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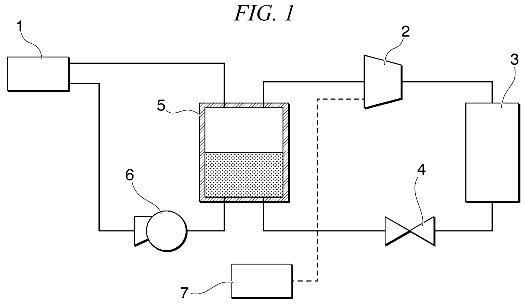
(54) COOLING DEVICE AND METHOD FOR CONROLLING COOLING DEVICE

(57) An object of the present invention is to prevent cavitation in a refrigerant pump from occurring due to a decrease in a net positive suction head in a cooling device.

A cooling device of the present invention is a cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver (1), a compressor (2), a heat radiator (3), and an expander (4), and includes a tank (5) that separates the refrigerant supplied from the expander (4) into a gas phase refrigerant and a liquid phase refrigerant, a pump (6) that sends the liquid phase refrigerant separated in the tank (5) to the heat receiver (1), and a control unit (7) that controls the amount of increase in pressure of the compressor 2 in the refrigeration cycle, and the control unit (7) increases the pressure of the compressor (2) in a limited range in which the value of the net positive suction head of the pump (6) does not fall below a predetermined value.

FIG. 1



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Description

TECHNICAL FIELD

[0001] The present invention relates to a cooling device and a control method therefor. In particular, the present invention relates to a cooling device using a refrigeration cycle suitable for air conditioning equipment in a data center and a control method therefor.

BACKGROUND ART

[0002] A cooling device using a refrigeration cycle for radiating heat to an atmosphere via a refrigerant that has received heat from heat generation sources through steps of heat-receiving, compressing, heat-radiating, and expanding a refrigerant is used to cool a space in which a large number of the heat generation sources such as electronic devices are housed, such as a server room in a data center.

[0003] In this refrigeration cycle, because the refrigerant repeats the phase change between a liquid phase and a gas phase in each step of the cycle, it is necessary to achieve an efficient operation of the refrigeration cycle by appropriately maintaining a phase state of the refrigerant in pipelines between the respective steps.

[0004] For example, in the refrigerant circulation system, because a compressor that sucks a refrigerant in a gas-liquid mixed phase state of which heat has been received by a heat receiver and increases the pressure at a predetermined compression ratio has a structure on the basis of compression of a gas-phase refrigerant, it is not possible to compress a liquid-phase refrigerant. Therefore, before the refrigerant is sucked into the compressor, it is necessary to separate the refrigerant in the mixed phase state into gas and liquid phase refrigerants by temporarily storing the refrigerant in a gas-liquid separation tank (generally, also serving as a tank that separates a gas phase refrigerant from a gas-liquid mixed phase refrigerant directed to the heat receiver and stores a liquid phase refrigerant at a predetermined level).

[0005] On the other hand, switching from conventional high-pressure hydro fluoro carbons (HFCs: high-pressure HFCs) having a difference between an evaporating pressure and a condensing pressure on the order of 1000 kPa to low-pressure hydro fluoro olefins (low-pressure HFOs) having a difference between an evaporating pressure and a condensing pressure of about 100 kPa and a maximum vapor pressure of 1000 kPa or less, as a refrigerant that is used in the refrigeration cycle, has been expected in consideration of an environmental load in recent years.

[0006] In the refrigeration cycle using the low-pressure refrigerant, because it is necessary to appropriately perform gas-liquid separation in each step of the heat reception side and the heat radiation side of the refrigerant circulation system, for example, a tank (gas-liquid separator) having a predetermined capacity is provided for the purpose of gas-liquid separation on the inlet side of the compressor and gas-liquid separation on the suction side of a pump that sends the refrigerant to the heat receiver.

[Prior Art Documents]

[Patent Documents]

[0007]

[Patent Document 1] International Publication No. 2018/056201
[Patent Document 2] Japanese Unexamined Patent Application, First Publication No. 2019-174001
[Patent Document 3] Japanese Unexamined Patent Application, First Publication No. 2021-076364

SUMMARY OF THE INVENTION

Problem to be Solved by the Invention

[0008] However, in a case in which the tank is connected to a suction side of the compressor, when the pressure inside the tank decreases with the suction of the compressor, the pressure decreases below a saturated vapor pressure of a low-pressure refrigerant stored in the tank, and cavitation may occur in the liquid phase refrigerant sucked into a pump for sending the liquid phase refrigerant from the tank to the heat receiver.

[0009] When cavitation occurs due to such a cause, a decrease in flow rate of the refrigerant to be sent from the pump is caused, the liquid phase refrigerant having a sufficient flow rate cannot be supplied to the heat receiver, and it becomes difficult to maintain cooling air supplied from the cooling device to a cooling target below a predetermined temperature.

[0010] Because this cavitation is a phenomenon that occurs with an operation of increasing pressure of the compressor, it is necessary to pay close attention to control of a compression operation in order to prevent the cavitation from occurring.

[0011] Further, because this phenomenon is significant when a low-pressure refrigerant is used, it is required to operate the pump stably while preventing the cavitation from occurring in order to maintain the temperature of the server appropriately.

[0012] Patent Document 1 related to the present application describes a pump provided in a refrigeration cycle to supply a refrigerant, but does not disclose a technology for preventing cavitation of the refrigerant supplied to the pump from occurring due to an influence of the compressor of the refrigerant.

[0013] Patent Document 2 related to the present application relates to a technology for adjusting a degree of opening of an expansion valve according to a change in rotation speed of a compressor in a refrigeration cycle, and does not disclose a technology for preventing cavitation of a refrigerant from occurring in a pump.

[0014] Patent Document 3 related to the present application describes a technology for preventing cavitation from occurring in a pump to which a refrigerant is supplied from a liquid receiver, but does not disclose a technology for preventing cavitation from occurring due to an influence of suction of a refrigerant by a compressor on the liquid receiver.

[0015] An object of the present invention is to prevent cavitation from occurring in a pump that is used for pumping of a liquid phase refrigerant in a refrigeration cycle in which cooling is performed through circulation of the refrigerant.

Means for Solving the Problem

[0016] In order to solve the above problem, a first example aspect of the present invention proposes the following means.

[0017] A cooling device according to the first example aspect of the present invention is a cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, the cooling device including: a gas-liquid separator configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and a liquid phase refrigerant; a pump configured to send the liquid phase refrigerant separated by the gas-liquid separator to the heat receiver; and a control unit configured to control the amount of increase in pressure of the compressor in the refrigeration cycle, wherein the control unit limits the value of a net positive suction head of the pump to a range in which the value does not fall below a predetermined value and increases the pressure of the compressor.

[0018] Furthermore, a second example aspect of the present invention proposes the following means.

[0019] A control method for a cooling device according to the second example aspect of the present invention is a control method for a cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, the control method including: controlling, by a control unit, an increase in the pressure of the compressor to a range in which a value of a net positive suction head of the pump does not fall below a predetermined value, the pump being configured to suck a liquid phase refrigerant from a gas-liquid separator configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and the liquid phase refrigerant.

Effect of the Invention

[0020] In the present invention, it is possible to allow the refrigerant to have an appropriate phase of a gas phase and a liquid phase at various places constituting the refrigeration cycle.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021]

Fig. 1 is a piping system diagram of a cooling device according to a minimum configuration example of the present invention.

Fig. 2 is a process diagram of a control method for a cooling device according to the minimum configuration example of the present invention.

Fig. 3 is a chart illustrating a change in pressure in a comparative example of a first embodiment of the present invention.

Fig. 4 is a chart illustrating a change in pressure in the first embodiment of the present invention.

Fig. 5 is a flowchart of the operation of a control unit of a cooling device according to the first embodiment of the present invention.

Fig. 6 is a piping system diagram illustrating an overall configuration of the cooling device according to the first embodiment of the present invention.

Fig. 7 is a piping system diagram illustrating an overall configuration of a cooling device according to a second embodiment of the present invention.

Fig. 8 is a flowchart of the operation of a control unit of a cooling device according to a third embodiment of the present invention.

Fig. 9 is a piping system diagram illustrating an overall configuration of the cooling device according to the third embodiment of the present invention.

Fig. 10 is an illustrative diagram of a pressure measurement position in the piping system diagram of Fig. 9.

Fig. 11 is a chart illustrating an example of measurement data in each unit of Fig. 10.

Fig. 12 is a flowchart of the operation of a control unit of a cooling device according to a fourth embodiment of the present invention.

Fig. 13 is a piping system diagram illustrating an overall configuration of the cooling device according to the fourth embodiment of the present invention.

Fig. 14 is a flowchart of the operation of a control unit of a cooling device according to a fifth embodiment of the present invention.

Fig. 15 is a piping system diagram illustrating an overall configuration of the cooling device according to the fifth embodiment of the present invention.

Fig. 16 is a flowchart of the operation of a control unit of a cooling device according to a sixth embodiment of the present invention.

Fig. 17 is a piping system diagram illustrating an overall configuration of the cooling device according to the sixth embodiment of the present invention.

Fig. 18 is a flowchart of the operation of a control unit of a cooling device according to a seventh embodiment of the present invention.

Fig. 19 is a piping system diagram illustrating an overall configuration of the cooling device according to the seventh embodiment of the present invention.

EXAMPLE EMBODIMENTS

[0022] The configuration of a cooling device according to a minimum configuration of the present invention will be described with reference to Fig. 1.

[0023] This cooling device is a cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver 1, a compressor 2, a heat radiator 3, and an expander 4, and includes a tank 5 that separates the refrigerant supplied from the expander 4 into a gas phase refrigerant and a liquid phase refrigerant, a pump 6 that sends the liquid phase refrigerant separated in the tank 5 to the heat receiver 1, and a control unit 7 that controls the amount of increase in pressure of the compressor 2 in the refrigeration cycle, and the control unit 7 is configured to limit the value of a net positive suction head of the pump 6 to a range in which the value does not fall below a predetermined value and increase the pressure of the compressor 2.

[0024] According to the above configuration, the control unit 7 controls an increase in the pressure (compression operation) of the compressor 2 so that the pressure determined according to the net positive suction head of the refrigerant sucked into the pump 6, that is, the pressure measurement value of a refrigerant liquid (a liquid phase refrigerant) separated in the tank 5 and sucked into the pump 6, a head difference from a liquid level in the tank 5 to the pump 6 (the pressure generated by the density of the refrigerant liquid at the temperature at that point in time and gravity due to a difference in height), and a saturated vapor pressure of the refrigerant in the tank 5 is maintained to be equal to or higher than a predetermined pressure, by controlling the amount of increase in pressure of the compressor 2.

[0025] More specifically, when the net positive suction head of the pump 6 is low and concern that cavitation may occur in the liquid phase refrigerant is high, the amount of increase in pressure of the compressor 2 is curbed, and when the net positive suction head increases and the concern that cavitation may occur in the refrigerant liquid is low, the amount of increase in pressure of the compressor 2 is increased, thereby making it is possible to prevent cavitation from occurring in the pump 6.

[0026] An example of a calculation equation using parameters actually measured in the control of the control unit 7 includes Equation (1) below.

$$\text{Net positive suction head} = (\text{pump inlet pressure} - \text{saturated vapor pressure})/(\text{density of refrigerant liquid} \times \text{gravitational acceleration}) \quad \cdots \quad \text{Equation (1)}$$

[0027] In a temperature range in which the present invention is implemented, because change in the density of the refrigerant liquid is negligibly small, the density can be treated as a constant in terms of control.

[0028] A control method for a cooling device according to the minimum configuration of the present invention will be described with reference to Fig. 2.

[0029] This control method for a cooling device is a control method for a cooling device using a refrigeration cycle in which a refrigerant is circulated through the heat receiver 1, the compressor 2, the heat radiator 3, and the expander 4, and the control unit 7 is configured to limit the value of the net positive suction head of the pump 6 that sucks the liquid phase refrigerant from the gas-liquid separator 5 that separates the refrigerant supplied from the expander into a gas phase refrigerant and a liquid phase refrigerant to a range in which the value does not fall below a predetermined value, and control increase in the pressure of the compressor 2.

[0030] More specific examples of control steps are as follows.

SP1

[0031] A net positive suction head is detected through calculation based on Equation (1) above on the basis of an inlet pressure of the pump 6, a detection value of the temperature, and a physical characteristic value of the refrigerant.

SP2

[0032] The detected net positive suction head is compared with a management value (predetermined value) of the net positive suction head obtained in advance.

