passage 32 that form the path of refrigerant passing through the cooling device 30 to cool the HV device 31 are provided in parallel with each other as the paths through which refrigerant flowing from the gas-liquid separator 40 toward the expansion valve 16. The cooling system for cooling the HV device 31, including the refrigerant lines 34 and 36, is connected in parallel with the refrigerant line 23. Therefore, only part of refrigerant flowing out from the heat exchanger 14 flows to the cooling device 30. Refrigerant in an amount required to cool the HV device 31 is caused to flow to the cooling device 30, and the HV device 31 is appropriately cooled. Thus, it is possible to prevent excessive cooling of the HV device 31.

[0054] The path of refrigerant that directly flows from the heat exchanger 14 to the heat exchanger 15 and the path of refrigerant that flows from the heat exchanger 14 to the heat exchanger 15 via the cooling device 30 are provided in parallel with each other, and only part of refrigerant is caused to flow to the refrigerant lines 34 and 36. By so doing, it is possible to reduce the pressure loss at the time when refrigerant flows through the cooling system for cooling the HV device 31. Not the entire refrigerant flows to the cooling device 30. Therefore, it is possible to reduce the pressure loss associated with flow of refrigerant via the cooling device 30, and, accordingly, it is possible to reduce power consumption required to operate the compressor 12 for circulating refrigerant.

[0055] When low-temperature and low-pressure refrigerant after passing through the expansion valve 16 is used to cool the HV 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 device 30 for cooling the HV device 31 is provided between the heat exchanger 14 and the heat exchanger 15. The heat exchanger 15 is provided on the path of refrigerant flowing from the cooling device 30 toward the expansion valve 16.

[0056] By sufficiently cooling refrigerant, which receives latent heat of vaporization from the HV 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. In this way, by setting the heat radiation performance for the heat exchanger 15 so as to be able to sufficiently cool refrigerant, the HV device 31 may be cooled without any influence on the cooling performance for cooling the cabin. Thus, both the cooling performance for cooling the HV device 31 and the cooling performance for cooling the cabin may be reliably ensured.

[0057] When refrigerant flowing from the heat exchanger 14 to the cooling device 30 cools the HV device 31, the refrigerant receives heat from the HV 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 device 30, the amount of heat exchanged between the refrigerant and the HV device 31 reduces, and the HV 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 HV device 31.

[0058] 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 HV device 31 may be maintained in a wet steam state, and a reduction in the amount of heat exchanged between refrigerant and the HV device 31 may be avoided, so it is possible to sufficiently cool the HV device 31. Refrigerant in a wet steam state after cooling the HV 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 HV device 31.

[0059] Refrigerant in a gas-liquid two-phase state at the outlet of the heat exchanger 14 is separated into gas and liquid in the gas-liquid separator 40. Gaseous refrigerant separated in the gas-liquid separator 40 flows via the refrigerant lines 23 and 24 and is directly supplied to the heat exchanger 15. Liquid refrigerant separated in the gas-liquid separator 40 flows via the refrigerant line 34 and is supplied to the cooling device 30 to cool the HV device 31. The liquid refrigerant is refrigerant in a just saturated liquid state. By taking only liquid refrigerant from the gas-liquid separator 40 and flowing the liquid refrigerant to the cooling device 30, the performance of the heat exchanger 14 may be fully utilized to cool the HV device 31, so it is possible to provide the cooling system 1 having improved cooling performance for cooling the HV device 31.

[0060] Refrigerant in a saturated liquid state at the outlet of the gas-liquid separator 40 is introduced into the cooling passage 32 that cools the HV device 31 to thereby make it possible to minimize gaseous refrigerant within refrigerant that flows in the cooling system for cooling the HV device 31, including the refrigerant lines 34 and 36 and the cooling passage 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 HV 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.

[0061] Refrigerant liquid in a saturated liquid state is stored inside the gas-liquid separator 40. The gas-liquid separator 40 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 40, the flow rate of refrigerant flowing from the gas-liquid separator 40 to the cooling device 30 may be maintained at the time of fluctuations in load. Because the gas-liquid separator 40 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 HV device 31 may be stabilized.

[0062] Referring back to FIG. 1, the cooling system 1 includes a flow regulating valve 28. The flow regulating valve 28 is arranged in the refrigerant line 23, which forms one of the parallel connected paths, on the path of refrigerant from the heat exchanger 14 toward the expansion valve 16. The flow regulating valve 28 changes its valve opening degree to increase or reduce the pressure loss of refrigerant flowing in the refrigerant line 23 to thereby selectively adjust the flow rate of refrigerant flowing in the refrigerant line 23 and the flow rate of refrigerant flowing in the cooling system for cooing the HV device 31, including the cooling passage 32.

[0063] For example, as the flow regulating valve 28 is fully closed to set the valve opening degree at 0%, the entire amount of refrigerant from the heat exchanger 14 flows into the refrigerant line 34 via the gas-liquid separator 40. When the valve opening degree of the flow regulating valve 28 is increased, the flow rate of refrigerant that flows directly to the heat exchanger 15 via the refrigerant line 23 increases and the flow rate of refrigerant that flows to the cooling passage 32 via the refrigerant line 34 to cool the HV device 31 reduces within refrigerant that flows from the heat exchanger 14 to the refrigerant line 22. When the valve opening degree of the flow regulating valve 28 is reduced, the flow rate of refrigerant that directly flows to the heat exchanger 15 via the refrigerant line 23 reduces and the flow rate of refrigerant that flows via the cooling passage 32 to cool the HV device 31 increases within refrigerant that flows from the heat exchanger 14 to the refrigerant line 22.

[0064] As the valve opening degree of the flow regulating valve 28 is increased, the flow rate of refrigerant that cools the HV device 31 reduces, so cooling performance for cooling the HV device 31 decreases. As the valve opening degree of the flow regulating valve 28 reduces, the flow rate of refrigerant that cools the HV device 31 increases, so cooling performance for cooling the HV device 31 improves. The flow regulating valve 28 is used to make it possible to optimally adjust the amount of refrigerant flowing to the HV device 31, so it is possible to reliably prevent excessive cooling of the HV device 31, and, in addition, it is possible to reliably reduce pressure loss associated with flow of refrigerant in the cooling system for cooling the HV device 31 and the power consumption of the compressor 12 for circulating refrigerant.

[0065] The cooling system 1 further includes a communication line 51. The communication line 51 provides fluid communication between the refrigerant line 21, through which refrigerant flows between the compressor 12 and the heat exchanger 14, and the refrigerant line 36 on the downstream side of the cooling device 30 between the refrigerant lines 34 and 36 that flow refrigerant through the cooling device 30. A selector valve 52 is provided in the refrigerant line 36 and the communication line 51. The selector valve 52 switches the state of fluid communication between the communication line 51 and the refrigerant lines 21 and 36. The selector valve 52 switches between the open state and the closed state to thereby allow or interrupt flow of refrigerant via the communication line 51. The refrigerant line 36 is divided into a refrigerant line 36a on the upstream side of a branching portion from the communication line 51 and a refrigerant line 36b on the downstream side of the branching portion from the communication line 51.

