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(19) **United States**(12) **Patent Application Publication****Ishikawa et al.**(10) **Pub. No.: US 2007/0125106 A1**(43) **Pub. Date:****Jun. 7, 2007**(54) **SUPERCRITICAL REFRIGERATION CYCLE**(52) **U.S. CL.** 62/183; 62/186(75) Inventors: **Hiroshi Ishikawa**, Kariya-city (JP);
Toshio Tsuboko, Anjo-city (JP)(57) **ABSTRACT**

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HARNES, DICKEY & PIERCE, P.L.C.**P.O. BOX 828****BLOOMFIELD HILLS, MI 48303 (US)**(73) Assignee: **DENSO Corporation**, Kariya-city (JP)(21) Appl. No.: **11/600,254**(22) Filed: **Nov. 15, 2006**(30) **Foreign Application Priority Data**

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A supercritical refrigeration cycle comprises a radiator 2 for cooling the refrigerant discharged from a compressor 1, a cooling fan 2a for blowing the atmospheric air to the radiator 2, a decompression unit 4 for decompressing the refrigerant at the outlet of the radiator 2 and having the opening degree thereof controlled to achieve a target high pressure, and an evaporator 5 for evaporating the low-pressure refrigerant decompressed by the decompression unit 4. The high pressure exceeds the critical pressure of the refrigerant. A value of information representing the difference between the actual radiation state of the refrigerant at the outlet of the radiator 2 and the ideal radiation state determined by the atmospheric temperature is calculated, and based on this value of information, the air capacity of the cooling fan 2a is controlled to decrease the difference. Thus, the cooling fan of the high-pressure radiator can be properly controlled in the supercritical refrigeration cycle.