SP3

[0033] When the net positive suction head is smaller than the predetermined value, for example, the rotation speed of a drive motor (not illustrated) of the compressor 2 is decreased in order to curb the increase in the pressure of the compressor 2, and when the net positive suction head is greater than the predetermined value, the increase in the pressure of the compressor 2 is maintained.

[0034] According to the above configuration, because the pressure of the refrigerant liquid sucked into the pump 6 is maintained to be equal to or higher than a predetermined value according to the saturated vapor pressure at that time, it is possible to prevent cavitation from occurring on the suction side of the pump 6.

(First Embodiment)

[0035] Hereinafter, a first embodiment of the present invention will be described with reference to Figs. 3 to 6. In Fig. 6, the same components as those in Fig. 1 are denoted by the same reference signs, and a description thereof will be simplified.

[0036] The heat receiver 1 is provided in, for example, a ceiling-mounted unit disposed above a heat generation source such as an internal server of a server room or the like, and includes, for example, a pipe through which a refrigerant flows, and fins having a predetermined contact area to promote heat exchange. Further, the heat receiver 1 receives heat from the air that absorbs heat of an internal heat generation source by passing through the inside of the server, is discharged to a hot aisle side of the server room (a passage in the server room on the side from which cooling air having an increased temperature is discharged), and has become an updraft to be brought into contact with the fins, and the refrigerant flowing inside evaporates according to the amount of received heat, and most of the refrigerant flows out in a liquid phase when the amount of received heat is small.

[0037] A pipe 8a connects the heat receiver 1 to a gas-liquid separator (specifically, a closed tank, which is hereinafter referred to as a tank) 5, and a pipe 8b connects the gas phase portion (an upper portion) of the tank 5 to the suction side of the compressor 2.

[0038] A pipe 8c connects a discharge side of the compressor 2 to the heat radiator 3. The heat radiator 3 is installed, for example, outside in a building including the server room, and radiates heat by heat-exchanging the refrigerant compressed by the compressor 2 with, for example, an atmosphere, so that the refrigerant is below a boiling point and becomes a liquid phase refrigerant.

[0039] A pipe 8d connects the heat radiator 3 to the expansion valve 4. The refrigerant that has radiated the heat in the heat radiator 3 and become a liquid phase refrigerant expands in the expansion valve 4 as an expander.

[0040] A pipe 8e supplies the refrigerant that has expanded by the expansion valve 4 and entered a gas-liquid mixed phase state to the tank 5.

[0041] A pipe 8f connects a portion below a liquid level L of the tank 5 to the suction side of the pump 6, and a pipe 8g connects a discharge side of the pump 6 to the heat receiver 1.

[0042] The liquid phase refrigerant obtained by the gas and liquid separation in the tank 5 is sucked into the pump 6 via the pipe 8f and supplied to the heat receiver 1 via the pipe 8g. Then, in the heat receiver 1, heat is received from a heat source such as an exhaust gas of the server, the refrigerant flows into the tank 5 again and circulates in the refrigeration cycle.

[0043] A temperature sensor T measures the temperature of the refrigerant at a position immediately before the refrigerant is sucked into the pump 6 in the middle of the pipe 8f, and a pressure sensor P similarly measures the pressure of the refrigerant at the position immediately before the refrigerant is sucked into the pump 6.

[0044] The control unit 7 calculates the required amount of increase in pressure of the compressor 2 from data of the temperature and the pressure input from the temperature sensor T and the pressure sensor P, a calculation equation for a required amount of increase in pressure stored in a database DB1, and a calculation equation for the required suction head stored in a database DB2, and controls the compressor 2. Details of the control of the control unit 7 will be described below with reference to Fig. 5 together with the operation of the cooling device.

[0045] Control content of the control unit 7 will be described together with the operation of the cooling device of the first embodiment having the configuration of Fig. 6 with reference to a flowchart of Fig. 5.

SP11

[0046] Control is executed on condition that the compressor 2 is operated and the refrigerant is circulated in the refrigeration cycle.

SP12

[0047] The temperature of the refrigerant increases by the refrigerant receiving heat in the heat receiver 1 with an increase in the outside air temperature (the temperature inside the server room).

SP13

[0048] The control unit 7 refers to the database DB 1 to acquire the amount of increase in pressure required for the compressor 2. Specifically, the required amount of increase in pressure obtained by using Equation (2) in which the amount of increase Δt of a refrigerant liquid temperature is multiplied by the predetermined constant K is acquired. The databases DB1 and DB2 to be described below are mounted in a memory as a control program or storage data in the control unit 7, or are stored in a server physically separate from the control unit 7 and send and receive data via a communication line.

$$\text{Required amount of increase in pressure} = K \times \Delta t \quad \cdots \quad \text{Equation (2)}$$

SP14

[0049] The control unit 7 acquires measurement values required for calculation, specifically, data of the refrigerant temperature of a suction port of the pump 6 from the temperature sensor T, and data of a refrigerant pressure of the suction port of the pump 6 from the pressure sensor P.

SP15

[0050] The control unit 7 refers to the database DB2 to acquire data of the amount of increase in pressure required for the compressor 2. The database DB2 calculates the saturated vapor pressure and the refrigerant liquid density of the refrigerant from the refrigerant liquid temperature T (or acquires the saturated vapor pressure and the refrigerant liquid density from an existing data table stored in the database DB2), calculates the net positive suction head from a gravitational acceleration of 9.8 kg/s^2 using Equation (1), and calculates the amount by which the pressure of the compressor 2 can be increased by using Equation (3) below.

$$\text{Amount by which pressure can be increased} = f \times (\text{net positive suction head} - \text{required suction head}) \quad \cdots \quad \text{Equation (3)}$$

[0051] Here, f is a constant that is set in consideration of a safety factor in which the operational fluctuation in the amount by which the pressure of the compressor 2 can be increased, which is determined on the basis of a head difference, is anticipated.

SP16

[0052] The control unit 7 limits the increase in the pressure of the compressor 2 to the amount by which the pressure can be increased and increases the pressure of the compressor 2. Specifically, rotation of the compressor 2 is controlled. Here, the pump inlet pressure in Equation (1) above is decreased due to the increase in the pressure of the compressor 2, but the net positive suction head can be maintained to be a predetermined value or more due to the decrease in the refrigerant temperature and the decrease in the saturated vapor pressure due to the increase in the pressure and heat radiation.

SP17

[0053] The control unit 7 determines whether or not the compressor 2 has reached a predetermined amount of increase in pressure, returns to SP14 according to a determination result to repeat control of the amount of increase in pressure, and proceeds to the next step on condition that the compressor 2 has reached the predetermined amount of increase in pressure.

SP18

[0054] The increase in pressure ends when the compressor 2 has reached the predetermined amount of increase in pressure (then, a steady operation according to the predetermined amount of increase in pressure is continued).

[0055] Although the net positive suction head decreases when the compressor 2 reaches the predetermined amount of increase in pressure, it is possible to maintain the predetermined net positive suction head by decreasing the temperature as the refrigerant is compressed and dissipated.

[0056] In the calculation of the net positive suction head based on Equation (1) above, the pump inlet pressure P, a refrigerant temperature T decreases with the increase in pressure of the refrigerant by the compressor 2, and the saturated vapor pressure decreases with the decrease in the refrigerant temperature. In this embodiment, it is assumed that the density of the refrigerant is constant regardless of the change in the refrigerant temperature T.

[0057] By the control unit 7 executing the above control to limit the increase in the pressure of the compressor 2 and curb the decrease in the pressure inside the tank 5, it is possible to maintain the pressure of the refrigerant sucked into the pump 6 below the net positive suction head and prevent cavitation of the refrigerant in the pump 6.

[0058] The operation and effects of the first embodiment will be further described with reference to Figs. 3 and 4.

[0059] Fig. 3 illustrates a comparative example in a case in which restriction of the increase in the pressure of the compressor 2 is not performed. In the figure, the horizontal axis indicates the passage of time, but the vertical axis does not indicate changes in absolute values of temperature, pressure, and the like, but is an index merely indicating relative changes in the values over time.

[0060] Here, in the figure, a dashed line a indicates change in the amount of increase in pressure due to the drive of the compressor 2, an alternating chain line b indicates change in the pressure inside the tank 5, a dashed line c indicates change in the refrigerant temperature due to the increase in the pressure of the compressor 2, a chain line d indicates change in the saturated vapor pressure of the refrigerant, a thick line e indicates a change in the net positive suction head, and a thin line f indicates a required suction head with less concern of causing cavitation.

[0061] Specifically, in the vertical axis of Figs. 3 and 4, the dashed line a indicates the rotation speed (of the drive motor) of the compressor 2, the chain line b indicates the pressure inside the tank 5, the dashed line c indicates the temperature of the refrigerant, the chain line d indicates the saturated vapor pressure of the refrigerant, and the solid lines e and f indicate a net positive suction head (NPSH) and pressure of the required suction head.

[0062] The compressor 2 is activated, an increase in the pressure (compression) of the refrigerant is started, a degree of increase in the pressure of the compressor 2 increases as indicated by the dashed line a (more specifically, the rotation speed of the drive motor of the compressor 2 increases), and the refrigerant is compressed. Further, the pressure inside the tank 5 decreases with a time delay as indicated by the chain line b due to the suction of the compressor 2. By the compressed refrigerant circulating in the refrigeration cycle, the temperature of the refrigerant, which was initially room temperature, decreases further after the pressure decrease, as indicated by the dashed line c. The saturated vapor pressure of the refrigerant indicated by the chain line d decreases with the decrease in the temperature (which depends on physical characteristics of the refrigerant having a predetermined composition). Further, as indicated by a solid line e, the net positive suction head of the pump 6 decreases due to suction pressure (negative pressure) with the increase in pressure indicated by the dashed line a and the changes indicated by the chain lines b and d.

[0063] The net positive suction head falls below the required suction head, which is a lower limit of the pressure that does not cause cavitation in the pump 6, during a period from time t1 to t2 due to this decrease in the net positive suction head. That is, because a required refrigerant cannot be supplied from the pump 6 to the heat receiver 1 due to the occurrence of the cavitation, it is inevitable that a cooling capacity becomes insufficient. Thereafter, when the pressure of the compressor 2 continuously increases, the refrigerant flows into the tank 5 via the heat radiator 3 and the expansion valve 4, and the refrigerant is stored until the liquid level L reaches a predetermined height or higher, the net positive suction head increases as indicated by the solid line e, and the state in which the pump 6 can normally supply the refrigerant to the heat receiver 1 when the net positive suction head exceeds the required suction head at time t2 is obtained.

[0064] Thus, a predetermined time elapses since the pressure of the compressor 2 is increased, the amount of refrigerant sent by the pump 6 is stable, the refrigerant temperature, the pressure in the gas-liquid separator, and the saturated vapor pressure are all stable, and refrigerant is circulated in the refrigeration cycle.

[0065] On the other hand, according to the control by the operation of the first embodiment illustrated in Fig. 4, when the net positive suction head decreases to such an extent that the net positive suction head indicated by the solid line e approaches the required suction head indicated by a solid line f due to the control of the net positive suction head in the control unit 7, the control unit 7 curbs an increase in the amount of increase in pressure of the compressor 2. That is, the increase in the pressure of the compressor 2 is curbed each time a net positive suction head e decreases to the extent that the net positive suction head e approaches a required suction head f, to achieve recovery of the net positive suction head e, thereby making it possible to prevent cavitation from occurring in the pump 6 and stably supply the refrigerant to the heat receiver 1.

[0066] Further, because the refrigerant can circulate in the refrigeration cycle while the occurrence of cavitation is curbed, the pressure inside the tank 5 gradually decreases linearly as indicated by the chain line b in Fig. 4, the temperature of the refrigerant also decreases linearly as indicated by the chain line d, and a stable state is obtained.

[0067] In order to curb the increase in the pressure of the compressor 2, it is possible to use a means such as rotation speed control of the drive motor of the compressor 2 and a temporary unloading operation.

[0068] In the first embodiment, because the net positive suction head of the pump 6 can be maintained above the required suction head, it is possible to stably supply the refrigerant from the pump 6 to the heat receiver 1 without causing cavitation immediately after the start of the operation of the refrigeration cycle.

(Second Embodiment)

[0069] A second embodiment of the present invention will be described with reference to Fig. 7. In Fig. 7, the same components as those in Figs. 1 and 6 are denoted by the same reference signs and a description thereof will be simplified.

[0070] In the second embodiment, a suction side and a discharge side of a pump 6 are connected by a bypass pipe 8h, a bypass valve 9a is provided in the middle of the bypass pipe 8h, and a degree of opening of the bypass valve 9a is controlled by the control unit 7.