[0066] By switching the path of refrigerant using the selector valve 52, refrigerant after cooling the HV device 31 may be caused to flow to any selected one of the paths, that is, to the heat exchanger 15 via the refrigerant lines 36b and 24 or to the heat exchanger 14 via the communication line 51 and the refrigerant line 21.

[0067] More specifically, two valves 57 and 58 are provided as the selector valve 52. During cooling operation of the vapor compression refrigeration cycle 10, the valve 57 is fully open (valve opening degree 100%) and the valve 58 is fully closed (valve opening degree 0%), and the valve opening degree of the flow regulating valve 28 is adjusted such that a sufficient amount of refrigerant flows through the cooling device 30. By so doing, refrigerant flowing through the cooling passage 36a after cooling the HV device 31 may be reliably caused to flow to the heat exchanger 15 via the refrigerant line 36b. On the other hand, during a stop of the vapor compression refrigeration cycle 10, the valve 58 is fully open and the valve 57 is fully closed, and, furthermore, the flow regulating valve 28 is fully closed. By so doing, refrigerant flowing through the refrigerant line 36a after cooling the HV device 31 may be caused to flow to the heat exchanger 14 via the communication line 51 to make it possible to form an annular path that causes refrigerant to circulate between the cooling device 30 and the heat exchanger 14.

[0068] FIG. 3 is a schematic view that shows flow of refrigerant that cools the HV device 31 during operation of the vapor compression refrigeration cycle 10. FIG. 4 is a schematic view that shows flow of refrigerant that cools the HV device 31 during a stop of the vapor compression refrigeration cycle 10. FIG. 3 shows flow of refrigerant when the vapor compression refrigeration cycle 10 is operated, that is, when the compressor 12 is operated to flow refrigerant through the whole of the vapor compression refrigeration cycle 10. On the other hand, FIG. 4 shows flow of refrigerant when the vapor compression refrigeration cycle 10 is stopped, that is, when the compressor 12 is stopped to circulate refrigerant via the annular path that connects the cooling device 30 to the heat exchanger 14.

[0069] As shown in FIG. 3, during "air-conditioner operation mode" in which the compressor 12 is driven and the vapor compression refrigeration cycle 10 is operated, the flow regulating valve 28 is adjusted in valve opening degree such that a sufficient amount of refrigerant flows through the cooling device 30. The selector valve 52 is operated so as to flow refrigerant from the cooling device 30 to the expansion valve 16 via the heat exchanger 15. That is, as the valve 57 is fully open and the valve 58 is fully closed, the path of refrigerant that causes refrigerant to flow through the whole of the cooling system 1 is selected. Therefore, the cooling performance of the vapor compression refrigeration cycle 10 may be ensured, and the HV device 31 may be efficiently cooled.

[0070] As shown in FIG. 4, during "heat pipe operation mode" in which the compressor 12 is stopped and the vapor compression refrigeration cycle 10 is stopped, the selector valve 52 is operated so as to circulate refrigerant from the cooling device 30 to the heat exchanger 14. That is, as the valve 57 is fully closed, the valve 58 is fully open and the flow regulating valve 28 is fully closed, refrigerant does not flow to the refrigerant line 36b but flows via the communication line 51. By so doing, a closed annular path is formed. The closed annular path is routed from the heat exchanger 14 to the cooling device 30 via the refrigerant line 22 and the refrigerant line 34 sequentially, further passes through the refrigerant line 36a, the communication line 51 and the refrigerant line 21 sequentially and returns to the heat exchanger 14.

[0071] Refrigerant may be circulated between the heat exchanger 14 and the cooling device 30 via the annular path without operating the compressor 12. When refrigerant cools the HV device 31, the refrigerant receives latent heat of vaporization from the HV device 31 to evaporate. Refrigerant steam vaporized by exchanging heat with the HV device 31 flows to the heat exchanger 14 via the refrigerant line 36a, the communication line 51 and the refrigerant line 21 sequentially. In the heat exchanger 14, refrigerant steam is cooled to condense by running wind of the vehicle or draft from an engine cooling radiator fan. Refrigerant liquid liquefied in the heat exchanger 14 returns to the cooling device 30 via the refrigerant lines 22 and 34.

[0072] In this way, a heat pipe in which the HV device 31 serves as a heating portion and the heat exchanger 14 serves as a cooling device is formed by the annular path that passes through the cooling device 30 and the heat exchanger 14. Thus, when the vapor compression refrigeration cycle 10 is stopped, that is, when a cooler for the vehicle is stopped as well, the HV device 31 may be reliably cooled without the necessity of start-up of the compressor 12. Because the compressor 12 is not required to constantly operate in order to cool the HV device 31, the power consumption of the compressor 12 is reduced to thereby make it possible to improve the fuel economy of the vehicle and, in addition, to extend the life of the compressor 12, so it is possible to improve the reliability of the compressor 12.

[0073] FIG. 3 and FIG. 4 show a ground 60. The cooling device 30 is arranged below the heat exchanger 14 in the vertical direction perpendicular to the ground 60. In the annular path that circulates refrigerant between the heat exchanger 14 and the cooling device 30, the cooling device 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 device 30.

[0074] In this case, refrigerant steam heated and vaporized in the cooling device 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 device 30. That is, a thermo-siphon heat pipe is formed of the cooling device 30, the heat exchanger 14 and the refrigerant paths that connect them. Because the heat transfer efficiency from the HV device 31 to the heat exchanger 14 may be improved by forming the heat pipe, when the vapor compression refrigeration cycle 10 is stopped as well, the HV device 31 may be further efficiently cooled without additional power.

[0075] The selector valve 52 that switches the state of fluid communication between the communication line 51 and the refrigerant lines 21 and 36 may be the above described pair of valves 57 and 58 or may be a three-way valve that is arranged at the branching portion between the refrigerant line 36 and the communication line 51. In any cases, during both operation and stop of the vapor compression refrigeration cycle 10, the HV device 31 may be efficiently cooled. The valves 57 and 58 just need to have a simple structure so as to be able to open or close the refrigerant line, so the valves 57 and 58 are not expensive, and the two valves 57 and 58 are used to make it possible to provide the further low-cost cooling system 1. On the other hand, it is presumable that a space required to arrange the three-way valve is smaller than a space required to arrange the two valves 57 and 58, and the three-way valve is used to make it possible to provide the cooling system 1 having a further reduced size and excellent vehicle mountability.

[0076] The cooling system 1 further includes a check valve 54. The check valve 54 is arranged in the refrigerant line 21 between the compressor 12 and the heat exchanger 14 on the side closer to the compressor 12 than the connection portion between the refrigerant line 21 and the communication line 51. The check valve 54 allows flow of refrigerant from the compressor 12 toward the heat exchanger 14 and prohibits flow of refrigerant in the opposite direction. By so doing, during the heat pipe operation mode shown in FIG. 4, a closed loop path of refrigerant for circulating refrigerant between the heat exchanger 14 and the cooling device 30 may be reliably formed.