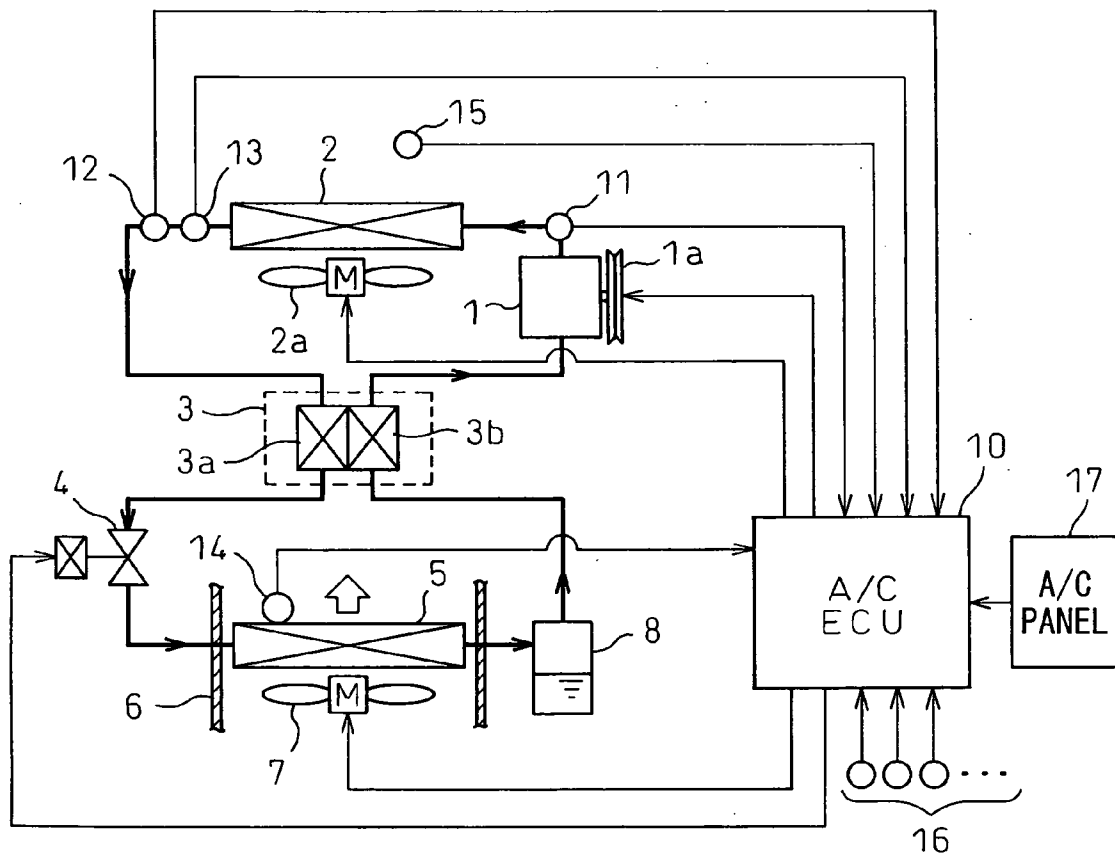


FIG. 1

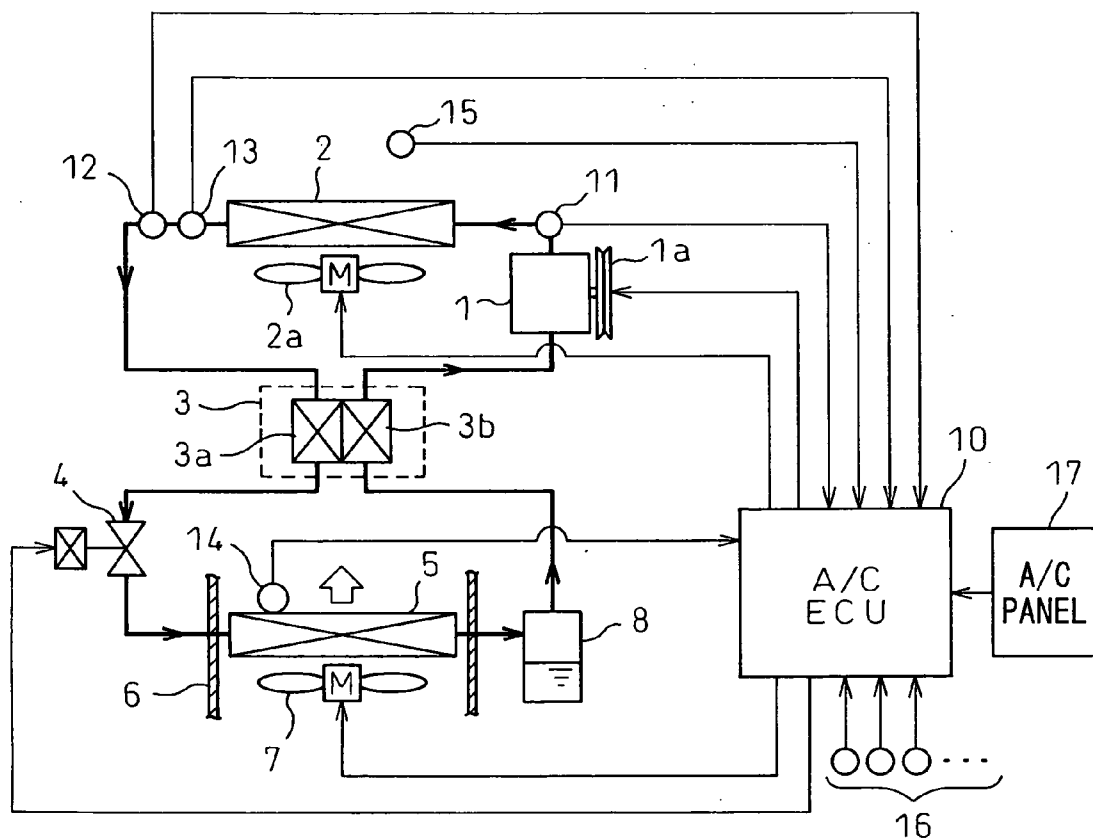


FIG. 2

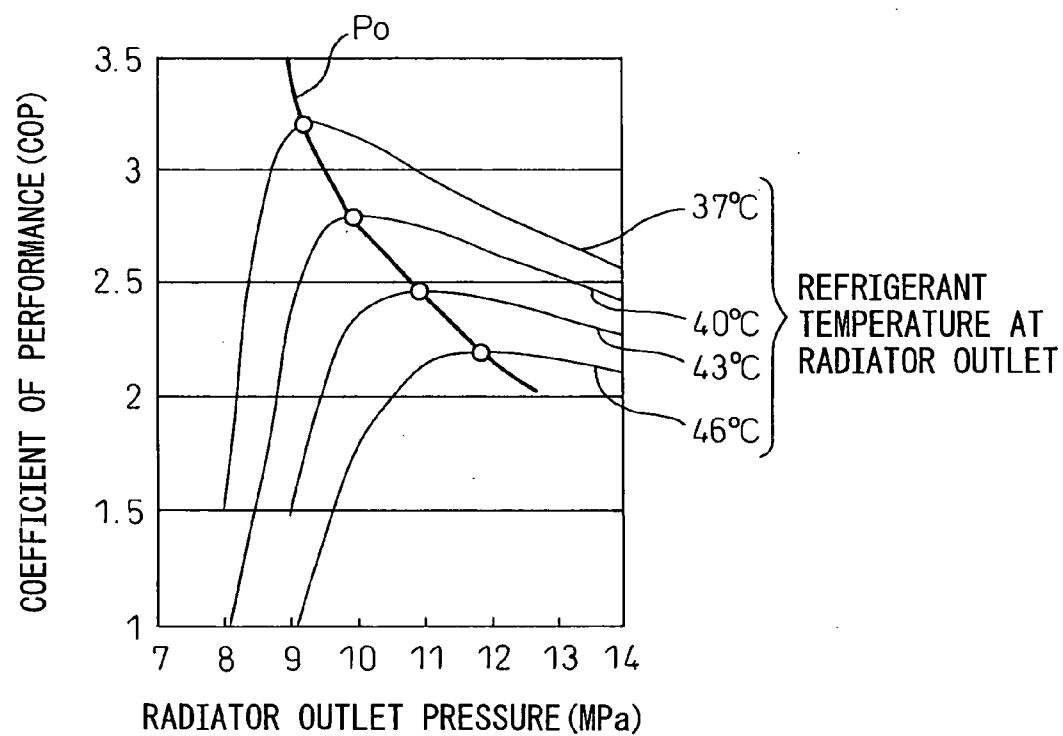


FIG. 3