[0071] Even in the second embodiment, the control unit 7 performs control according to the same processing as the flowchart illustrated in Fig. 5 that is executed in the first embodiment.

[0072] That is,

SP11

Control is executed on condition that the compressor 2 is operated and the refrigerant is circulated in the refrigeration cycle.

SP12

[0073] The temperature of the refrigerant increases by the refrigerant receiving heat in the heat receiver 1 with an increase in the outside air temperature (the temperature inside the server room).

SP13

[0074] The control unit 7 refers to the database DB1 to acquire the amount of increase in pressure required for the compressor 2. Specifically, the control unit 7 acquires the required amount of increase in pressure obtained by using Equation (2) above in which the amount of increase Δt of the refrigerant liquid temperature is multiplied by the predetermined constant K.

SP14

[0075] The control unit 7 acquires measurement values required for calculation, specifically, data of the refrigerant temperature from the temperature sensor T, and data of a refrigerant pressure from the pressure sensor P. In the second embodiment, the control unit 7 acquires data of the temperature and the pressure of the refrigerant that is sucked into the pump 6 again from the bypass pipe 8h on the suction side of the pump 6.

SP15

[0076] The control unit 7 refers to the database DB2 to acquire data of the amount of increase in pressure required for the compressor 2. The database DB2 calculates the saturated vapor pressure and the refrigerant liquid density of the refrigerant from the refrigerant liquid temperature T (or acquires the saturated vapor pressure and the refrigerant liquid density of the refrigerant from the table stored in the database DB2), calculates the net positive suction head from a gravitational acceleration 9.8 kg/s^2 using Equation (1), and calculates the amount by which the pressure of the compressor 2 can be increased using Equation (3) above.

SP16

[0077] The control unit 7 limits the amount by which the pressure can be increased and increases the pressure of the compressor 2. Specifically, rotation of the compressor 2 is controlled.

SP17

[0078] The control unit 7 determines whether or not the compressor 7 has reached a predetermined amount of increase in pressure, returns to SP14 according to a determination result to repeat control of the amount of increase in pressure, and proceeds to the next step on condition that the compressor 2 has reached the predetermined amount of increase in pressure.

SP18

[0079] The increase in pressure ends when the compressor 2 has reached the predetermined amount of increase in pressure (then, a steady operation according to the predetermined amount of increase in pressure is continued).
[0080] Respective steps thereof are executed.
[0081] Further, in the second embodiment, when the flow rate of the refrigerant becomes extremely small as a result of curbing the amount of increase in pressure of the compressor 2 in order to maintain the net positive suction head when steps SP11 to SP18 above are executed, the bypass valve 9a is opened to return the refrigerant from the discharge side of the pump 6 to the suction side via the bypass pipe 8h so that the refrigerant is sucked into the pump 6 again.
[0082] Thus, by circulating a part of the refrigerant to be supplied to the heat receiver 1, it is possible to secure the minimum refrigerant flow rate for continuity of the operation (sending of the refrigerant) of the pump 6 and to prevent cavitation from occurring due to a reduction of the suction flow rate.
[0083] Also in the second embodiment, it is possible to secure the net positive suction head sucked into the pump 6 and stably send the refrigerant using the pump 6.

(Third Embodiment)

[0084] A third embodiment of the present invention will be described with reference to Figs. 8 to 11. In Figs. 8, 9, and 10, the same components as those in Figs. 1 and 6 are denoted by the same reference signs and a description thereof will be simplified.
[0085] In the third embodiment, a regulation valve 9b is included in a pipe 8b on the suction side of a compressor 2. The regulation valve 9b adjusts a flow rate of a gas phase refrigerant sucked into the compressor 2, and it is possible to prevent pressure inside the tank 5 from excessively decreasing and thus maintain a net positive suction head, by decreasing a degree of opening of the regulation valve 9b to curb the amount of the refrigerant sucked from a tank 5.
[0086] Further, a DB3 for calculating a required amount of increase in pressure that is obtained by using Equation 2 in which the amount of increase Δt of the refrigerant liquid temperature is multiplied by the predetermined constant K, and also calculating the degree of opening of the regulation valve 9b from the amount of increase in pressure of the compressor, and a DB4 for calculating the saturated vapor pressure and the refrigerant liquid density from the refrigerant liquid temperature, and calculating the net positive suction head are mounted in the control unit 7.
[0087] The operation of the cooling device of the third embodiment having the configuration of Fig. 9 and control content of the control unit 7 will be described with reference to a flowchart of Fig. 8.

SP11

[0088] Control is executed on condition that the compressor 2 is operated and the refrigerant is circulated in the refrigeration cycle.

SP12

[0089] The temperature of the refrigerant increases by the refrigerant receiving heat in the heat receiver 1 with an increase in the outside air temperature (the temperature inside the server room).

SP33

[0090] The control unit 7 refers to the database DB3 to acquire the amount of increase in pressure required for the compressor 2. Specifically, the required amount of increase in pressure that is obtained by using Equation (2) in which the amount of increase Δt of the refrigerant liquid temperature is multiplied by the predetermined constant K is calculated.

$$\text{The required amount of increase in pressure calculated from amount of increase in refrigerant liquid temperature} = K \times \Delta t \quad \cdots \quad \text{Equation (2)}$$

[0091] K is a constant for conversion of the amount of temperature increase into the amount of increase in pressure.

$$\text{Degree of opening of regulation valve 9b at compressor inlet} = Kv \times \text{required amount of increase in pressure} \quad \cdots \quad \text{Equation (4)}$$

[0092] Kv is a constant for converting the degree of opening of the regulation valve 9b required to obtain the amount of increase in pressure from the required amount of increase in pressure in anticipation of a predetermined safety factor.

SP34

[0093] The control unit 7 controls rotation of the compressor 2 to obtain a predetermined required amount of increase in pressure based on Equation (2) above, and adjusts the degree of opening of the regulation valve 9b to a predetermined degree of opening based on Equation (4) above.

SP35

[0094] The control unit 7 acquires data of refrigerant temperature at a suction port of the pump 6 from a temperature sensor T and data of refrigerant pressure at the suction port of the pump 6 from a pressure sensor P.

SP36

[0095] The control unit 7 refers to the database DB4 to calculate the saturated vapor pressure and the refrigerant liquid density from the refrigerant liquid temperature. The gravitational acceleration is 9.8 m/sec^2, and the required suction head is a value determined according to a specification of the pump 6. The required suction head is calculated by using Equation (1) above, and a changeable amount of the degree of opening of the regulation valve 9b is calculated from the required suction head by using Equation (5) below.

$$\text{Changeable amount of degree of opening} = f1 \times (\text{net positive suction head} - \text{required suction head}) \quad \cdots \quad \text{Equation (5)}$$

f1 in Equation (5) is a coefficient for converting the amount by which the pressure can be increased from a head difference in anticipation of a safety factor, and is, in this case, a constant that is determined by a specification (a flow rate according to the degree of opening) of the regulation valve 9b.

SP37

[0096] The control unit 7 limits the changeable amount of the degree of opening calculated in SP36 above and opens the regulation valve 9b. More specifically, a command according to the degree of opening is output to a circuit that drives an actuator (not illustrated) that operates the regulation valve 9b. The amount of refrigerant according to the degree of opening of the regulation valve 9b according to this command is sucked into the compressor 2, the pressure of the refrigerant is increased, and the refrigerant is circulated in a refrigeration cycle.

SP38

[0097] The control unit 7 determines whether the regulation valve 9b reaches a predetermined degree of opening, repeats SP35 to SP37 above until the regulation valve 9b reaches a predetermined degree of opening, and proceeds to SP18 to complete the increase in the pressure when the regulation valve 9b reaches the predetermined degree of opening (thereafter, a steady operation according to a predetermined amount of increase in pressure is continued).

[0098] Here, because the amount of suction into the compressor 2 is limited by the regulation valve 9b, a phenomenon that the pressure inside the tank 5 decreases below the required suction head is curbed, and therefore, it is possible to prevent cavitation in the pump 6 from occurring.

[0099] An example of an effect of curbing the decrease in the net positive suction head regardless of the amount of increase in pressure of the compressor 2 according to control for adjusting the degree of opening of the regulation valve 9b will be described in detail with reference to Figs. 10 and 11.

[0100] A relationship between the degree of opening of the regulation valve 9b and change in the amount of increase in pressure (a compression ratio of the compressor 2) is arranged as a relationship illustrated in a chart of Fig. 11, in which pressure on the upstream side of the regulation valve 9b provided at the inlet of the compressor 2 is A, pressure on the suction side of the compressor 2 on the downstream side is B, and pressure on the outlet side of the compressor 2 on the downstream side is C, as illustrated in Fig. 10.

[0101] In a case in which the degree of opening of the regulation valve 9b is 100%, that is, a case in which the regulation valve 9b is not provided as a comparative example, for example, the pressures A and B are 100 kPa (kilopascal) and the pressure C at the outlet of the compressor 2 is 150 kPa, and the amount of increase in the pressure (the compression ratio) is 1.5 times.

[0102] Further, the pressure at the outlet of the compressor 2 is determined by the amount of heat radiation based on the difference between the heat radiator 3 on the downstream side and the outside temperature when the degree of opening of the regulation valve 9b is set to 100% and the degree of opening is not controlled, and therefore, when the pressure at the outlet of the compressor 2 is, for example, 150 kPa, the pressures on the upstream and downstream sides of the regulation valve 9b become 75 kPa, which is half of the pressure at the outlet of the compressor 2, in order to obtain a double compression ratio. As a result, because the pressure inside the tank 5 decreases, the net positive suction head of the pump 6 may be equal to or smaller than the required suction head.

[0103] On the other hand, in a case in which the degree of opening of the regulation valve 9b is controlled by the control unit 7 so that the degree of opening is 60%, even when the pressure B on the downstream side of the regulation valve 9b is 75 kPa, the pressure C at the outlet of the compressor 2 is 150 kPa, and the compression ratio is doubled, it is possible to set the pressure A on the upstream side of the regulation valve 9b to about 95 kPa, curb a decrease in pressure inside the tank 5, and maintain the net positive suction head of the pump 6 to be equal to or greater than the required suction head.

(Fourth Embodiment)

[0104] A fourth embodiment of the present invention will be described with reference to Figs. 12 and 13. In Fig. 13, the same components as those in Figs. 1, 6, 7, and 9 are denoted by the same reference signs, and a description thereof will be simplified.

[0105] In the fourth embodiment, a heat radiator 3 that radiates heat of a refrigerant compressed by a compressor 2 into atmosphere is provided with a fan 3a that supplies cooling air to the heat radiator 3. Further, databases DB1a and DB4a in which an equation for calculating a net positive suction head as in the third embodiment and calculating the amount by which the rotation speed of the fan 3a can be increased is stored are mounted on a control unit 7.

[0106] In the fourth embodiment, it is possible to adjust the temperature of a refrigerant supplied to a tank 5 by controlling the amount of air of the fan 3a provided in the heat radiator 3 using the heat radiator 3, and to adjust the net positive suction head calculated by using Equation (1) through the adjustment of the refrigerant temperature.

[0107] Control content of the control unit 7 will be described together with the operation of the cooling device of the fourth embodiment with reference to a flowchart of Fig. 12.

SP11

[0108] Control is executed on condition that the compressor 2 is operated and the refrigerant is circulated in the refrigeration cycle.

SP12

[0109] The temperature of the refrigerant increases by the refrigerant receiving heat in the heat receiver 1 with an increase in the outside air temperature (the temperature inside the server room).

SP43

[0110] The control unit 7 determines whether or not an upper limit of increase in the pressure (an upper limit of a discharge capacity) of the compressor 2 has been reached, and proceeds to the next step 44 on condition that the upper limit has been reached. When the upper limit has not been reached, for example, the rotation speed of a drive motor is increased in order to further increase the pressure in the compressor 2.

SP44

[0111] The control unit 7 refers to the database DB1a to calculate the amount of increase in rotation speed required for the fan 3a to blow the amount of air required for heat radiation, from the amount of temperature increase of the liquid phase refrigerant.

[0112] Here, a required amount of increase in the rotation speed of the fan 3a is

$$\text{Required amount of increase} = \text{K1} \times \text{increase value of refrigerant temperature} \quad \cdots \quad \text{Equation (6)}$$

[0113] K1 is a constant that is determined by performance of the fan 3a and heat radiation capacity of the heat radiator 3.