[0077] When no check valve 54 is provided, refrigerant may flow from the communication line 51 to the refrigerant line 21 adjacent to the compressor 12. By providing the check valve 54, it is possible to reliably prohibit flow of refrigerant from the communication line 51 toward the side adjacent to the compressor 12, so it is possible to prevent a decrease in the cooling performance for cooling the HV device 31 during a stop of the vapor compression refrigeration cycle 10, using the heat pipe that forms the annular refrigerant path. Thus, when the cooler for the cabin of the vehicle is stopped as well, it is possible to efficiently cool the HV device 31.

[0078] In addition, when the amount of refrigerant in the closed loop path of refrigerant is insufficient during a stop of the vapor compression refrigeration cycle 10, the compressor 12 is operated only in a short period of time to thereby make it possible to supply refrigerant to the closed loop path via the check valve 54. By so doing, the amount of refrigerant in the closed loop may be increased to thereby increase the amount of heat exchanged in the heat pipe. Thus, the amount of refrigerant in the heat pipe may be ensured, so it is possible to avoid insufficient cooling of the HV device 31 because of an insufficient amount of refrigerant.

[0079] Hereinafter, the detailed structure of the cooling device 30 will be described. FIG. 5 is a partially cross-sectional view of the cooling device 30. The HV device 31 that serves as the heat generating source includes a plurality of HV devices 31a to 31d. The HV devices 31a to 31d are mounted on a substrate 70. The HV devices 31a to 31d are, for example, insulated gate bipolar transistors (IGBTs) included in an inverter and/or a converter. The HV devices 31 (31a to 31d) are in thermal contact with the outer face 69 of the bottom portion 65 of the cooling passage 32 via the substrate 70. As described above, the substrate 70 may be directly in contact with the outer face 69 or a heat pipe may be interposed between the substrate 70 and the outer face 69.

[0080] The cooling passage 32 included in the cooling device 30 has a tank shape. Refrigerant flows through the internal space of the cooling passage 32. The cooling passage 32 has an inlet end portion 61 and an outlet end portion 63. The inlet end portion 61 is an end portion to which the refrigerant line 34 is coupled. The outlet end portion 63 is an end portion to which the refrigerant line 36 is coupled. The inlet end portion 61 shown at the left side in FIG. 5 has a through hole 62. Refrigerant flowing through the refrigerant line 34 flows into the cooling passage 32 via the through hole 62. The outlet end portion 63 shown at the right side in FIG. 5 has a through hole 64. Refrigerant flows out from the cooling passage 32 via the through hole 64, and flows to the refrigerant line 36.

[0081] The cooling passage 32 also has the bottom portion 65. The bottom portion 65 forms part of the vertically lower side of the cooling passage 32. Liquid refrigerant flowing inside the cooling passage 32 flows along the bottom portion 65 from the inlet end portion 61 toward the outlet end portion 63. The bottom portion 65 has an inner face 66 and the outer face 69. Liquid refrigerant flowing inside the cooling passage 32 contacts with the inner face 66 of the bottom portion 65. The inner face 66 is a contact face with which refrigerant liquid contacts.

[0082] FIG. 6 is a partially enlarged perspective view of the inner face 66 of the bottom portion 65 of the cooling passage 32. As shown in FIG. 6, the inner face 66 is subjected to surface processing to thereby form a plurality of ridges 67 and a plurality of grooves 68. The ridges 67 and the grooves 68 extend from the inlet end portion 61 of the cooling passage 32 toward the outlet end portion 63. That is, the ridges 67 and the grooves 68 extend in the flow direction of refrigerant that flows inside the cooling passage 32.

[0083] Surface processing to which the inner face 66 is subjected in order to form the ridges 67 and the grooves 68 may be any known processing. For example, small grooves are formed on the inner face 66 to partially recess the inner face 66 to thereby form the ridges 67 and the grooves 68 or small fins are assembled to the inner face 66 to partially protrude the inner face 66 to thereby form the ridges 67 and the grooves 68. In addition, the shape of the inner face 66 is not limited to the shape having the ridges 67 and the grooves 68. For example, a plurality of pores may be formed in the inner face 66 to form the bottom portion 65 in a porous shape or a mesh member may be assembled to the inner face 66.

[0084] The inner face 66 is subjected to processing to thereby form a capillarity generating portion by which liquid refrigerant is movable from the lower side to the upper side because of capillarity. In the case of the inner face 66 configured as shown in FIG. 6, the grooves 68 function as the capillarity generating portion. That is, when the cooling passage 32 is inclined such that one of the inlet end portion 61 and the outlet end portion 63 is located on the upper side and the other one is located on the lower side, refrigerant liquid is able to rise from the lower one of the inlet end portion 61 and the outlet end portion 63 toward the upper one through the grooves 68.

[0085] FIG. 7 is a schematic view that shows a vehicle 100 that is running on a flat road. FIG. 8 is a cross-sectional view that shows the state of refrigerant liquid 80 inside the cooling passage 32 while the vehicle 100 is running on the flat road. When the vehicle 100 is running on the flat ground 60 shown in FIG. 7, the cooling device 30 is maintained parallel to the ground 60. Therefore, as shown in FIG. 8, the bottom portion 65 of the cooling passage 32 is arranged substantially horizontally, and the liquid surface of the refrigerant liquid 80 is also substantially horizontal. As described with reference to FIG. 1 and FIG. 2, liquid refrigerant flows from the inlet end portion 61 into the cooling passage 32, and the refrigerant liquid 80 is stored inside the cooling passage 32. The refrigerant liquid 80 is in contact with the entire bottom portion 65 of the cooling passage 32, so the plurality of HV devices 31a to 31d are uniformly cooled. Refrigerant steam that is generated through evaporation of the refrigerant liquid 80 as a result of heat exchange between refrigerant and the HV device 31 inside the cooling passage 32 flows out from the cooling passage 32 via the through hole 64 of the outlet end portion 63.

[0086] FIG. 9 is a schematic view that shows the vehicle 100 that is running on an uphill. FIG. 10 is a cross-sectional view that shows the state of the refrigerant liquid 80 inside the cooling passage 32 while the vehicle 100 is running on the uphill. When the ground 60 is inclined with respect to a horizontal plane and the vehicle 100 is running so as to go up the inclined ground 60 as shown in FIG. 9, the cooling passage 32 is inclined such that the inlet end portion 61 is relatively located on the upper side and the outlet end portion 63 is relatively located on the lower side as shown in FIG. 10. Therefore, the bottom portion 65 of the cooling passage 32 is also inclined such that the side adjacent to the inlet end portion 61 is located at a higher position and the side adjacent to the outlet end portion 63 is located at a lower position.