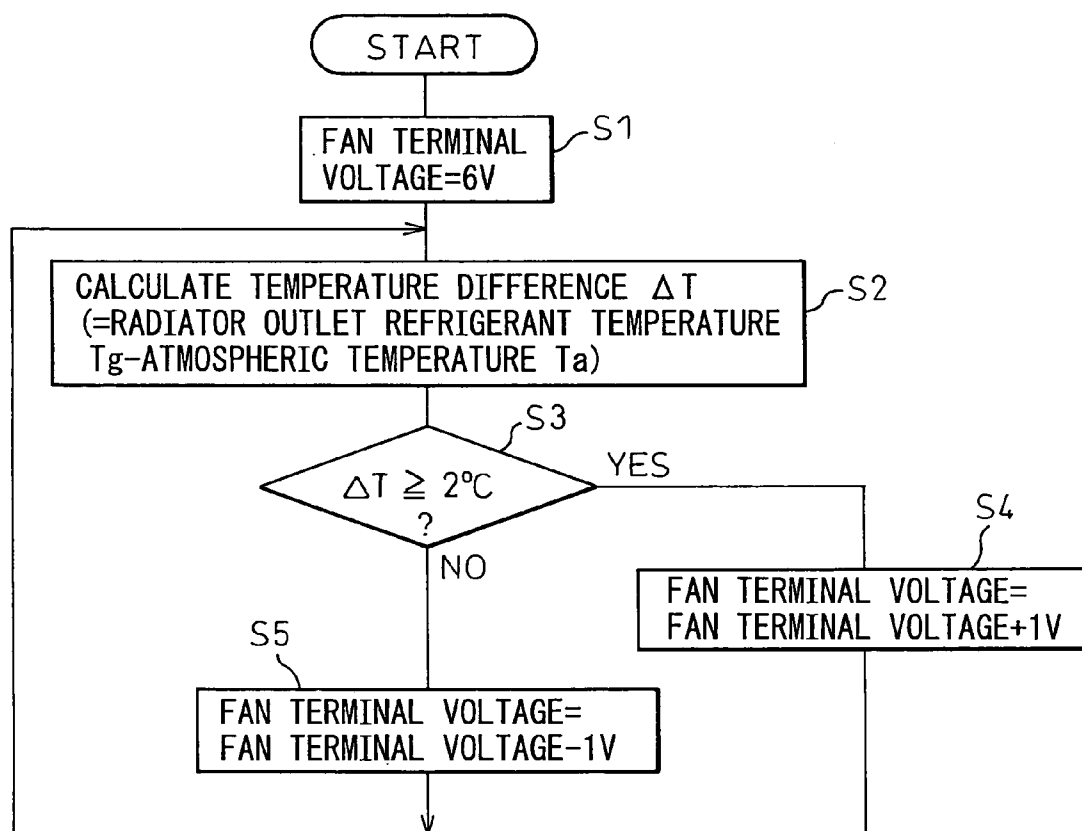


FIG. 4

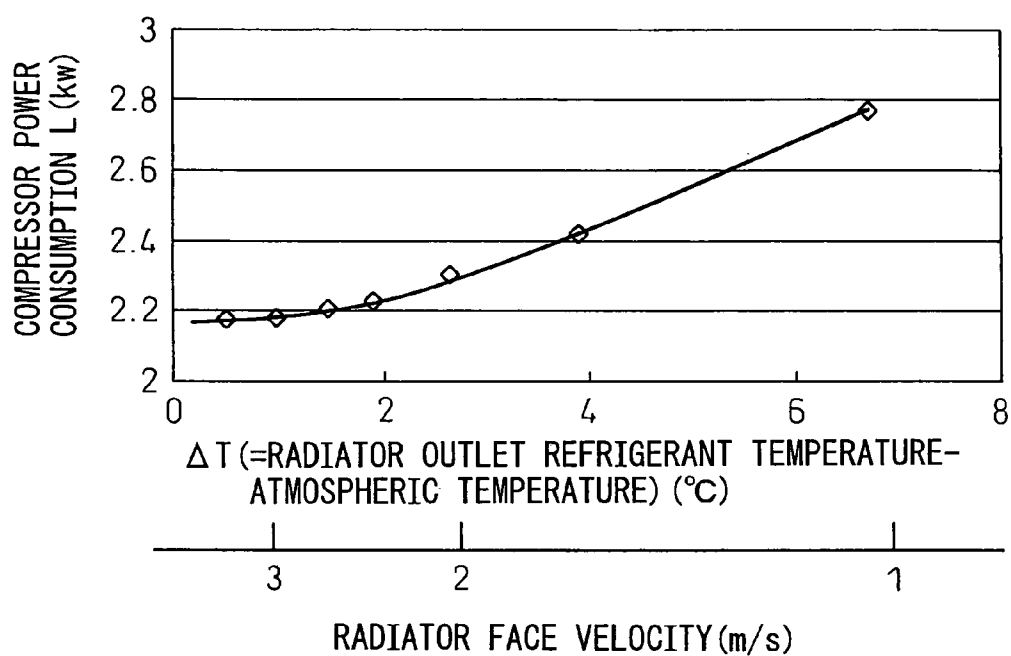


FIG. 5

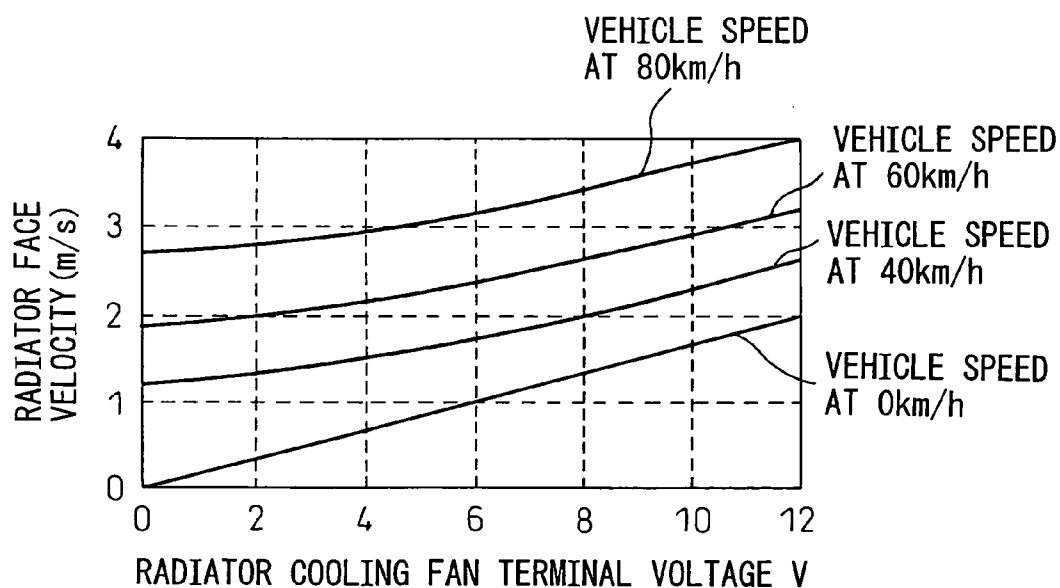
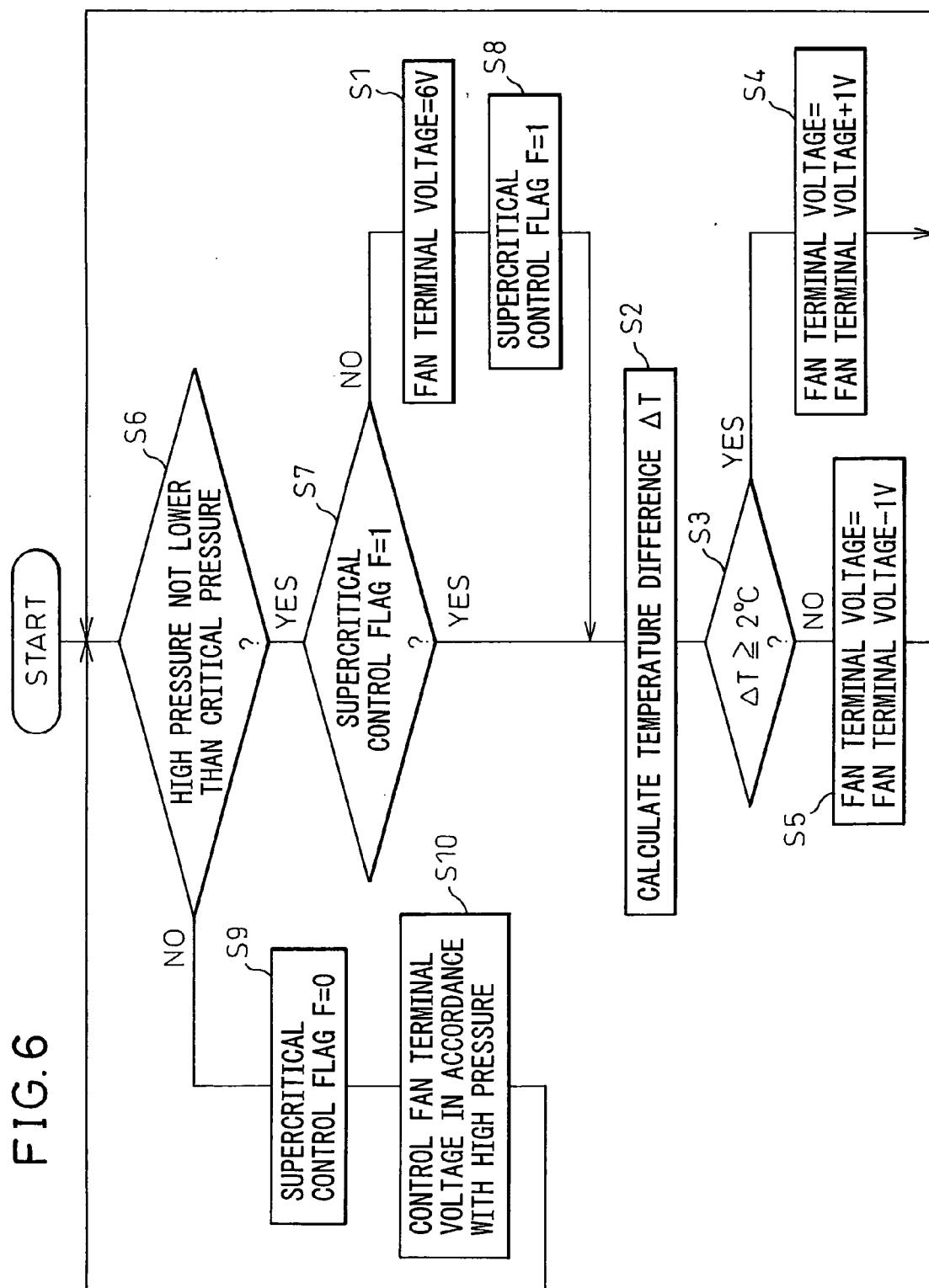