SP45

[0114] The control unit 7 acquires data of refrigerant temperature at a suction port of the pump 6 from a temperature sensor T and data of refrigerant pressure at the suction port of the pump 6 from a pressure sensor P.

SP46

[0115] The control unit 7 refers to a database DB4a to calculate the saturated vapor pressure and the refrigerant liquid density from the refrigerant liquid temperature. The gravitational acceleration is 9.8 m/sec^2, and the required suction head is a value determined according to a specification of the pump 6. The required suction head is calculated by using Equation (1) above, and the amount by which the rotation speed of the fan can be increased is calculated by using Equation (7) below.

$$\text{Amount by which rotation speed of fan can be increased} = \text{f2} \times (\text{net positive suction head - required suction head}) \quad \cdots\cdot \quad \text{Equation (7)}$$

f2 is a coefficient for conversion of the amount by which the power can be increased from the head difference in anticipation of a safety factor, and is, in this case, a constant determined by a specification of the fan 3a (the amount of blown air according to the rotation speed).

SP47

[0116] The control unit 7 limits the rotation speed to the amount by which the rotation speed can be increased, which is calculated in SP46 above, and increases the rotation speed of the fan 3a. More specifically, a control signal is output to a drive circuit of a motor (not illustrated) that drives the fan 3a in order to obtain rotation at a predetermined rotation speed. Accordingly, the amount of heat radiation of the heat radiator 3 is limited, and the liquid phase refrigerant is limited to a predetermined temperature.

SP48

[0117] The control unit 7 determines whether the fan 3a has reached a predetermined rotation speed, repeats SP45 to SP47 above until the fan 3a has reached the predetermined speed, and proceeds to SP49 to end the control of the rotation speed of the fan 3a when the fan 3a has reached the predetermined speed (thereafter, a steady operation according to a predetermined amount of increase in pressure and amount of heat radiation is continued).
[0118] According to the curbing of the rotation speed of the heat radiation fan 3a, for example, when the rotation speed of the fan 3a of the heat radiator 3 increases in order to decrease the refrigerant temperature with an operation of increasing the pressure of the compressor 2 to near an upper limit of a rated capacity thereof, it is possible to maintain the net positive suction head of the refrigerant temperature by curbing the increase in the rotation speed of the fan 3a when the pump inlet temperature decreases due to the increased in pressure of the compressor 2 and the saturated vapor pressure decreases due to the decrease in the refrigerant temperature in Equation (1).
[0119] The curbing of heat radiation according to curbing of the amount of air of the fan 3a is suitably adopted for free cooling in which a heat medium is moved between the heat receiver 1 and the heat radiator 3 without using a compressor (including a case in which the refrigerant is caused to pass through with the compressor stopped or the compressor bypassed, in addition to a case in which the compressor is not provided in the first place), such as a case in which the outside air temperature is sufficiently low or when the refrigeration cycle is started.
[0120] As a modification example of the fan 3a that adjusts the amount of heat radiation of the heat radiator 3, a mechanism (so-called louver) for adjusting an angle of a cooling air adjustment plate 3b that adjusts the amount of outside air passing through the heat radiator 3 as indicated by a dashed line in Fig. 13 is provided, the amount of outside air flowing into the heat radiator 3 can be limited by adjusting an angle of the cooling air adjustment plate 3b, or this can also be applied to a case in which a scheme of adjusting the flow rate and temperature of cooling water coming into contact with a pipe through which the refrigerant flows when the heat radiator 3 is a water-cooled type is adopted.

(Fifth Embodiment)

[0121] A fifth embodiment of the present invention will be described with reference to Figs. 14 and 15. In Fig. 15, the same components as those in Figs. 1, 6, 7, 9, and 13 are denoted by the same reference signs and a description thereof will be simplified.
[0122] In the fifth embodiment, a heat radiator 3 that radiates heat of a refrigerant compressed by a compressor 2 into atmosphere is provided with a fan 3a that supplies cooling air to the heat radiator 3. Further, a database DB5 that calculates a net positive suction head in consideration of the amount by which the pressure of the compressor 2 can be increased and the changeable amount of air amount of the fan 3a, in addition to the database DB1, is mounted on a control unit 7.
[0123] The database DB5 calculates the saturated vapor pressure and the refrigerant liquid density of the refrigerant from the refrigerant liquid temperature T (or acquires the saturated vapor pressure and the refrigerant liquid density of the refrigerant from an existing data table stored in the database DB1), and calculates the net positive suction head from the gravitational acceleration 9.8 kg/s^2 using Equation (1).
[0124] Control content of the control unit 7 will be described together with the operation of the cooling device of the fifth embodiment with reference to a flowchart of Fig. 14.

SP11

[0125] Control is executed on condition that the compressor 2 is operated and the refrigerant is circulated in the refrigeration cycle.

SP12

[0126] The temperature of the refrigerant increases by the refrigerant receiving heat in the heat receiver 1 with an increase in the outside air temperature (the temperature inside the server room).

SP13

[0127] The control unit 7 refers to the database DB1 to acquire the amount of increase in pressure required for the compressor 2. Specifically, the required amount of increase in pressure obtained by using Equation (2) in which the amount of increase Δt of the refrigerant liquid temperature is multiplied by the predetermined constant K is acquired.

SP54

[0128] The control unit 7 acquires data of a pump inlet pressure from the pressure sensor P and the data of refrigerant temperature from the temperature sensor T.

SP55

[0129] The control unit 7 obtains the net positive suction head from the database DB5 by using Equation (1), calculates the amount by which the pressure of the compressor 2 can be increased by using Equation (3) in which the difference between this net positive suction head and the required suction head is multiplied by the constant f, and multiplies the amount by which the pressure can be increased by a constant K2 to calculate the changeable amount of rotation speed of the fan 3a.

$$\text{Changeable amount of rotation speed} = \text{K2} \times \text{amount by which pressure of compressor can be increased} \quad \cdots \quad \text{Equation (8)}$$

SP56

[0130] The control unit 7 limits the amount by which the pressure of the compressor 2 can be increased and then increases the rotation speed.

SP57

[0131] The control unit 7 decreases the rotation speed of the fan 3a within a range of the calculated changeable amount, and curbs the amount of heat radiation of the heat radiator 3.

SP17

[0132] The control unit 7 repeats SP54 to 57 above until the compressor 2 reaches the predetermined amount of increase in pressure, and proceeds to the next step on condition that the compressor 2 has reached the predetermined amount of increase in pressure.

SP18

[0133] The increase in pressure ends on the condition that the compressor 2 has reached the predetermined amount of increase in pressure (then, a steady operation according to the predetermined amount of increase in pressure is continued). Control for adjusting the degree of opening of the regulation valve provided at the inlet of the compressor 2 adopted in the third embodiment may be adopted instead of the control of the increase in the pressure of the compressor 2 that is performed in steps SP56 and SP57.
[0134] In the fifth embodiment, it is possible to compensate for the pressure decrease of the tank 5 due to the increase in pressure of the compressor 2 through the decrease in the refrigerant temperature to curb a decrease in the net positive suction head and prevent cavitation from occurring in the pump 6 by decreasing the rotation speed of the fan 3a to increase the temperature of the refrigerant.
[0135] According to curbing of the rotation of the fan 3a, for example, it is possible to curb excessive heat radiation of the heat radiator 3 immediately after the increase in the pressure of the compressor 2 starts due to the an increase in the temperature of the server room from a free cooling state in which the compressor 2 is not operated because the temperature of the server room is low and the amount of heat received by the heat receiver 1 is small, and to stabilize the operation of the pump 6.

(Sixth Embodiment)

[0136] A sixth embodiment of the present invention will be described with reference to Figs. 16 and 17. In Fig. 17, the same components as those in Figs. 1, 6, 7, 9, 13, and 15 are denoted by the same reference signs and a description thereof will be simplified.
[0137] In the sixth embodiment, a control unit 7 controls an inverter 6a that drives a motor (not illustrated) that rotates a rotor of a pump 6, in addition to control of the amount of increase in pressure of the compressor 2. Further, the control

unit 7 receives data from the pressure sensor P in the gas-liquid separator, the refrigerant temperature sensor T in the gas-liquid separator, and a liquid level height sensor L in the gas-liquid separator.

[0138] Further, the control unit 7 includes a database DB5a, and the database DB5a calculates a net positive suction head by using Equation (1') below.

$$\text{Net positive suction head} = \text{liquid level height in gas-liquid separator} + (\text{pressure inside gas-liquid separator} - \text{pipe pressure loss} - \text{saturated vapor pressure})/(\text{refrigerant liquid density} \times \text{gravitational acceleration}) \quad \cdots \quad \text{Equation (1')}$$

[0139] The pipe pressure loss can be calculated by multiplying the flow rate of the refrigerant (determined by a flow velocity and a pipe diameter) by a predetermined pressure loss coefficient α.

[0140] Control content of the control unit 7 will be described together with the operation of the cooling device of the sixth embodiment with reference to a flowchart of Fig. 16.

SP11

[0141] Control is executed on condition that the compressor 2 is operated and the refrigerant is circulated in the refrigeration cycle.

SP12

[0142] The temperature of the refrigerant increases by the refrigerant receiving heat in the heat receiver 1 with an increase in the outside air temperature (the temperature inside the server room).

SP13

[0143] The control unit 7 refers to the database DB1 to acquire the amount of increase in pressure required for the compressor 2. Specifically, the required amount of increase in pressure obtained by using Equation (2) in which the amount of increase Δt of the refrigerant liquid temperature is multiplied by the predetermined constant K is acquired.

SP64

[0144] The control unit 7 acquires data of the pressure inside the tank 5 from the pressure sensor P, the temperature of the refrigerant in the tank 5 from the temperature sensor T, and the height of the liquid level L in the gas-liquid separation tank 5 from the liquid level sensor L.

SP65

[0145] The control unit 7 obtains the net positive suction head from the database DB5a by using Equation (1'), and calculates the amount by which the pressure of the compressor 2 can be increased by using Equation (3) in which the difference between this net positive suction head and the required suction head is multiplied by the constant f. Here, a pressure L in the tank decreases due to the increase in the pressure of the compressor 2, a pressure loss occurs due to a flow path resistance of the pipe to the suction port of the pump 6, and a net positive suction head corresponding to the pressure of the suction port of the pump 6, which has reflected an influence of the decrease in the saturated vapor pressure due to the decrease in the refrigerant temperature with the increase in pressure of the compressor 2, is calculated. The constant f is a constant that is set in consideration of a safety factor in which the operational fluctuation in the amount by which the pressure of the compressor 2 can be increased, which is determined on the basis of a head difference, is anticipated.

SP66

[0146] The control unit 7 limits the amount by which the pressure of the compressor 2 can be increased and then increases the pressure.

SP17

[0147] The control unit 7 repeats SP64 to 66 above until the compressor 2 reaches the predetermined amount of increase in pressure, and proceeds to the next step on condition that the compressor 2 has reached the predetermined amount of increase in pressure.

SP18

[0148] The increase in pressure ends on condition that the compressor 2 has reached the predetermined amount of increase in pressure (then, a steady operation according to the predetermined amount of increase in pressure is continued).

[0149] According to the above configuration, it is possible to calculate the required suction head that can prevent the occurrence of cavitation of the pump 6, on the basis of the data acquired by the sensors provided in order to measure the pressure, the temperature, and the liquid level in the tank 5 using the sensors without separately providing sensors in the pipe 8f of the suction portion of the pump 6.

(Seventh Embodiment)

[0150] A seventh embodiment of the present invention will be described with reference to Figs. 18 and 19. In Fig. 19, the same components as those in Figs. 1, 6, 7, 9, 13, 15, and 17 are denoted by the same reference signs and a description thereof will be simplified.

[0151] In the seventh embodiment, a control unit 7 performs control according to the number of pressure increase steps stored in a database DB6 and a waiting time until an increase in pressure by the compressor 2 starts.

[0152] For the number of pressure increase steps, for example, data of pressure increase steps of the compressor 2 that can maintain the net positive suction head without causing cavitation in the pump 6 on the basis of operation record data of the refrigeration cycle for each outside air temperature is collected and stored in advance. Further, the waiting time is calculated by using Equation (9) below.

$$\text{Waiting time} = \text{KT} \times \text{amount of increase in pressure of compressor/total refrigerant flow rate of heat receiver} \quad \cdots \quad \text{Equation (9)}$$

[0153] KT is a time sufficient for the refrigerant temperature to begin to decrease with an increase in the pressure, and is an constant that is determined on the basis of operation record data for a degree of increase in pressure of the refrigeration cycle and occurrence or non-occurrence of the cavitation (the operation situation of the pump), and used to convert the flow rate into a waiting time.