[0087] In this case, refrigerant that flows into the cooling passage 32 via the through hole 62 of the inlet end portion 61 flows from the side adjacent to the inlet end portion 61, located at a relatively high position, toward the side adjacent to the outlet end portion 63, and the refrigerant liquid 80 forms liquid pool at the outlet end portion 63 located at a relatively low position. The refrigerant liquid 80 continuously flows from the inlet end portion 61 to the outlet end portion 63 to maintain a state where the refrigerant liquid 80 contacts with the entire bottom portion 65 of the cooling passage 32. Therefore, the plurality of HV devices 31a to 31d are uniformly cooled.

[0088] FIG. 11 is a schematic view that shows the vehicle 100 that is running on a downhill. FIG. 12 is a cross-sectional view that shows the state of the refrigerant liquid 80 inside the cooling passage 32 while the vehicle 100 is running on the downhill. When the ground 60 is inclined with respect to a horizontal plane and the vehicle is running so as to go down the inclined ground 60 as shown in FIG. 11, the cooling passage 32 is inclined such that the inlet end portion 61 is relatively located on the lower side and the outlet end portion 63 is relatively located on the upper side as shown in FIG. 12. Therefore, the bottom portion 65 of the cooling passage 32 is also inclined such that the side adjacent to the inlet end portion 61 is located at a relatively low position and the side adjacent to the outlet end portion 63 is located at a relatively high position.

[0089] In this case, refrigerant flowing into the cooling passage 32 forms liquid pool at the inlet end portion 61 located at a relatively low position because of the inclined bottom portion 65. Here, the inner face 66 of the bottom portion 65 of the cooling passage 32 according to the present embodiment has the plurality of grooves 68 that function as the capillarity generating portion and that are described with reference to FIG. 6. Therefore, the refrigerant liquid 80 flows through the grooves so as to rise from the side adjacent to the inlet end portion 61 toward the side adjacent to the outlet end portion 63 due to capillarity.

[0090] Refrigerant liquid is caused to uniformly reach all the areas in the direction in which refrigerant liquid flows inside the cooling device 30 by utilizing capillarity to thereby maintain a state where the refrigerant liquid 80 contacts with the bottom portion 65 at the outlet end portion 63 as well. The amount of the refrigerant liquid 80 that flows toward the outlet end portion 63 in the grooves 68 using capillarity as driving force is small such that the liquid surface does not reach the height of the inner face 66. However, due to flow of the refrigerant liquid 80, a state where the refrigerant liquid 80 is in contact with the bottom portion 65 is kept over the entire bottom portion 65. Therefore, the cooling performance for cooling the HV device 31 does not fluctuate among positions within the bottom portion 65. That is, the HV device 31a adjacent to the inlet end portion 61 and the HV device 31d adjacent to the outlet end portion 63 are cooled by the refrigerant liquid 80 with the same cooling performance. Thus, the plurality of HV devices 31a to 31d may be uniformly cooled.

[0091] When the cooling passage 32 is inclined with running of the vehicle 100 and then a state (dryout) where the refrigerant liquid 80 partially does not contact with the bottom portion 65 of the cooling passage 32 occurs, the cooling performance for cooling any one of the HV devices 31 at that portion decreases. As a result, there occurs an inconvenience that the plurality of HV devices 31 cannot be uniformly cooled. In contrast to this, in the cooling system 1 according to the present embodiment, the inner face 66 of the bottom portion 65 of the cooling passage 32 has the capillarity generating portion. By so doing, even when the vehicle 100 is inclined, refrigerant liquid is caused to rise due to capillarity to thereby make it possible to keep a state where the entire bottom portion 65 is in contact with the refrigerant liquid 80. Therefore, it is possible to avoid occurrence of an inconvenience that the HV devices 31 are nonuniformly cooled.

[0092] Depending on the condition that the cooling device 30 is mounted on the vehicle 100, it is conceivable that the cooling passage 32 may be inclined even while the vehicle 100 is running on a flat road. In such a case as well, the capillarity generating portion is provided to thereby make it possible to cause refrigerant liquid to rise due to capillarity as in the case of the above, so a state where the entire bottom portion 65 is in contact with the refrigerant liquid 80 may be kept irrespective of the condition that the cooling device 30 is mounted, and it is possible to ensure the cooling performance for cooling the HV devices 31.

[0093] During the "air-conditioner operation mode" described with reference to FIG. 3, because the compressor 12 is driven, driving force for flowing refrigerant inside the cooling passage 32 is large, and dryout is hard to occur. In contrast to this, during the "heat pipe operation mode" described with reference to FIG. 4, a pressure difference that slightly occurs between the cooling device 30 and the heat exchanger 14 and liquid refrigerant supplied from the heat exchanger 14 to the cooling device 30 due to gravity operate as driving force for flowing refrigerant into the cooling passage 32. That is, during the "heat pipe operation mode", driving force that acts on refrigerant is relatively small, and the flow rate of refrigerant is relatively low, so dryout tends to occur.

[0094] Therefore, in the case of the cooling system 1 according to the present embodiment, which includes the communication line 51 to make it possible to switch between the "air-conditioner operation mode" and the "heat pipe operation mode", the inner face 66 of the bottom portion 65 inside the cooling passage 32 particularly desirably has the capillarity generating portion. The capillarity generating portion is formed of the above described grooves 68, or the like, to generate driving force. By so doing, during the "heat pipe operation mode" in which the flow rate of refrigerant is low as well, it is possible to further reliably supply refrigerant in a liquid state to the entire bottom portion 65. Thus, occurrence of dryout may be further suppressed, so the HV devices 31 may be further uniformly cooled.

[0095] Note that, in the above described embodiment, the cooling system 1 that cools an electrical device mounted on the vehicle is described using the HV 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 target temperature range for cooling is an appropriate temperature range as a temperature environment in which the electrical devices are operated.

[0096] The embodiment of the invention is described above. 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.

[0097] The cooling system according to the aspect of 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.

CLAIMS:

1. A cooling system that cools a heat generating source mounted on a vehicle, characterized by comprising:

a compressor that circulates refrigerant;

a first heat exchanger that performs heat exchange between the refrigerant and outside air;

a decompressor that decompresses the refrigerant;

a second heat exchanger that performs heat exchange between the refrigerant and air-conditioning air; and

a cooling device that is provided on a path of the refrigerant flowing between the first heat exchanger and the decompressor and that uses the refrigerant to cool the heat generating source, the cooling device including a capillarity generating portion that causes the refrigerant to rise due to capillarity.

2. The cooling system according to claim 1, wherein the capillarity generating portion is formed by subjecting an inner face of a bottom portion of the cooling device to surface processing.

3. The cooling system according to claim 2, wherein the inner face of the bottom portion of the cooling device has a plurality of grooves.

4. The cooling system according to any one of claims 1 to 3, wherein the capillarity generating portion extends in a flow direction of the refrigerant flowing through the cooling device.

5. The cooling system according to any one of claims 1 to 4, wherein the heat generating source is in thermal contact with an outer face of a bottom portion of the

cooling device.