FIG. 6



SUPERCRITICAL REFRIGERATION CYCLE

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] This invention relates to the operation of controlling the cooling fan of a high-pressure radiator in a supercritical refrigeration cycle that uses CO₂ (carbon dioxide), of which the high pressure increases beyond the critical pressure (supercritical state), as a refrigerant.

[0003] 2. Description of the Related Art

[0004] In the supercritical refrigeration cycle using CO₂ as the refrigerant, as indicated by thick solid line in FIG. 2, the pressure at the outlet of the high-pressure radiator assuming the maximum value of the coefficient of performance (COP) is known to change with the refrigerant temperature at the outlet of the high-pressure radiator.

[0005] In view of this, it is known that the refrigerant temperature at the outlet of the high-pressure radiator is detected and, based on this refrigerant temperature at the outlet of the high-pressure radiator, the pressure at the outlet of the high-pressure radiator associated with the maximum COP is set as a target pressure Po, and the opening degree of an expansion valve is controlled so that the actual pressure at the outlet of the high-pressure radiator reach the target pressure Po thereby to improve the operating efficiency of the supercritical refrigeration cycle (Japanese Unexamined Patent Publication Nos. 11-125471 and 9-264622).

[0006] As described above, in the supercritical refrigeration cycle, the high pressure is automatically controlled to improve COP. Therefore, the high pressure is not an value of information representing the cooling load unlike the normal refrigeration cycle (hereinafter referred to as the subcritical refrigeration cycle) using an HFC-134a or similar refrigerant of which the high pressure does not exceed the critical pressure.

[0007] In the case where the operation of controlling the cooling fan of the high-pressure radiator in the subcritical refrigeration cycle, i.e. the operation of controlling the air capacity of the cooling fan, corresponding to the high pressure, is used as it is for the supercritical refrigeration cycle, therefore, the air capacity of the cooling fan would be inconveniently controlled upward more than necessary in spite of the fact that the radiation performance of the high-pressure radiator is sufficiently secured, thereby undesirably wasting the power consumed by the cooling fan.

SUMMARY OF THE INVENTION

[0008] In view of this situation, the object of this invention is to properly control the cooling fan of the high-pressure radiator in the supercritical refrigeration cycle.

[0009] In order to achieve this object, according to a first aspect of the invention, there is provided a supercritical refrigeration cycle comprising a radiator (2) for cooling the refrigerant discharged from a compressor (1), a cooling fan (2a) for blowing the atmospheric air to the radiator (2), a decompressor (4) for decompressing the refrigerant at the outlet of the radiator (2) and having the opening degree thereof controlled to achieve a target high pressure and an evaporator (5) for evaporating the low-pressure refrigerant

decompressed by the decompressor (4), the high pressure exceeding the critical pressure of the refrigerant,

[0010] wherein an value of information representing the difference between the actual radiation state of the refrigerant at the outlet of the radiator (2) and the ideal radiation state determined by the atmospheric temperature is calculated, and

[0011] wherein the air capacity of the cooling fan (2a) is controlled to reduce the difference based on the value of information.

[0012] In this aspect of the invention, the air capacity of the cooling fan (2a) can be controlled to reduce the difference between the actual radiation state of the refrigerant at the outlet of the radiator in the supercritical refrigeration cycle and the ideal radiation state determined by the atmospheric temperature, and therefore, the air capacity of the cooling fan (2a) can be properly controlled in accordance with the actual operation of the supercritical refrigeration cycle.

[0013] As a result, the power consumption of the compressor (1) and the cooling fan (2a) is reduced.

[0014] In view of the fact that the velocity and the capacity of the air passing through the radiator (2) are proportional to each other, the operation to control the air capacity according to the invention includes the operation to control the air velocity.

[0015] According to a second aspect of the invention, there is provided a supercritical refrigeration cycle, wherein the value of information is specifically the difference (ΔT) between the refrigerant temperature at the outlet of the radiator (2) and the atmospheric temperature.

[0016] According to a third aspect of the invention, there is provided a supercritical refrigeration cycle wherein, as long as the temperature difference (ΔT) is not less than a predetermined value, the air capacity of the cooling fan (2a) is controlled upward while, in the case where the temperature difference (ΔT) is less than the predetermined value, the air capacity of the cooling fan (2a) is controlled downward.

[0017] In this aspect of the invention, as long as the temperature difference (ΔT) is not less than the predetermined value, the air capacity of the cooling fan (2a) is increased so that the actual radiation state of the refrigerant at the outlet of the radiator (2) is made to approach the ideal radiation state, thereby reducing the high pressure of the cycle to reduce the power consumption of the compressor (1).

[0018] In the case where the temperature difference (ΔT) is less than the predetermined value, on the other hand, the actual radiation state of the refrigerant at the outlet of the radiator (2) is regarded to have substantially reached the ideal state, and the air capacity of the cooling fan (2a) is reduced, so that the power consumption of the cooling fan (2a) is reduced.

[0019] Also, in this aspect of the invention, only a temperature sensor is used as a detection means for controlling the air capacity of the cooling fan and, therefore, as compared with the pressure sensor, the air capacity of the cooling fan (2a) can be properly controlled using an inexpensive sensor having a simple configuration.

[0020] According to a fourth aspect of the invention, there is provided a supercritical refrigeration cycle, wherein the value of information may specifically be a pressure difference (ΔP) between the actual high pressure and the high-pressure setting determined by the atmospheric temperature.