[0154] The measurement of the amount of increase in pressure of the compressor and the refrigerant flow rate is not limited to actual measurement values using sensors such as a pressure sensor and a flow rate sensor, and the amounts may be obtained through conversion from a load current of the drive motor of the compressor 2 and a load current of a drive motor of the pump 6, that is, current values obtained from ammeters of the respective motors.

[0155] Control content of the control unit 7 will be described together with the operation of the cooling device of the seventh embodiment with reference to a flowchart of Fig. 18.

SP11

[0156] Control is executed on condition that the compressor 2 is operated and the refrigerant is circulated in the refrigeration cycle.

SP12

[0157] The temperature of the refrigerant increases by the refrigerant receiving heat in the heat receiver 1 with an increase in the outside air temperature (the temperature inside the server room).

SP73

[0158] The control unit 7 acquires data of the amount of increase in pressure in each predetermined step and a predetermined time to wait until the increase in pressure is completed, from the database DB6.

SP74

[0159] The control unit 7 gradually increases the rotation speed of the compressor 2 to obtain the amount of increase in pressure in each step acquired from the database DB7. Also, the temperature of the refrigerant begins to drop with the increase in pressure.

SP75

[0160] The control unit 7 compares a predetermined waiting time with an elapsed time of the increase in pressure, and proceeds to the next step on condition that the waiting time is exceeded.

SP76

[0161] The control unit 7 repeats SP74 to SP76 above until the temperature of the refrigerant reaches a target value, and proceeds to the next step on condition that the temperature of the refrigerant has reached a predetermined target value.

SP18

[0162] The increase in pressure of the compressor 2 ends when the refrigerant temperature has reached the predetermined target value (then, a steady operation according to the predetermined amount of increase in pressure is continued).

[0163] According to the above configuration, it is possible to prevent the cavitation from occurring in the pump 6 by gradually increasing the pressure using the compressor 2 over a predetermined time when the pressure of the refrigerant is expected to reach the net positive suction head of the pump 6. Further, because the above control is executed according to preset pressure increase steps, it is not necessary to provide sensors at various places in the refrigeration cycle to measure the pressure, temperature, and the like, and it is possible to simplify the configuration of a refrigeration device. This control is suitable for shift from a so-called free cooling state in which the increase in pressure is not performed by the compressor 2 and the heat is simply transferred from the heat receiver 1 to the heat radiator 3 by the refrigerant, for example, when the temperature of the server room is not so high, to a state in which it is necessary to increase the pressure of the refrigerant using the compressor 2 due to temperature increase in the server room.

[0164] Specific configurations of the heat receiver, the compressor, the heat radiator, the gas-liquid separator, the expander, the pump, and the control unit that constitute the refrigeration cycle are not limited to the embodiments and, of course, may be changed without departing from the gist of the present invention. For example, the expander has a function of depressurizing and expanding a refrigerant in a flow path of the liquid phase refrigerant by applying a throttle to the flow path, and an orifice (simply, a throttle) or a capillary (which is a thin tube having a predetermined length formed in a coil shape, and gives resistance to a fluid by flowing through a flow path having a small cross-sectional area) can be adopted, in addition to the valve in the embodiment.

[0165] Further, control of the compressor, the heat radiator, and the valve that is performed in the first to seventh embodiments is not limited to a single implementation, and a plurality of controls may be implemented in combination. Further, when the plurality of controls may be implemented in combination, any one of the controls may be preferentially executed in consideration of conditions such as, for example, the response speed to an increase or decrease of the net positive suction head, and the influence on loads of refrigeration cycles of other systems.

[0166] Some or all of the above embodiments may also be described as in the following supplementary notes, but the present inventions is not limited thereto: In supplementary notes 1 to 32, the compressor constituting the refrigeration cycle is not necessarily limited to a device having a function of positively compressing a refrigerant, such as a compressor, and is assumed to include a component having an operation of substantially compressing a refrigerant without using special power, such as a pipe between the heat receiver and the heat radiator, according to so-called free cooling.

(Supplementary note 1)

[0167] A cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, the cooling device including: a gas-liquid separator configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and a liquid phase refrigerant; a pump configured to send the liquid phase refrigerant separated by the gas-liquid separator to the heat receiver; and a control unit configured to control the amount of increase in pressure of the compressor in the refrigeration cycle, wherein the control unit limits a value of a net positive suction head of the pump to a range in which the value does not fall below a predetermined value and increases the pressure of the compressor.

(Supplementary note 2)

[0168] The cooling device according to supplementary note 1, wherein the control unit calculates the net positive suction head from an inlet pressure of the pump, a saturated vapor pressure of the refrigerant, and a density of the refrigerant.

(Supplementary note 3)

[0169] The cooling device according to supplementary note 1, wherein the control unit calculates the net positive suction head from detection data of a pressure sensor and a temperature sensor, the pressure sensor being configured to measure an inlet pressure of the pump, the temperature sensor configured to measure the temperature of a liquid phase portion of an inlet of the pump.

(Supplementary note 4)

[0170] The cooling device according to supplementary note 1, wherein the control unit calculates the net positive suction head from detection data of a pressure sensor and a temperature sensor, the pressure sensor being configured to measure the pressure of the refrigerant inside a bypass pipe configured to connect a discharge side to a suction side of the pump, the temperature sensor configured to measure the temperature of the refrigerant.

(Supplementary note 5)

[0171] The cooling device according to supplementary note 1, wherein the control unit calculates the net positive suction head from the pressure, the temperature, and a liquid level height of the refrigerant inside the gas-liquid separator.

(Supplementary note 6)

[0172] The cooling device according to supplementary note 1, wherein the control unit increases the pressure of the compressor in a plurality of stages.

(Supplementary note 7)

[0173] The cooling device according to any one of supplementary notes 1 to 6, wherein the control unit controls the amount of heat radiated from the heat radiator together with the increase in pressure of the compressor.

(Supplementary note 8)

[0174] A control method for a cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, the control method including: limiting, by a control unit, a value of a net positive suction head of a pump to a range in which the value does not fall below a predetermined value, the pump being configured to suck a liquid phase refrigerant from a gas-liquid separator and send the liquid phase refrigerant to the heat receiver, the gas-liquid separator being configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and the liquid phase refrigerant; and controlling, by the control unit, an increase in the pressure of the compressor.

(Supplementary note 9)

[0175] A control device for a cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, wherein the control device limits the amount of increase in the pressure of the compressor to a range in which a value of a net positive suction head of a pump does not fall below a predetermined value, the pump being configured to send a liquid phase refrigerant separated by a gas-liquid separator to the heat receiver, the gas-liquid separator being configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and the liquid phase refrigerant.

(Supplementary note 10)

[0176] A program for causing a computer to execute limitation of the amount of increase in pressure in the control device according to supplementary note 9.

(Supplementary note 11)

[0177] A cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, the cooling device including: a gas-liquid separator configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and a liquid phase refrigerant; a pump configured to send the liquid phase refrigerant separated by the gas-liquid separator to the heat receiver; and a control unit configured to control the amount of increase in pressure of the compressor in the refrigeration cycle, wherein the control unit limits a value of a net positive suction head of the pump to a range in which the value does not fall below a predetermined value and controls a flow rate of the refrigerant sucked by the compressor.

(Supplementary note 12)

[0178] The cooling device according to supplementary note 11, wherein the control unit controls a suction flow rate of the compressor according to a degree of opening of a regulation valve provided in a pipe configured to supply a refrigerant from the gas-liquid separator to the compressor.

(Supplementary note 13)

[0179] A control method for a cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, the control method including: limiting, by a control unit, a value of a net positive suction head of the pump to a range in which the value does not fall below a predetermined value, the pump being configured to suck a liquid phase refrigerant from a gas-liquid separator configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and the liquid phase refrigerant; and adjusting, by the control unit, the amount of suction of the refrigerant of the compressor.

(Supplementary note 14)

[0180] A control device for a cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, wherein the control device limits a value of a net positive suction head of a pump to a range in which the value does not fall below a predetermined value , the pump being configured to send a liquid phase refrigerant separated by a gas-liquid separator to the heat receiver, the gas-liquid separator being configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and the liquid phase refrigerant, and controls a flow rate of the refrigerant sucked by the compressor.

(Supplementary note 15)

[0181] A program for causing a computer to execute limitation of a flow rate of the refrigerant in the control device according to supplementary note 14.

(Supplementary note 16)

[0182] A cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, the cooling device including: a gas-liquid separator configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and a liquid phase refrigerant; a pump configured to send the liquid phase refrigerant separated by the gas-liquid separator to the heat receiver; and a control unit configured to control the amount of increase in pressure of the compressor in the refrigeration cycle, wherein the control unit limits a value of a net positive suction head of the pump to a range in which the value does not fall below a predetermined value and limits the amount of heat radiated from the heat radiator.

(Supplementary note 17)

[0183] The cooling device according to supplementary note 16, wherein the control unit controls the amount of air sent by a fan configured to supply cooling air to the heat radiator.

(Supplementary note 18)

[0184] A control method for a cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, the control method including: limiting, by a control unit, a value of a net positive suction head of the pump to a range in which the value does not fall below a predetermined value, the pump being configured to suck a liquid phase refrigerant from a gas-liquid separator configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and the liquid phase refrigerant; and controlling, by the control unit, the amount of heat radiated from the heat radiator.

(Supplementary note 19)

[0185] A control device for a cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, wherein the control device limits a value of a net positive suction head of a pump to a range in which the value does not fall below a predetermined value, the pump being configured to send a liquid phase refrigerant separated by a gas-liquid separator to the heat receiver, the gas-liquid separator being configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and the liquid phase refrigerant, and controls the amount of heat radiated from the heat radiator.

(Supplementary note 20)

[0186] A program for causing a computer to execute control of the amount of heat radiated from the refrigerant in the control device according to supplementary note 19.

(Supplementary note 21)

[0187] A cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, the cooling device including: a gas-liquid separator configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and a liquid phase refrigerant; a pump configured to send the liquid phase refrigerant separated by the gas-liquid separator to the heat receiver; and a control unit configured to control the amount of increase in pressure of the compressor in the refrigeration cycle, wherein the control unit gradually increases the pressure of the compressor over a predetermined time.

(Supplementary note 22)

[0188] A control method for a cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, the control method including: gradually increasing, by a control unit, the pressure of the compressor over a predetermined time.

(Supplementary note 23)

[0189] A control device for a cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, wherein the control device gradually increases the pressure of a compressor over a predetermined time, the compressor being configured to compress a liquid phase refrigerant separated by a gas-liquid separator configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and the liquid phase refrigerant.

(Supplementary note 24)

[0190] A program for causing a computer to execute a stepwise increase in pressure using the control device according to supplementary note 23.

(Supplementary note 25)

[0191] A cooling device for controlling the net positive suction head in combination of a plurality of controls executed by the respective control units according to supplementary notes 1, 11, 16, and 21.

(Supplementary note 26)

[0192] The cooling device according to supplementary note 25, wherein, in the control in which a plurality of controls executed by the control unit of the cooling device according to supplementary notes 1, 11, 16 and 21 are combined, any one of the controls is executed in preference to the other controls.

(Supplementary note 27)

[0193] A control method for controlling the net positive suction head in combination of a plurality of controls executed by using the respective control methods according to supplementary notes 8, 13, 18, and 22.

(Supplementary note 28)

[0194] The cooling device according to supplementary note 27, wherein, in the control in which a plurality of controls executed by using the respective control methods according to supplementary notes 8, 13, 18, and 22 are combined, any one of the controls is executed in preference to the other controls.

(Supplementary note 29)

[0195] A control device for controlling the net positive suction head in combination of a plurality of controls executed by the respective control devices according to supplementary notes 9, 14, 19, and 23.

(Supplementary note 30)

[0196] The control device according to supplementary note 29, wherein, in the control in which a plurality of controls executed by the respective control device according to supplementary notes 9, 14, 19, and 23 are combined, any one of the controls is executed in preference to the other controls.

(Supplementary note 31)

[0197] A program for controlling the net positive suction head in combination of a plurality of the processes that the respective programs according to supplementary notes 10, 15, 20, and 24 cause a computer to execute.

(Supplementary note 32)

[0198] The program according to supplementary note 31, wherein, in the processes that the respective programs according to supplementary notes 10, 15, 20, and 24 cause a computer to execute, any one of the processes is executed in preference to the other processes.

INDUSTRIAL APPLICABILITY

[0199] The cooling device and cooling method of the present invention can be used for air conditioning applications of a data center or the like.