6. The cooling system according to claim 5, wherein the heat generating source is directly in contact with the outer face of the bottom portion of the cooling device or is in contact with the outer face via a heat pipe.

7. The cooling system according to any one of claims 1 to 6, further comprising:

a first line through which the refrigerant flows between the compressor and the first heat exchanger;

a second line through which the refrigerant flows between the cooling device and the decompressor; and

a communication line that provides fluid communication between the first line and the second line.

8. The cooling system according to claim 7, further comprising:

a third line through which the refrigerant flows between the decompressor and the second heat exchanger; and

a fourth line through which the refrigerant flows between the second heat exchanger and the compressor.

FIG. 1

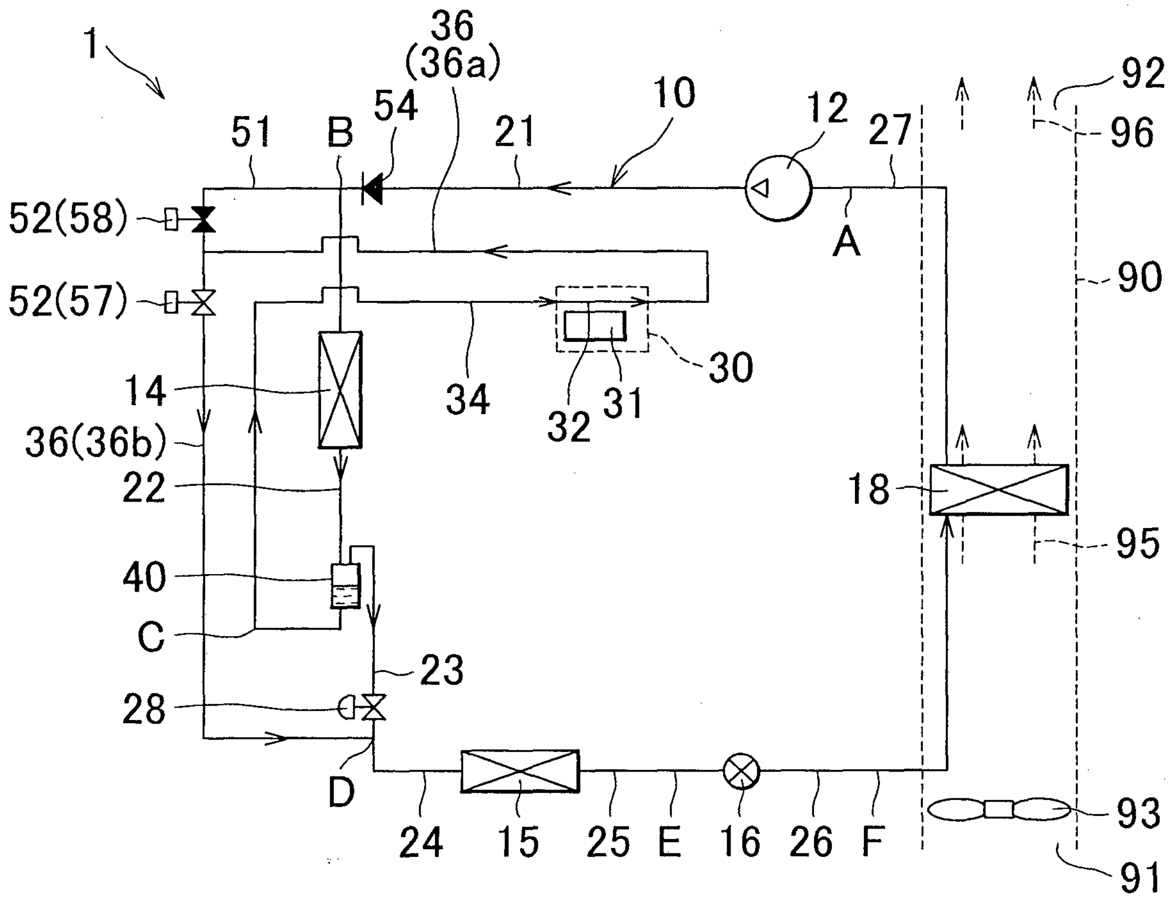

1
36
(36a)
54
10
12
92
51
B
21
27
96
52(58)
A
52(57)
90
14
34
30
36(36b)
32
31
22
18
40
95
C
23
28
D
24
15
25
E
16
26
F
93
91