[0021] According to a fifth aspect of the invention, there is provided a supercritical refrigeration cycle, wherein in the case where the pressure difference (ΔP) is not less than a predetermined value, the air capacity of the cooling fan (2a) may be controlled upward, while in the case where the pressure difference (ΔP) is less than the predetermined value, on the other hand, the air capacity of the cooling fan (2a) may be controlled downward.

[0022] According to a sixth aspect of the invention, there is provided a supercritical refrigeration cycle mounted on the vehicle, wherein the radiator (2) is arranged at a position exposed to the dynamic pressure of a running vehicle, and the air capacity of the passing atmospheric air is changed with the vehicle velocity, and wherein the cooling fan (2a) is electrically driven and the air capacity of the cooling fan (2a) is controlled by the voltage across the drive motor of the cooling fan (2a).

[0023] In this aspect of the invention, the capacity of the air passing through the radiator (2) is increased due to the dynamic pressure of the vehicle running at a high speed and the difference described above is changed downward by the increased air capacity, thereby making it possible to control the air capacity of the cooling fan (2a) downward. As a result, the power consumption of the cooling fan (2a) can be further reduced at a high vehicle running speed.

[0024] According to a seventh aspect of the invention, there is specifically provided a supercritical refrigeration cycle, wherein it is determined whether the high pressure is not lower than the critical pressure of the refrigerant, and in the case where the high pressure is not lower than the critical pressure of the refrigerant, the air capacity of the cooling fan (2a) is controlled based on the value of information, while in the case where the high pressure is lower than the critical pressure of the refrigerant, on the other hand, the air capacity of the cooling fan (2a) is controlled directly based on the change in high pressure.

[0025] In this aspect of the invention, the air capacity of the cooling fan (2a) can be controlled in a suitable way in accordance with the supercritical state or the subcritical state.

[0026] The reference numerals in the parentheses attached to the name of each means described above and in the appended claims indicate the correspondence with the specific means described in the embodiments explained later.

[0027] The present invention may be more fully understood from the description of preferred embodiments of the invention, as set forth below, together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] FIG. 1 is a diagram showing a general configuration of the whole system according to a first embodiment of the invention.

[0029] FIG. 2 is a graph showing the relation between the coefficient of performance and the refrigerant pressure at the outlet of the radiator in the supercritical refrigeration cycle.

[0030] FIG. 3 is a flowchart showing the operation of controlling the voltage across the cooling fan of the radiator according to the first embodiment.

[0031] FIG. 4 is a graph showing the relation between the power consumption of the compressor and the temperature difference ΔT in the supercritical refrigeration cycle.

[0032] FIG. 5 is a graph showing the relation between the air velocity on the front surface of the radiator and the voltage across the cooling fan of the radiator.

[0033] FIG. 6 is a flowchart showing the operation of controlling the voltage across the cooling fan of the radiator according to a second embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

First Embodiment

[0034] FIG. 1 is a diagram showing a configuration of the refrigeration cycle for an automotive air conditioning system according to a first embodiment of the invention. This refrigeration cycle uses CO_2 as a refrigerant with the high pressure exceeding the critical pressure (supercritical state). This refrigeration cycle, therefore, constitutes a supercritical refrigeration cycle.

[0035] A compressor 1 for sucking in and compressing the refrigerant is either a fixed displacement refrigerant compressor or a variable displacement refrigerant compressor rotationally driven through an electromagnetic clutch 1a by the engine of an automotive vehicle not shown. The compressor 1 may be configured of an electrically-operated compressor.

[0036] A high-pressure radiator 2 generally called a gas cooler is arranged at the outlet of the compressor 1. This radiator 2 cools the refrigerant by exchanging heat between the discharged high-temperature high-pressure refrigerant in a supercritical state discharged from the compressor 1 and the atmospheric air (outdoor air).

[0037] The atmospheric air is blown into the radiator 2 by an electrically-operated cooling fan 2a. Also, the radiator 2 is arranged in the part exposed to the dynamic pressure of the running vehicle or, specifically, in the foremost part of the vehicle engine compartment and, therefore, the amount of atmospheric air passing therethrough changes with the vehicle speed.

[0038] A high-pressure flow path 3a of an internal heat exchanger 3 is arranged at the refrigerant outlet of the radiator 2. An electric expansion valve 4 making up a decompression means is arranged at the outlet of the high-pressure flow path 3a. The electric expansion valve 4 functions as a pressure control valve with the opening degree thereof controlled electrically so that the high pressure of the cycle constitutes a target pressure.

[0039] An evaporator 5 is arranged at the outlet of the electric expansion valve 4. The evaporator 5 is arranged in a case 6 forming an air path of the indoor air-conditioning unit of the automotive air conditioning system, and makes up a cooling means for cooling the air in the case 6. An electrically-operated blower 7 is arranged upstream of the evaporator 5 in the air flow. The internal or external air

introduced through an internal-external air switch box, not shown, is blown into the case 6 and passes through the evaporator 5.

[0040] Incidentally, a heater core, not shown and making up a heating means for heating the air, is arranged downstream of the evaporator 5 in the case 6. The air-conditioning air, regulated in temperature according to the degree to which the heater core is heated, is blown into the compartments from an outlet, not shown, at the downstream end of the case 6 in the air flow.

[0041] An accumulator 8 is arranged at the refrigerant outlet of the evaporator 5. The accumulator 8 is a gas-liquid separation means for separating the refrigerant at the outlet of the evaporator 5 into a liquid refrigerant and a gas refrigerant, and storing the extraneous refrigerant in the cycle. The gas refrigerant thus separated is introduced toward the inlet of the compressor 1.

[0042] At the outlet of the accumulator 8, a low-pressure flow path 3b of the internal heat exchanger 3 is arranged. Therefore, the outlet pipe of the accumulator 8 is connected to the inlet of the compressor 1 through the low-pressure flow path 3b.

[0043] The internal heat exchanger 3 exchanges heat between the low-pressure gas refrigerant (refrigerant sucked into the compressor) flowing out from the accumulator 8 and the high-pressure refrigerant at the outlet of the radiator 2, and by reducing the enthalpy of the refrigerant flowing into the evaporator 5, increases the enthalpy difference (refrigeration ability) of the refrigerant between the refrigerant inlet and the outlet of the evaporator 9, while at the same time preventing the liquid refrigerant from being sucked into the compressor 1.

[0044] Next, an outline of the electric control unit according to this embodiment is explained. The air-conditioning control unit 10, configured of a microcomputer and peripheral circuits, executes a predetermined arithmetic process in accordance with a predetermined program and controls the operation of the air-conditioning devices.