Reference Symbols

[0200]

1 Heat receiver
2 Compressor
3 Heat radiator
3a Fan
3b Cooling air adjustment plate
4 Expander
5 Gas-liquid separator (tank)
6 Pump
7 Control unit
8a, 8b, 8c, 8d, 8e, 8f, 8g, 8h Pipe
9a Bypass valve
9b Regulation valve
DB1, DB 1', DB2, DB3, DB3a Database
DB4, DB4a, DB5, DB5a Database
T Temperature sensor
P Pressure sensor

L Liquid level sensor

Claims

1. A cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, the cooling device comprising:

   a gas-liquid separator configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and a liquid phase refrigerant;
   a pump configured to send the liquid phase refrigerant separated by the gas-liquid separator to the heat receiver; and
   a control unit configured to control an amount of increase in pressure of the compressor in the refrigeration cycle, wherein the control unit limits a value of a net positive suction head of the pump to a range in which the value does not fall below a predetermined value and increases the pressure of the compressor.

2. The cooling device according to claim 1, wherein the control unit calculates the net positive suction head from an inlet pressure of the pump, a saturated vapor pressure of the refrigerant, and a density of the refrigerant.

3. The cooling device according to claim 1, wherein the control unit calculates the net positive suction head from detection data of a pressure sensor and a temperature sensor, the pressure sensor being configured to measure an inlet pressure of the pump, the temperature sensor configured to measure a temperature of a liquid phase portion of an inlet of the pump.

4. The cooling device according to claim 1, wherein the control unit calculates the net positive suction head from detection data of a pressure sensor and a temperature sensor, the pressure sensor being configured to measure a pressure of the refrigerant inside a bypass pipe configured to connect a discharge side to a suction side of the pump, the temperature sensor configured to measure a temperature of the refrigerant.

5. The cooling device according to claim 1, wherein the control unit calculates the net positive suction head from a pressure, a temperature, and a liquid level height of the refrigerant inside the gas-liquid separator.

6. The cooling device according to claim 1, wherein the control unit increases the pressure of the compressor in a plurality of stages.

7. The cooling device according to any one of claims 1 to 6, wherein the control unit controls an amount of heat radiated from the heat radiator together with the increase in pressure of the compressor.

8. A control method for a cooling device using a refrigeration cycle in which a refrigerant is circulated through a heat receiver, a compressor, a heat radiator, and an expander, the control method comprising:

   limiting, by a control unit, a value of a net positive suction head of a pump to a range in which the value does not fall below a predetermined value, the pump being configured to suck a liquid-phase refrigerant from a gas-liquid separator and send the liquid phase refrigerant to the heat receiver, the gas-liquid separator being configured to separate the refrigerant supplied from the expander into a gas phase refrigerant and the liquid phase refrigerant; and
   controlling, by the control unit, an increase in the pressure of the compressor.

FIG. 1

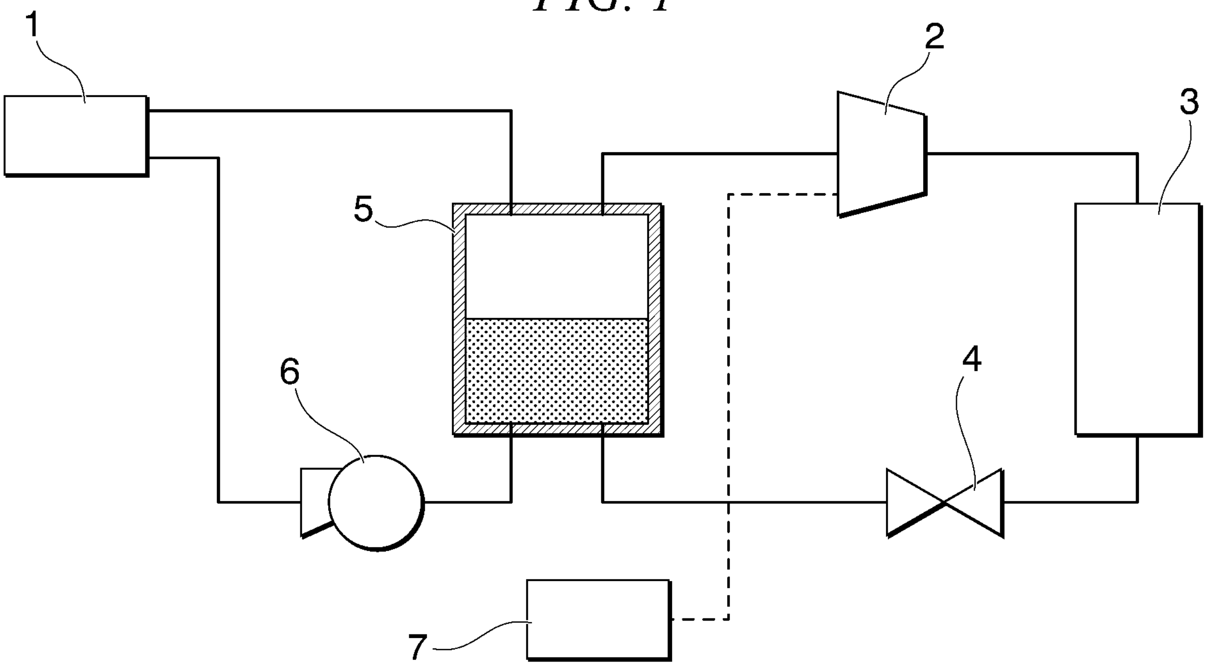

1
2
3
5
6
4
7

FIG. 2

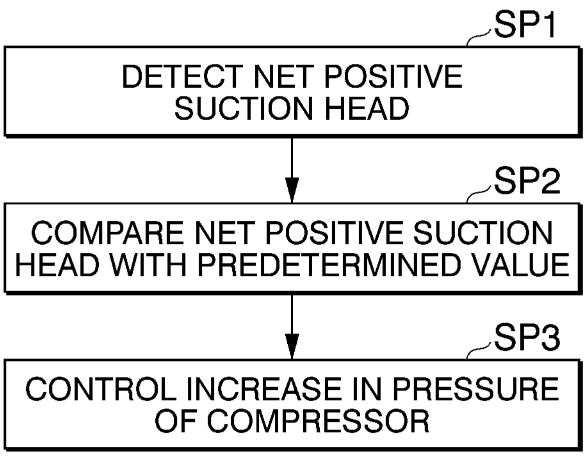

SP1
DETECT NET POSITIVE SUCTION HEAD
SP2
COMPARE NET POSITIVE SUCTION HEAD WITH PREDETERMINED VALUE
SP3
CONTROL INCREASE IN PRESSURE OF COMPRESSOR

FIG. 3

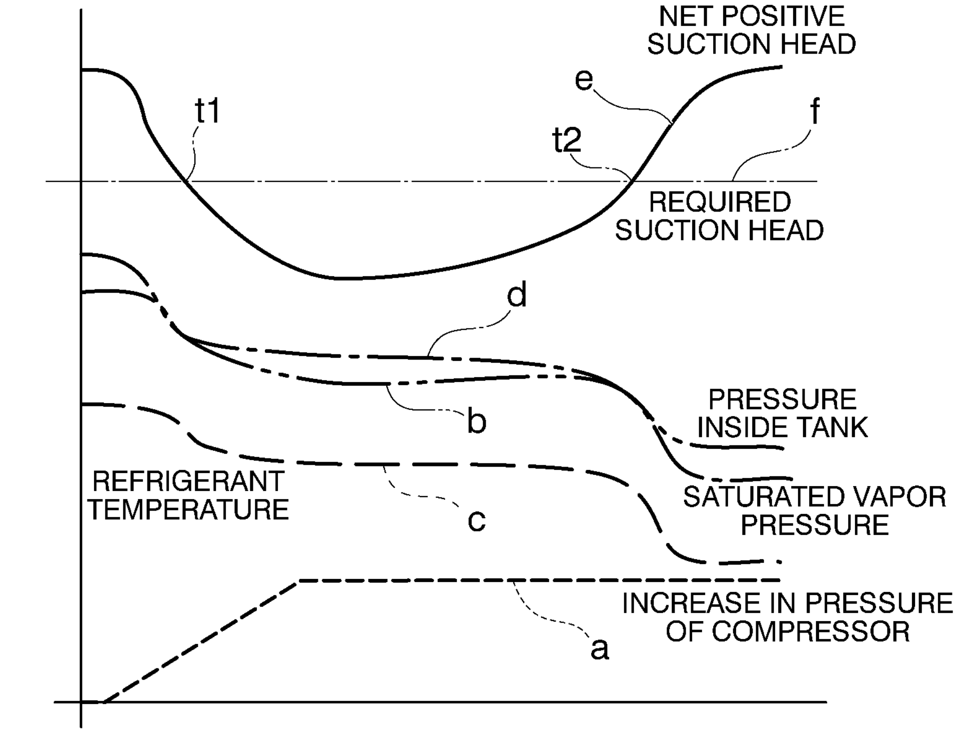

NET POSITIVE SUCTION HEAD
e
t1
t2
f
REQUIRED SUCTION HEAD
d
PRESSURE INSIDE TANK
b
REFRIGERANT TEMPERATURE
SATURATED VAPOR PRESSURE
c
INCREASE IN PRESSURE OF COMPRESSOR
a

FIG. 4

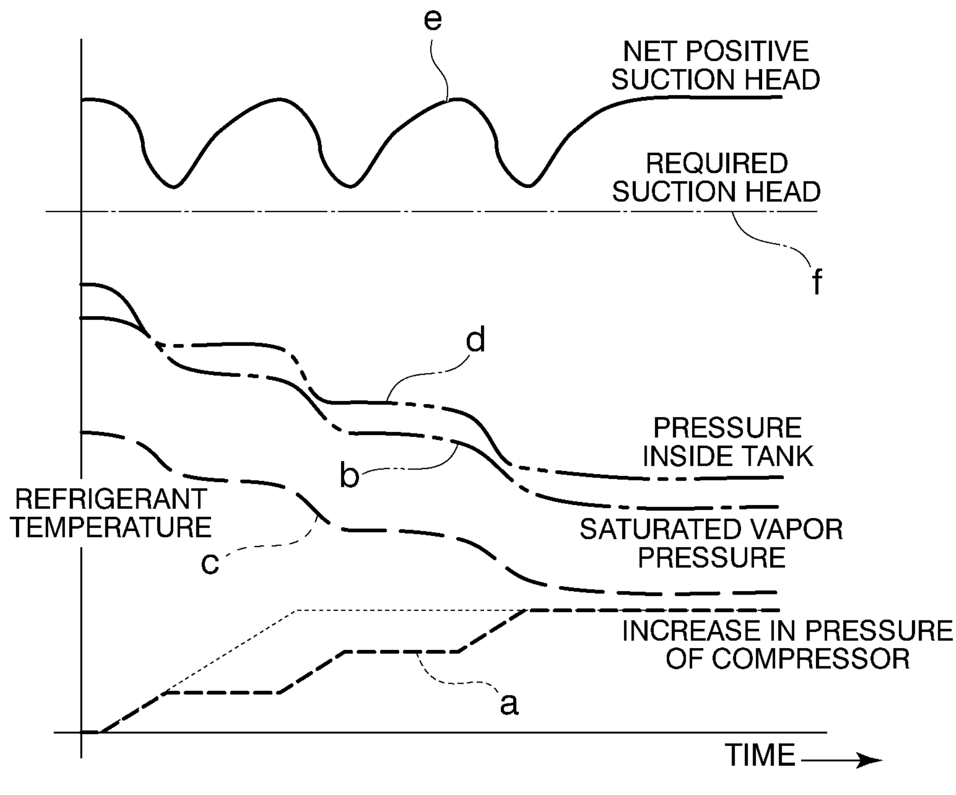

e
NET POSITIVE SUCTION HEAD
REQUIRED SUCTION HEAD
f
d
PRESSURE INSIDE TANK
b
REFRIGERANT TEMPERATURE
SATURATED VAPOR PRESSURE
c
INCREASE IN PRESSURE OF COMPRESSOR
a
TIME