FIG.2

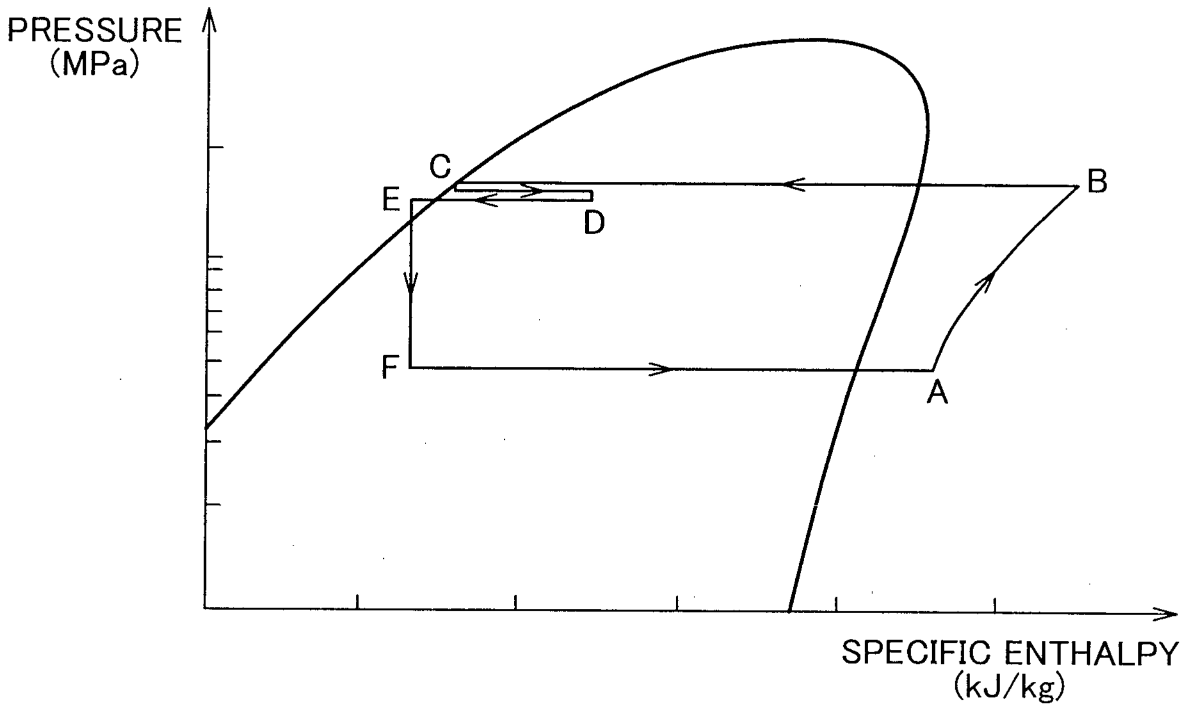
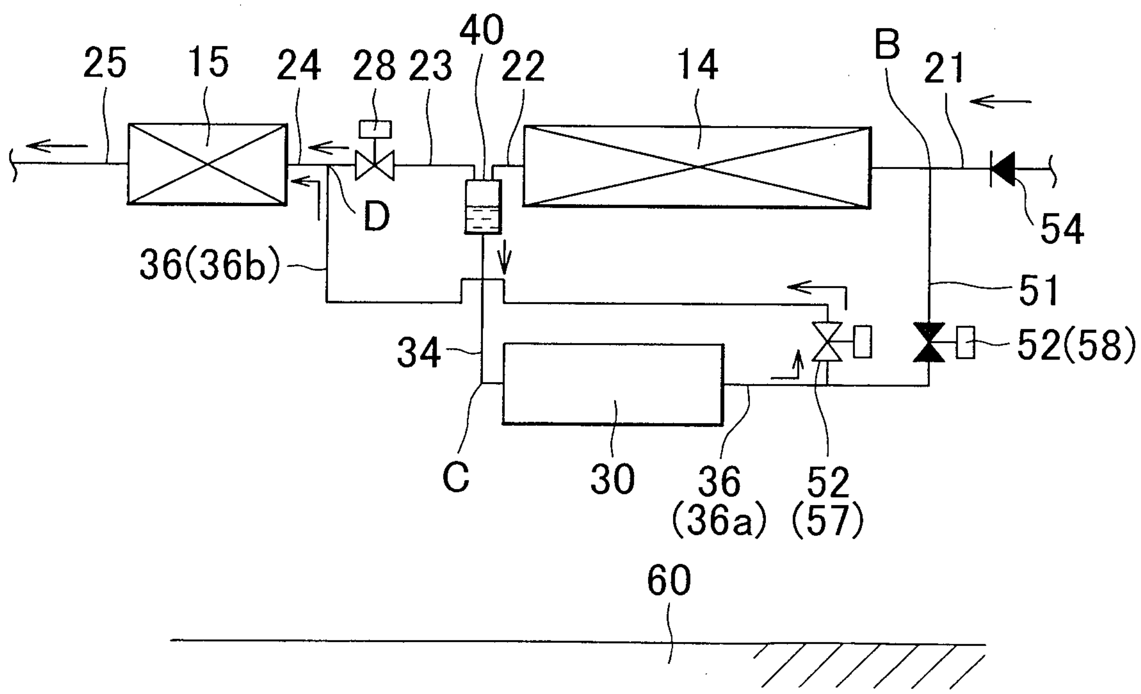

PRESSURE
(MPa)
C
B
E
D
F
A
SPECIFIC ENTHALPY
(kJ/kg)

FIG.3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28
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22
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B
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D
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36(36b)
51
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52(58)
C
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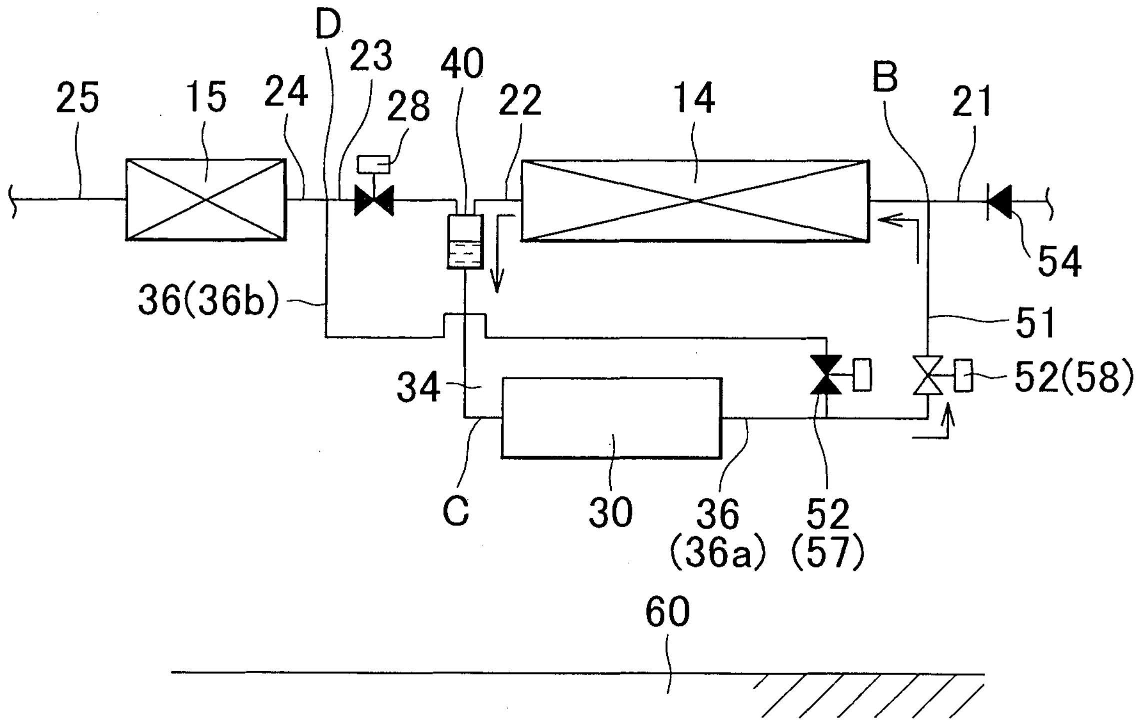
36
(36a)
52
(57)
60

FIG. 4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36(36b)
51
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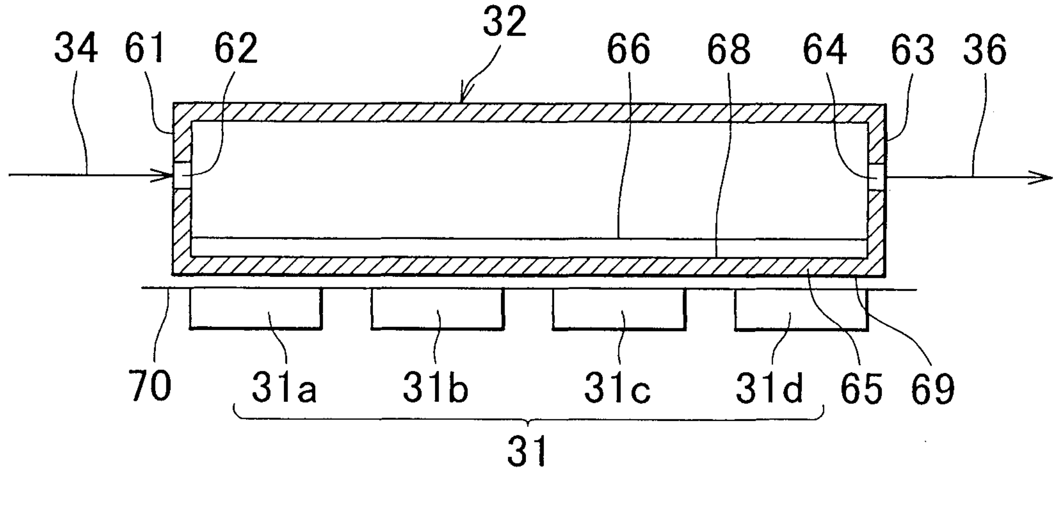
52(58)
C
30
36
(36a)
52
(57)
60