[0045] Specifically, the output of the air-conditioning control unit 10 is connected with the air-conditioning devices including the electromagnetic clutch 1a of the compressor 1, the cooling fan 2a of the radiator 2, the electric expansion valve 4 and the electrically-operated blower 7. The air-conditioning control unit 10 controls the operation of these air-conditioning devices.

[0046] The input of the air-conditioning control unit 10, on the other hand, is connected with a sensor 11 for detecting the refrigerant discharged from the compressor 1, a high-pressure sensor 12, a sensor 13 for detecting the temperature of the refrigerant at the outlet of the radiator 2, a sensor 14 for detecting the air blown out from the evaporator 5 and an atmospheric air temperature sensor 15.

[0047] The high-pressure sensor 12, as shown in FIG. 1, is arranged at the outlet of the radiator 2 to detect, for example, the refrigerant pressure at the outlet of the radiator 2. In view of the fact that the pressure loss of the radiator 2 can be estimated in the air-conditioning control unit 10, however, the high-pressure sensor 12 may alternatively be arranged at the inlet of the radiator 2 (outlet of the compressor 1) to detect the refrigerant pressure at the outlet of the compressor 1.

[0048] The air-conditioning control unit 10, as is well known, is supplied also with detection signals from the various sensors 16 including an internal temperature sensor, a sunlight sensor and an engine water temperature sensor. Further, the air-conditioning control unit 10 is supplied with various air-conditioning operation signals from the air-conditioning operation panel 17 arranged in the neighborhood of the instrument panel in the compartments.

[0049] Specifically, the air-conditioning operation signals, including the temperature setting signal for setting the internal temperature of the compartments, the operation command signal for the compressor 1, the air capacity switch signal for the electrically-operated blower 7, the blowout mode switch signal for the indoor air-conditioning unit and the internal-external air introduction mode switch signal for the internal-external air switch box are input into the air-conditioning control unit 10 from the operation members of the air-conditioning operation panel 17.

[0050] Next, the operation of an embodiment having the above-mentioned configuration is explained. First, the basic operation of the refrigeration cycle will be explained. Upon generation of the operation command signal to the compressor 1 by the operation member of the air-conditioning operation panel 17, the electromagnetic clutch 1a is energized into a connection state by the air-conditioning control unit 10. As a result, the drive force of the vehicle engine is transmitted to the compressor 1 through the electromagnetic clutch 1a and drives the compressor 1.

[0051] The refrigerant, compressed by the compressor 1, is increased in both temperature and pressure, with the pressure thereof increasing beyond the critical pressure into a supercritical state. The refrigerant in the supercritical state flows into the radiator 2, and after exchanging heat with the atmospheric air blown by the cooling fan 2a, releases heat into the atmosphere.

[0052] The refrigerant at the outlet of the radiator 2 passes through the high-pressure flow path 3a of the internal heat exchanger 3 and flows toward the expansion valve 4. The refrigerant at the outlet of the radiator 2, while passing through the high-pressure flow path 3a of the internal heat exchanger 3, exchanges heat with the low-temperature low-pressure refrigerant in the low-pressure flow path 3b and releases heat into the low-pressure refrigerant.

[0053] The refrigerant, after passing through the high-pressure flow path 3a of the internal heat exchanger 3, is decompressed in the reduction path of the expansion valve 4 into a liquid-gas double-phase low in temperature and pressure. This low-temperature low-pressure liquid-gas double-phase refrigerant flows into the evaporator 5, and is evaporated by absorbing heat from the air blown by the electrically-operated blower 7. As a result, the air blown by the electrically-operated blower 7 can be cooled by the evaporator 5 and the cool air can be blown into the compartment.

[0054] The low-pressure refrigerant, having passed through the evaporator 5 and flowed into the accumulator 8, is separated into a saturated liquid refrigerant and a saturated gas refrigerant in the accumulator 8. The saturated gas refrigerant flows out from the outlet of the accumulator 8 and is introduced toward the inlet of the compressor 1.

[0055] The low-pressure gas refrigerant (refrigerant sucked into the compressor) at the outlet of the accumulator

8 absorbs heat from the refrigerant at the outlet of the radiator 2 in the low-pressure flow path 3b of the internal heat exchanger 3. The refrigerant sucked into the compressor, therefore, is increased in enthalpy and is overheated. The overheated gas refrigerant having absorbed heat in the internal heat exchanger 3 is sucked into, and compressed again, by the compressor 1.

[0056] The pressure of the refrigerant at the outlet of the radiator can be controlled to maximize the COP by controlling the opening degree of the electric expansion valve 4. Specifically, the outlet pressure of the high-pressure radiator maximizing the COP, i.e. the target high pressure Po, is calculated by the air-conditioning control unit 10 based on the refrigerant temperature at the outlet of the high-pressure radiator, as shown in FIG. 2.

[0057] In the case where the actual high pressure Ph detected by the pressure sensor 12 is higher than the target high pressure Po, the opening degree of the electric expansion valve 4 is controlled upward, while in the case where the actual high pressure Ph is lower than the target high pressure Po, on the other hand, the opening degree of the electric expansion valve 4 is controlled downward.

[0058] By controlling the opening degree of the expansion valve 4 in this way, the actual high pressure Ph can be maintained at the target high pressure Po, so that the COP is maximized for an improved operating efficiency of the supercritical refrigeration cycle.

[0059] Next, the operation of controlling the cooling fan of the radiator according to this embodiment is explained specifically with reference to FIG. 3. FIG. 3 is a flowchart showing the control routine for the cooling fan of the radiator executed by the air-conditioning control unit 10. This control routine is started by activating the refrigeration cycle (activating the compressor 1).

[0060] First, in step S1, the terminal voltage of the drive motor of the cooling fan 2a of the radiator (hereinafter referred to as the fan terminal voltage) is set at a predetermined intermediate value of, say, 6 V. The predetermined intermediate value is defined as a predetermined value lower than the charge voltage (say, 12 V) of an on-vehicle battery (not shown), and in the case under consideration, is set at 6 V, i.e. half of the charge voltage (12 V) of the on-vehicle battery (not shown).

[0061] Next, in step S2, the temperature difference ΔT ($=T_g - T_a$) between the refrigerant temperature T_g at the outlet of the radiator detected by the refrigerant temperature sensor 13 and the atmospheric temperature T_a detected by the atmospheric temperature sensor 15 is calculated.

[0062] Step S3 determines whether the temperature difference ΔT is not lower than a predetermined value, or 2°C . in the case under consideration. In the case where the temperature difference ΔT is not lower than 2°C ., the process proceeds to step S4, in which the fan terminal voltage is updated to +1 V in the present state. As a result, the rotational speed of the cooling fan 2a of the radiator increases by an amount equal to the increase (1 V) in fan terminal voltage to increase the air capacity correspondingly.