FIG. 5

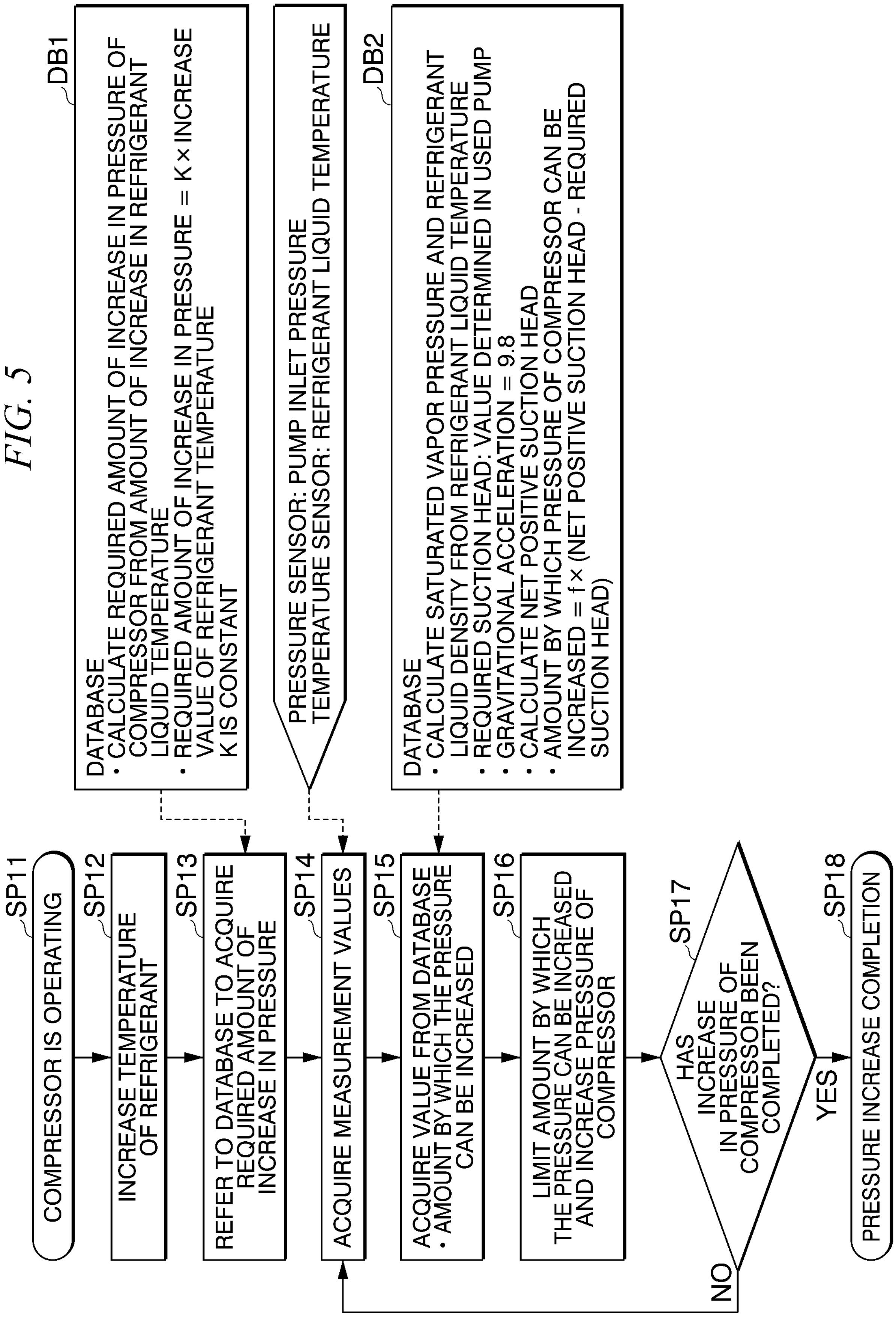

DB1
DATABASE
• CALCULATE REQUIRED AMOUNT OF INCREASE IN PRESSURE OF COMPRESSOR FROM AMOUNT OF INCREASE IN REFRIGERANT LIQUID TEMPERATURE
• REQUIRED AMOUNT OF INCREASE IN PRESSURE = K × INCREASE VALUE OF REFRIGERANT TEMPERATURE
K IS CONSTANT
PRESSURE SENSOR: PUMP INLET PRESSURE
TEMPERATURE SENSOR: REFRIGERANT LIQUID TEMPERATURE
DB2
DATABASE
• CALCULATE SATURATED VAPOR PRESSURE AND REFRIGERANT LIQUID DENSITY FROM REFRIGERANT LIQUID TEMPERATURE
• REQUIRED SUCTION HEAD: VALUE DETERMINED IN USED PUMP
• GRAVITATIONAL ACCELERATION = 9.8
• CALCULATE NET POSITIVE SUCTION HEAD
• AMOUNT BY WHICH PRESSURE OF COMPRESSOR CAN BE INCREASED = f × (NET POSITIVE SUCTION HEAD - REQUIRED SUCTION HEAD)
SP11
COMPRESSOR IS OPERATING
SP12
INCREASE TEMPERATURE OF REFRIGERANT
SP13
REFER TO DATABASE TO ACQUIRE REQUIRED AMOUNT OF INCREASE IN PRESSURE
SP14
ACQUIRE MEASUREMENT VALUES
SP15
ACQUIRE VALUE FROM DATABASE
• AMOUNT BY WHICH THE PRESSURE CAN BE INCREASED
SP16
LIMIT AMOUNT BY WHICH THE PRESSURE CAN BE INCREASED AND INCREASE PRESSURE OF COMPRESSOR
SP17
HAS INCREASE IN PRESSURE OF COMPRESSOR BEEN COMPLETED?
YES
NO
SP18
PRESSURE INCREASE COMPLETION

FIG. 6

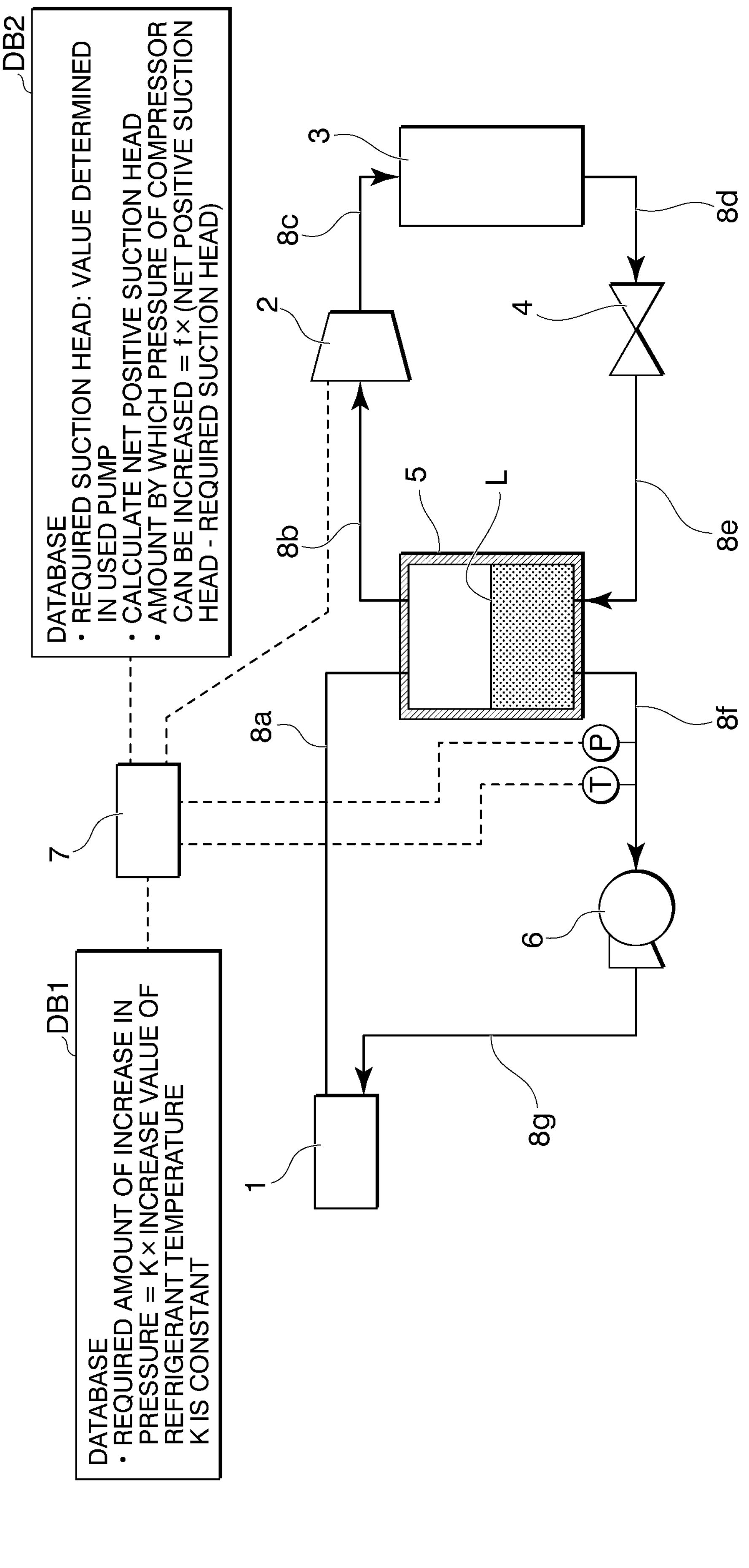

DB2
DATABASE
· REQUIRED SUCTION HEAD: VALUE DETERMINED IN USED PUMP
· CALCULATE NET POSITIVE SUCTION HEAD
· AMOUNT BY WHICH PRESSURE OF COMPRESSOR CAN BE INCREASED = f× (NET POSITIVE SUCTION HEAD - REQUIRED SUCTION HEAD)
DB1
DATABASE
· REQUIRED AMOUNT OF INCREASE IN PRESSURE = K×INCREASE VALUE OF REFRIGERANT TEMPERATURE
K IS CONSTANT
1
2
3
4
5
6
7
8a
8b
8c
8d
8e
8f
8g
L
T
P

FIG. 7

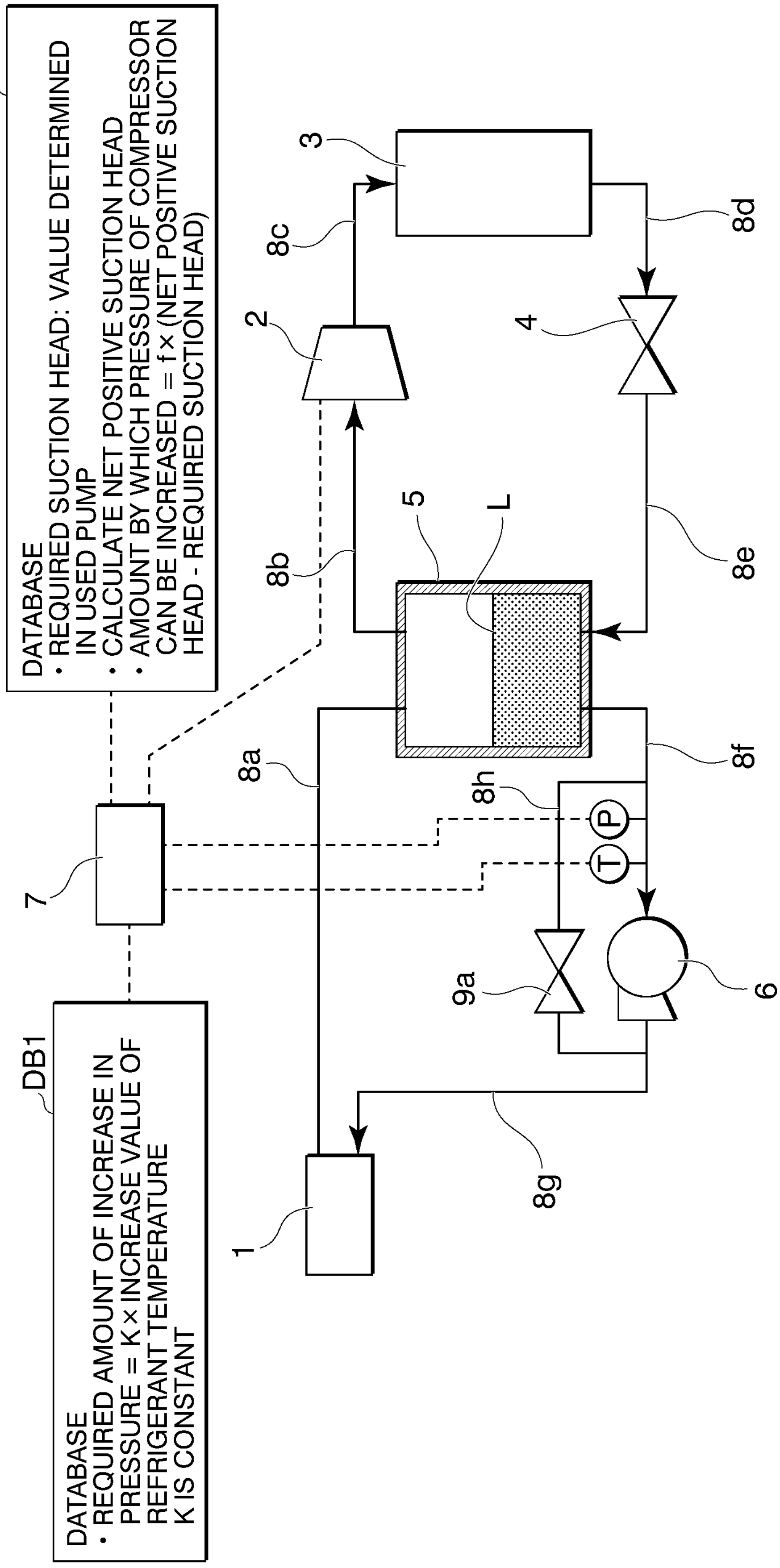

DB2
DATABASE
• REQUIRED SUCTION HEAD: VALUE DETERMINED IN USED PUMP
• CALCULATE NET POSITIVE SUCTION HEAD
• AMOUNT BY WHICH PRESSURE OF COMPRESSOR CAN BE INCREASED = f × (NET POSITIVE SUCTION HEAD - REQUIRED SUCTION HEAD)
DB1
DATABASE
• REQUIRED AMOUNT OF INCREASE IN PRESSURE = K × INCREASE VALUE OF REFRIGERANT TEMPERATURE
K IS CONSTANT
1
2
3
4
5
6
7
8a
8b
8c
8d
8e
8f
8g
8h
9a
L
T
P