FIG. 5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31c
31d
65
69
31

FIG. 6

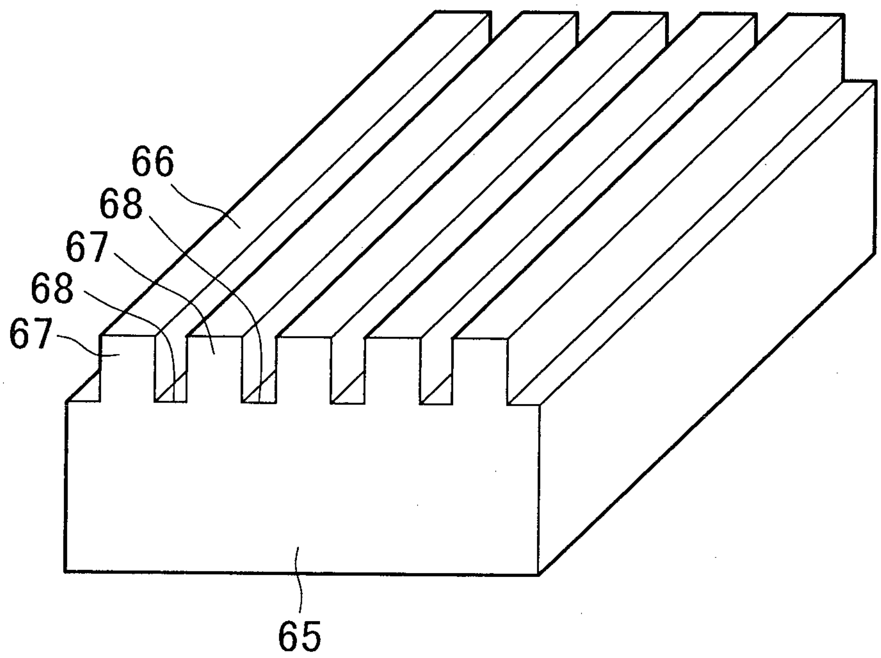


FIG. 7

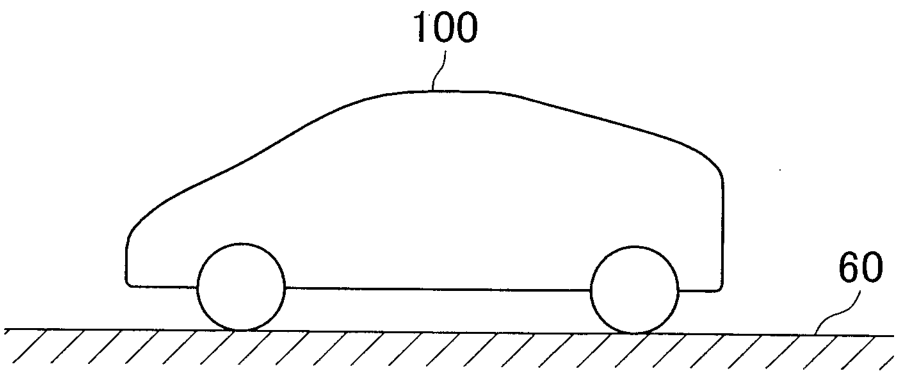


FIG. 8

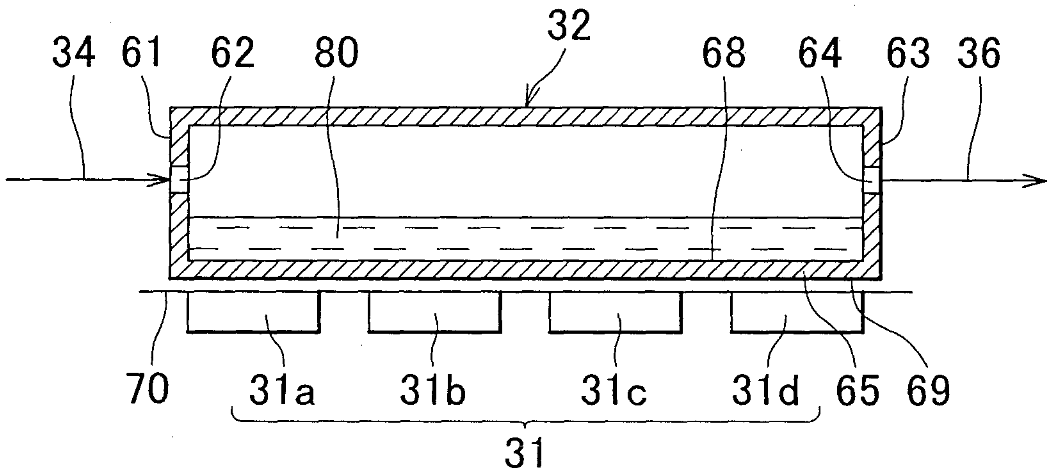


FIG. 9

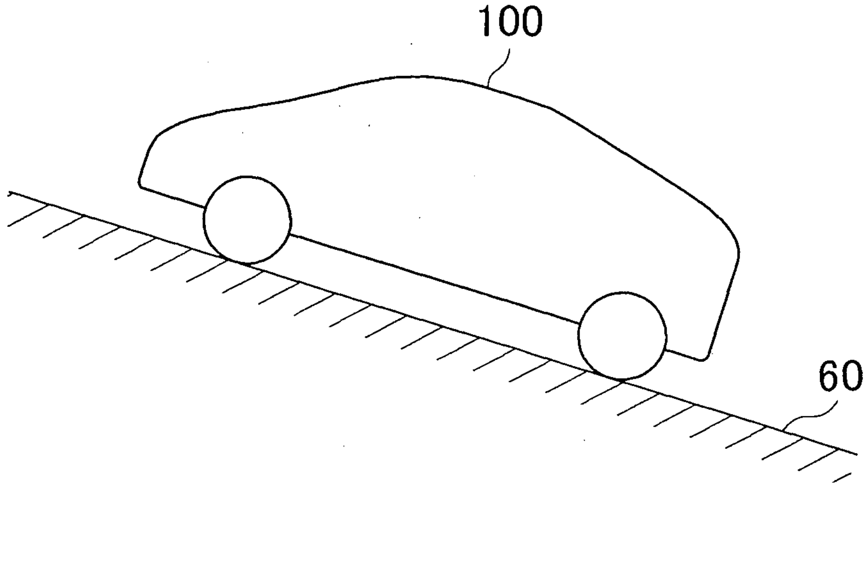


FIG. 10

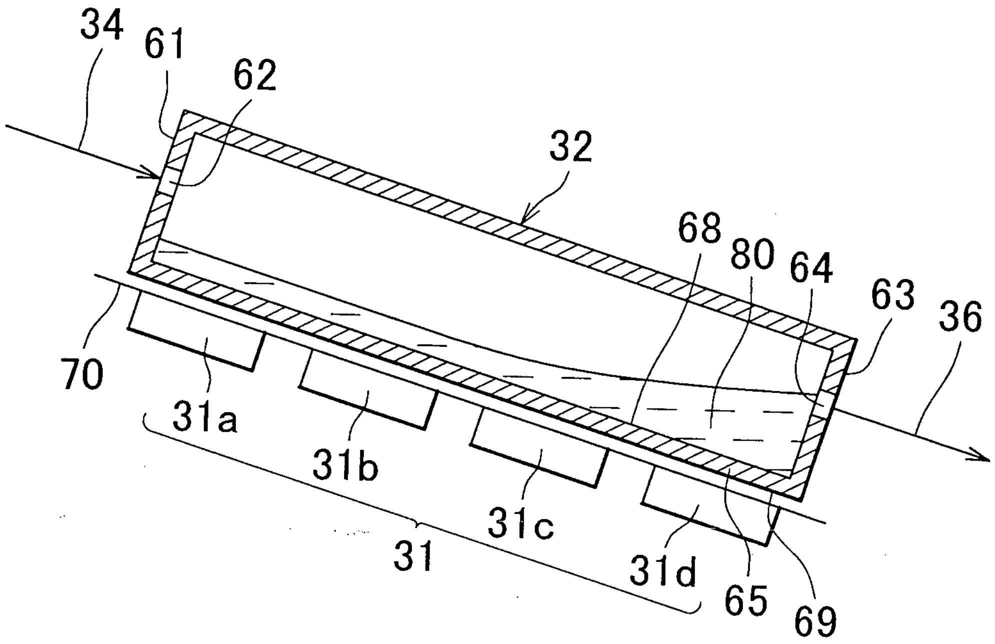


FIG. 11

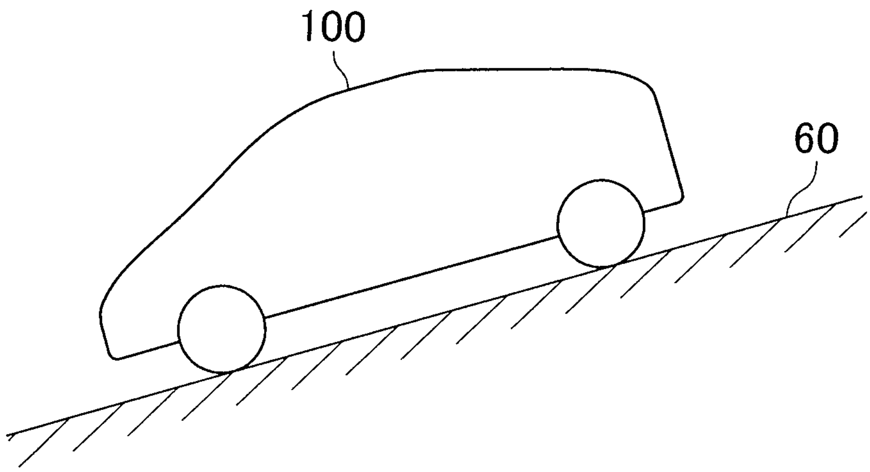
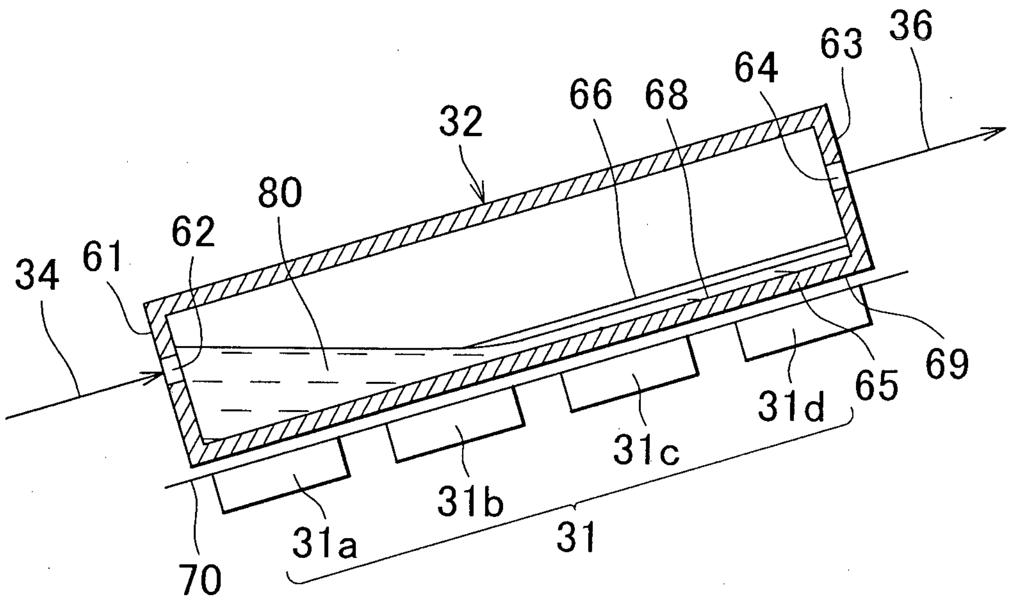


FIG. 12



INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/001419

A. CLASSIFICATION OF SUBJECT MATTER
INV. B60H1/00 B60H1/14
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B60H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2011/029538 A1 (AUDI NSU AUTO UNION AG [DE]; SCHROEDER DIRK [DE]; REBINGER CHRISTIAN [) 17 March 2011 (2011-03-17) columns 6-8; figure 2 -----	1-8
A	US 2003/200764 A1 (TAKEUCHI HIROTSUGU [JP] ET AL) 30 October 2003 (2003-10-30) paragraphs [0026] - [0043]; claims; figure 2 -----	1-8
A	EP 1 150 076 A2 (DENSO CORP [JP]) 31 October 2001 (2001-10-31) claims; figure 9 -----	1-8
A	US 2009/130513 A1 (TSUCHIYA NAOHISA [JP] ET AL) 21 May 2009 (2009-05-21) claim 1; figure 1 ----- -/--	1-8

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 November 2012	27/11/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Chavel, Jérôme

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2008 218718 A (TOYOTA MOTOR CORP) 18 September 2008 (2008-09-18) cited in the application abstract; figures 3-5	1-8
A	US 4 150 551 A (EISLER PAUL [GB]) 24 April 1979 (1979-04-24) claims; figures 1-5	1-8

1

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Information on patent family members

International application No
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