[0063] Upon determination in step S3 that the temperature difference ΔT is less than 2°C ., on the other hand, the

process proceeds to step S5, in which the fan terminal voltage is updated to the current level of -1 V. As a result, the rotational speed of the cooling fan 2a of the radiator decreases by an amount equal to the decrease (1 V) of the fan terminal voltage for a lower air capacity.

[0064] According to this embodiment, as described above, the fan terminal voltage is changed in accordance with the temperature difference ΔT so that the temperature difference ΔT is maintained at about a predetermined value ($=2^\circ\text{C}$.).

[0065] The technical significance of controlling the cooling fan of the radiator as described above is explained with reference to FIG. 5. In FIG. 4, the abscissa represents the temperature difference ΔT ($=T_g - T_a$) and the ordinate the power consumption L of the compressor. As understood from FIG. 4, as long as the temperature difference ΔT is not less than a predetermined value, or specifically, not lower than 2°C ., the temperature difference ΔT and the compressor power consumption L are substantially proportional to each other, and with the decrease in temperature difference ΔT , the compressor power consumption L decreases.

[0066] Specifically, the decrease in temperature difference ΔT means the approach of the refrigerant temperature T_g at the outlet of the radiator to the atmospheric temperature T_a . This indicates that as long as the heat of the high-pressure refrigerant can be ideally radiated (cooled) by the radiator 2, the refrigerant temperature T_g at the outlet of the radiator can be reduced to about the atmospheric temperature T_a .

[0067] The temperature difference ΔT , therefore, is considered the value of information indicating the difference between the actual radiation state of the refrigerant at the outlet of the radiator in the supercritical refrigeration cycle and the ideal radiation state determined by the atmospheric temperature. Thus, the decrease in the temperature difference ΔT , i.e. the approach of the refrigerant temperature T_g at the outlet of the radiator to the atmospheric temperature T_a is indicative of the downward change of the refrigerant pressure (high pressure) at the outlet of the radiator in FIG. 2.

[0068] According to this embodiment, upon determination that the radiator 2 is short of air capacity as compared with the ideal radiation state, at the temperature difference ΔT of not less than 2°C ., the process proceeds to step S4, in which the fan terminal voltage is increased to increase the air capacity of the cooling fan 2a of the radiator. As a result, the temperature difference ΔT can be reduced and so can the power consumption L of the compressor.

[0069] In the case where the temperature difference ΔT is less than 2°C ., on the other hand, it is understood from FIG. 4 that the compressor power consumption L is maintained at a substantially constant value in the neighborhood of the minimum value. This indicates that according to this embodiment, at a temperature difference ΔT of less than 2°C ., the radiator 2 is regarded to have reached substantially the ideal radiation state, and the process proceeds to step S5, in which the fan terminal voltage is reduced thereby to reduce the air capacity of the radiator cooling fan 2a. As a result, the compressor power consumption can be reduced while, at the same time, reducing the power consumption of the cooling fan 2a of the radiator.

[0070] In FIG. 4, the abscissa represents also the air velocity at the front of the radiator. With the increase in air

velocity on the front of the radiator, the cooling performance of the radiator is improved to reduce the temperature difference ΔT .

[0071] In FIG. 5, the abscissa represents the fan terminal voltage, and the ordinate the air velocity on the front of the radiator. As shown in FIG. 5, the air velocity on the front of the radiator is higher, the higher the fan terminal voltage or the vehicle speed. Even in the case where the fan terminal voltage is low at high vehicle speed, therefore, the air velocity on the front of the radiator can be increased to a sufficiently high level thereby to improve the cooling performance of the radiator.

[0072] With the increase in the air velocity on the front of the radiator, the cooling performance of the radiator is improved and the refrigerant temperature T_g at the outlet of the radiator decreases. As a result, the temperature difference $\Delta T (=T_g - T_a)$ decreases. According to this embodiment, therefore, the fan terminal voltage is controlled downward (the process of step S5). In this way, the power consumption of the cooling fan 2a of the radiator at high vehicle speed can be positively reduced.

Second Embodiment

[0073] The first embodiment represents a case in which the cooling fan 2a of the radiator shown in FIG. 3 is always controlled without determining whether the cycle operation is in a supercritical state or a subcritical state. According to the second embodiment, on the other hand, as shown in FIG. 6, it is determined whether the cycle operation is in a supercritical state or a subcritical state as shown in FIG. 6 and, based on this determination, the control operation of the cooling fan 2a of the radiator is switched.

[0074] FIG. 6 is a flowchart showing the operation of controlling the cooling fan 2a of the radiator according to the second embodiment. Steps S1 to S5 are identical to those of FIG. 3. According to the second embodiment, step S6 of FIG. 6 determines in step S6 whether the actual high pressure P_h detected by the pressure sensor 12 is higher than the critical pressure of the CO_2 refrigerant or not.

[0075] In the case where the actual high pressure P_h is higher than the critical pressure of the CO_2 refrigerant (in the supercritical state), the process proceeds to step S7 to determine whether the supercritical control flag F is 1 or not. In view of the fact that supercritical control flag F is initialized to 0 at the time of starting the control routine, the determination is NO in step S7 immediately after starting the control routine. In step S1, therefore, the fan terminal voltage is set to 6 V and, in step S8, the supercritical control flag F is set to 1. Subsequently, therefore, in the supercritical state, the process always proceeds from step S7 to step S2, so that the control process of steps S2 to S5 is executed as in the first embodiment.

[0076] In the case where step S6 determines that the actual high pressure P_h is lower than the critical pressure of the CO_2 refrigerant (subcritical state), on the other hand, the process proceeds to step S9, in which the supercritical control flag F is set to 0 and, in step S10, the fan terminal voltage is directly controlled based on the change in the actual high pressure P_h .

[0077] Specifically, the fan terminal voltage is controlled continuously (or stepwise) upward with the increase in the high pressure P_h .

[0078] In the subcritical state, the radiator 2 functions as a condenser for cooling and condensing the refrigerant discharged from the compressor and, therefore, the refrigerant at the outlet of the radiator 2 assumes the liquid phase, and the supercooling degree thereof is changed with the conditions for cycle operation. In this subcritical state, it is known that the COP can be improved by controlling the supercooling degree of the refrigerant at the outlet of the radiator 2 in a predetermined range.

[0079] In view of this, according to the second embodiment, upon determination of subcritical state, the supercooling degree of the refrigerant at the outlet of the radiator is calculated based on the actual high pressure P detected by the pressure sensor 12 and the actual refrigerant temperature at the outlet of the radiator detected by the temperature sensor 12, and the opening degree of the electric expansion valve 4 is controlled to maintain the supercooling degree within a predetermined range.

[0080] Specifically, the opening degree of the electric expansion valve 4 is controlled in such a manner that in the case where the supercooling degree of the refrigerant at the outlet of the radiator is reduced, the opening degree of the electric expansion valve 4 is reduced, while in the case where the supercooling degree of the refrigerant at the outlet of the radiator is increased beyond a predetermined range, on the other hand, the opening degree of the electric expansion valve 4 is increased. This operation of controlling the expansion valve opening degree maintains the supercooling degree of the refrigerant at the outlet of the radiator within a predetermined range.

[0081] As described above, in subcritical state, the high pressure is not controlled but the supercooling degree of the refrigerant at the outlet of the radiator by the electric expansion valve 4 and, therefore, the high pressure increases with the increase in the thermal load of the refrigeration cycle. In subcritical state, therefore, the air capacity (cooling performance) of the radiator can be properly controlled in accordance with the thermal load of the cycle by controlling the fan terminal voltage in accordance with the high pressure P_h .

Other Embodiments

[0082] (1) In the embodiments described above, the temperature difference $\Delta T (=T_g - T_a)$ between the temperature T_g of the refrigerant at the outlet of the radiator 2 and the atmospheric temperature T_a is calculated and, in accordance with the value of the temperature difference ΔT , the terminal voltage of the cooling fan 2a of the radiator, i.e. the air capacity is controlled. The refrigerant temperature T_g at the outlet of the radiator 2, however, is not limited to the temperature of the refrigerant flowing out from the radiator 2, but the temperature of the refrigerant in the refrigerant flow path on the outlet side of the internal flow path of the radiator 2 may alternatively be detected.

[0083] (2) In the embodiments described above, the air capacity of the cooling fan 2a of the radiator is controlled in accordance with the value of the temperature difference ΔT . As an alternative, the air capacity of the cooling fan 2a of the radiator may be controlled based on a cycle operation value of information other than the temperature difference ΔT , with equal effect.

[0084] Specifically, the refrigerant temperature T_g at the outlet of the radiator **2** and the atmospheric temperature are so correlated that by increasing the air capacity of the cooling fan **2a** of the radiator sufficiently, the refrigerant temperature T_g at the outlet of the radiator **2** can be ideally reduced almost to the atmospheric temperature T_a .

[0085] In view of this, in place of the refrigerant temperature T_g at the outlet of the radiator **2**, the pressure P_{set} is set as determined by the atmospheric temperature T_a , and this set pressure P_{set} is determined in such a manner as to increase with the increase in the atmospheric temperature T_a . Then, the difference ΔP between the actual high pressure P_h and the set pressure P_{set} is calculated. In other words, the pressure difference ΔP is calculated as the actual high pressure P_h less the set pressure P_{set} .

[0086] In the case where this pressure difference ΔP is not lower than a predetermined value, the terminal voltage of the cooling fan **2a** of the radiator (air capacity) is controlled upward (the control operation in step **S4** of FIGS. **3**, **6**), while in the case where the value of the pressure difference ΔP is less than the predetermined value, the terminal voltage of the cooling fan **2a** of the radiator (air capacity) is controlled downward (the control operation in step **S5** of FIGS. **3**, **6**). Also in the case where the air capacity of the cooling fan **2a** of the radiator is controlled in this way, operational effects similar to those of the aforementioned embodiments are exhibited.

[0087] (3) In the embodiments described above, CO_2 is used as a refrigerant to construct the supercritical refrigeration cycle in which the high pressure increases beyond the critical pressure of the refrigerant (supercritical state). As an alternative to CO_2 , however, ethylene, ethane, etc. may be used as a refrigerant to construct the supercritical refrigeration cycle.

[0088] (4) In the embodiments described above, the supercritical refrigeration cycle is used as the refrigeration cycle for the automotive air conditioning system. This invention, however, is also applicable to refrigeration cycles in various fields, such as housing, with equal effect.

[0089] While the invention has been described by reference to specific embodiments chosen for purposes of illustration, it should be apparent that numerous modifications could be made thereto, by those skilled in the art, without departing from the basic concept and scope of the invention.

What is claimed is:

1. A supercritical refrigeration cycle where the high pressure exceeds the critical pressure of the refrigerant, comprising:

- a compressor for sucking in and compressing a refrigerant;
- a radiator for cooling the refrigerant discharged from the compressor by exchanging heat between the refrigerant discharged from the compressor and the atmospheric air;
- a cooling fan for blowing the atmospheric air to the radiator;
- a decompressor for decompressing the refrigerant at the outlet of the radiator and having the opening degree thereof controlled to achieve a target high pressure; and

an evaporator for evaporating the low-pressure refrigerant decompressed by the decompressor and leading the evaporated gas refrigerant to the inlet of the compressor;

wherein an value of information representing the difference between the actual radiation state of the refrigerant at the outlet of the radiator and the ideal radiation state determined by the atmospheric temperature is calculated, and

wherein the air capacity of the cooling fan is controlled in such a manner as to decrease the difference based on the value of information.

2. A supercritical refrigeration cycle according to claim 1,

wherein the value of information is specifically the difference between the refrigerant temperature at the outlet of the radiator and the atmospheric temperature.

3. A supercritical refrigeration cycle according to claim 2,

wherein, as long as the temperature difference is not less than a predetermined value, the air capacity of the cooling fan is controlled upward while, in the case where the temperature difference is less than the predetermined value, the air capacity of the cooling fan is controlled downward.

4. A supercritical refrigeration cycle according to claim 1,

wherein the value of information is the pressure difference between the actual high pressure and the high-pressure setting determined by the atmospheric temperature.

5. A supercritical refrigeration cycle according to claim 4,

wherein in the case where the pressure difference is not less than a predetermined value, the air capacity of the cooling fan is controlled upward, while in the case where the pressure difference is less than the predetermined value, the air capacity of the cooling fan is controlled downward.

6. A supercritical refrigeration cycle mounted on an automotive vehicle according to claim 1,

wherein a radiator is arranged at a position exposed to the dynamic pressure of the running vehicle, and the air capacity of the passing atmospheric air is changed with the vehicle speed, and

wherein a cooling fan is electrically driven, and the air capacity of the cooling fan is controlled by the voltage across the drive motor of the cooling fan.

7. A supercritical refrigeration cycle according to claim 1 wherein it is determined whether the high pressure is not lower than the critical pressure of the refrigerant or not,

wherein in the case where the high pressure is not lower than the critical pressure of the refrigerant, the air capacity of the cooling fan is controlled based on the value of information, and

wherein in the case where the high pressure is lower than the critical pressure of the refrigerant, the air capacity of the cooling fan is controlled directly based on the change in the high pressure.