FIG. 8

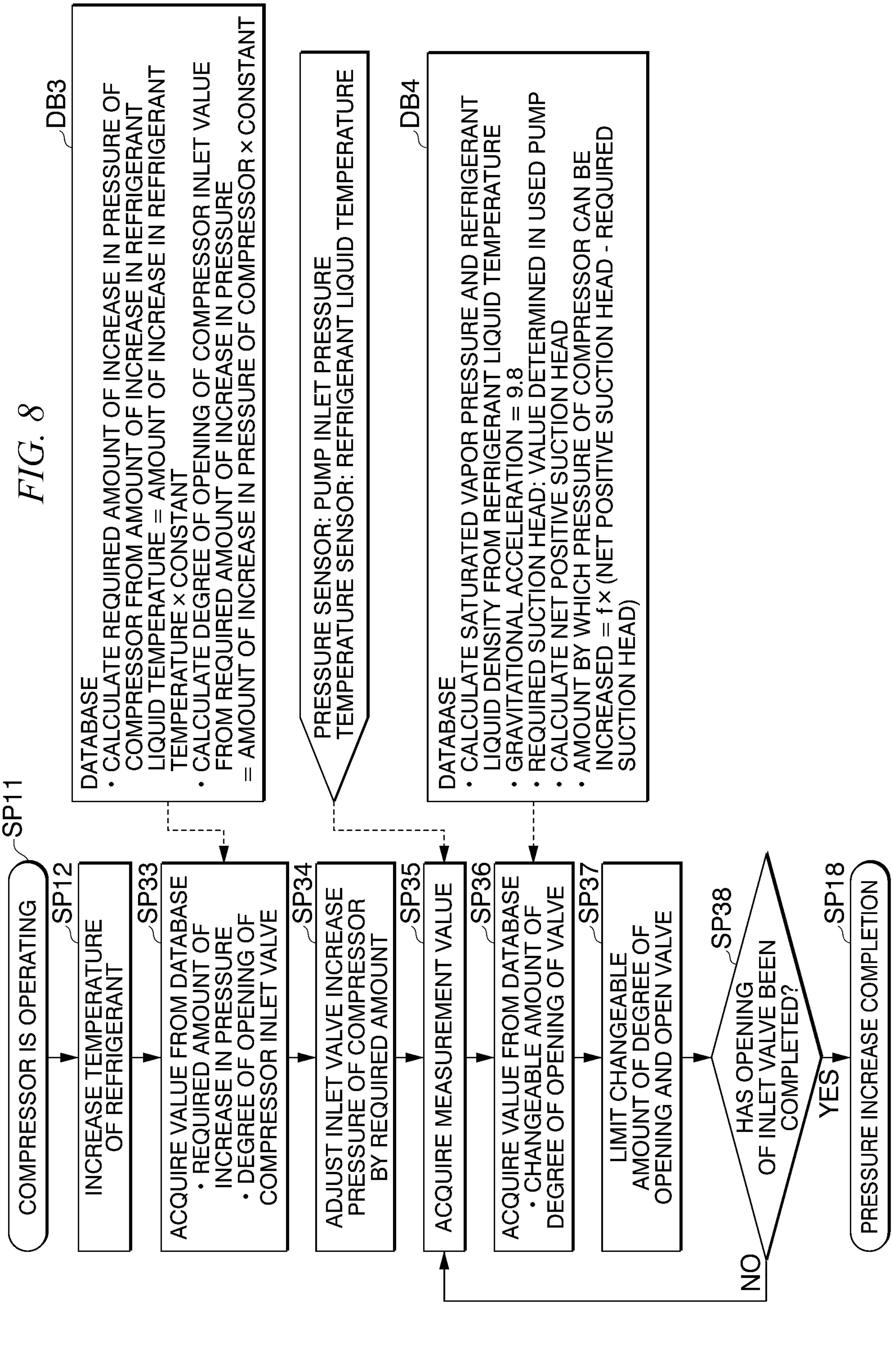

SP11
COMPRESSOR IS OPERATING
SP12
INCREASE TEMPERATURE OF REFRIGERANT
SP33
ACQUIRE VALUE FROM DATABASE
· REQUIRED AMOUNT OF INCREASE IN PRESSURE
· DEGREE OF OPENING OF COMPRESSOR INLET VALVE
SP34
ADJUST INLET VALVE INCREASE PRESSURE OF COMPRESSOR BY REQUIRED AMOUNT
SP35
ACQUIRE MEASUREMENT VALUE
SP36
ACQUIRE VALUE FROM DATABASE
· CHANGEABLE AMOUNT OF DEGREE OF OPENING OF VALVE
SP37
LIMIT CHANGEABLE AMOUNT OF DEGREE OF OPENING AND OPEN VALVE
SP38
HAS OPENING OF INLET VALVE BEEN COMPLETED?
YES
NO
SP18
PRESSURE INCREASE COMPLETION
DB3
DATABASE
· CALCULATE REQUIRED AMOUNT OF INCREASE IN PRESSURE OF COMPRESSOR FROM AMOUNT OF INCREASE IN REFRIGERANT LIQUID TEMPERATURE
LIQUID TEMPERATURE = AMOUNT OF INCREASE IN REFRIGERANT TEMPERATURE × CONSTANT
· CALCULATE DEGREE OF OPENING OF COMPRESSOR INLET VALUE FROM REQUIRED AMOUNT OF INCREASE IN PRESSURE
= AMOUNT OF INCREASE IN PRESSURE OF COMPRESSOR × CONSTANT
PRESSURE SENSOR: PUMP INLET PRESSURE
TEMPERATURE SENSOR: REFRIGERANT LIQUID TEMPERATURE
DB4
DATABASE
· CALCULATE SATURATED VAPOR PRESSURE AND REFRIGERANT LIQUID DENSITY FROM REFRIGERANT LIQUID TEMPERATURE
· GRAVITATIONAL ACCELERATION = 9.8
· REQUIRED SUCTION HEAD: VALUE DETERMINED IN USED PUMP
· CALCULATE NET POSITIVE SUCTION HEAD
· AMOUNT BY WHICH PRESSURE OF COMPRESSOR CAN BE INCREASED = f × (NET POSITIVE SUCTION HEAD - REQUIRED SUCTION HEAD)

FIG. 9

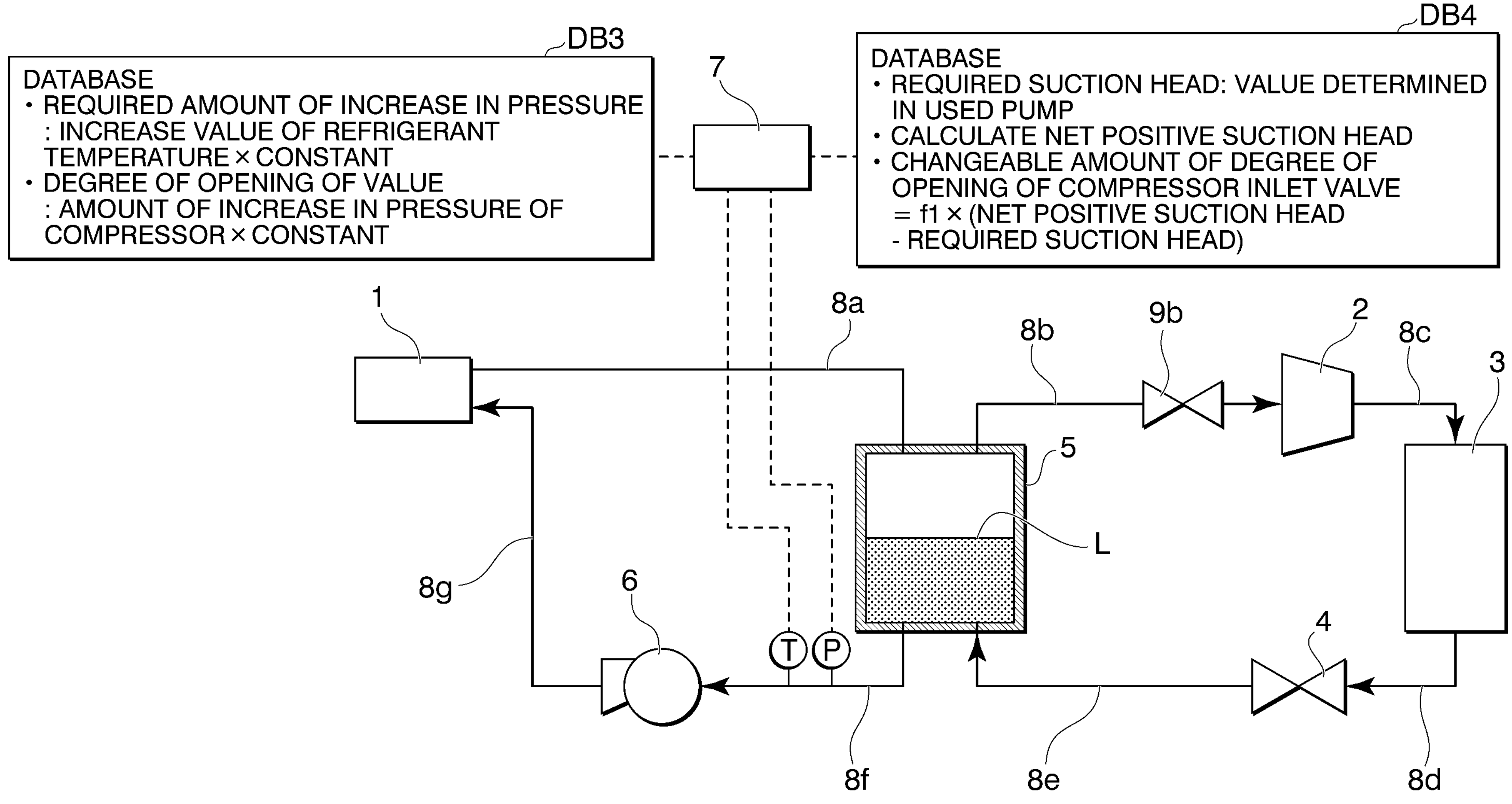

DB3
DATABASE
• REQUIRED AMOUNT OF INCREASE IN PRESSURE
: INCREASE VALUE OF REFRIGERANT TEMPERATURE × CONSTANT
• DEGREE OF OPENING OF VALUE
: AMOUNT OF INCREASE IN PRESSURE OF COMPRESSOR × CONSTANT
7
DB4
DATABASE
• REQUIRED SUCTION HEAD: VALUE DETERMINED IN USED PUMP
• CALCULATE NET POSITIVE SUCTION HEAD
• CHANGEABLE AMOUNT OF DEGREE OF OPENING OF COMPRESSOR INLET VALVE
= f1 × (NET POSITIVE SUCTION HEAD - REQUIRED SUCTION HEAD)
1
8a
8b
9b
2
8c
3
5
L
6
8g
T
P
4
8f
8e
8d

FIG. 10

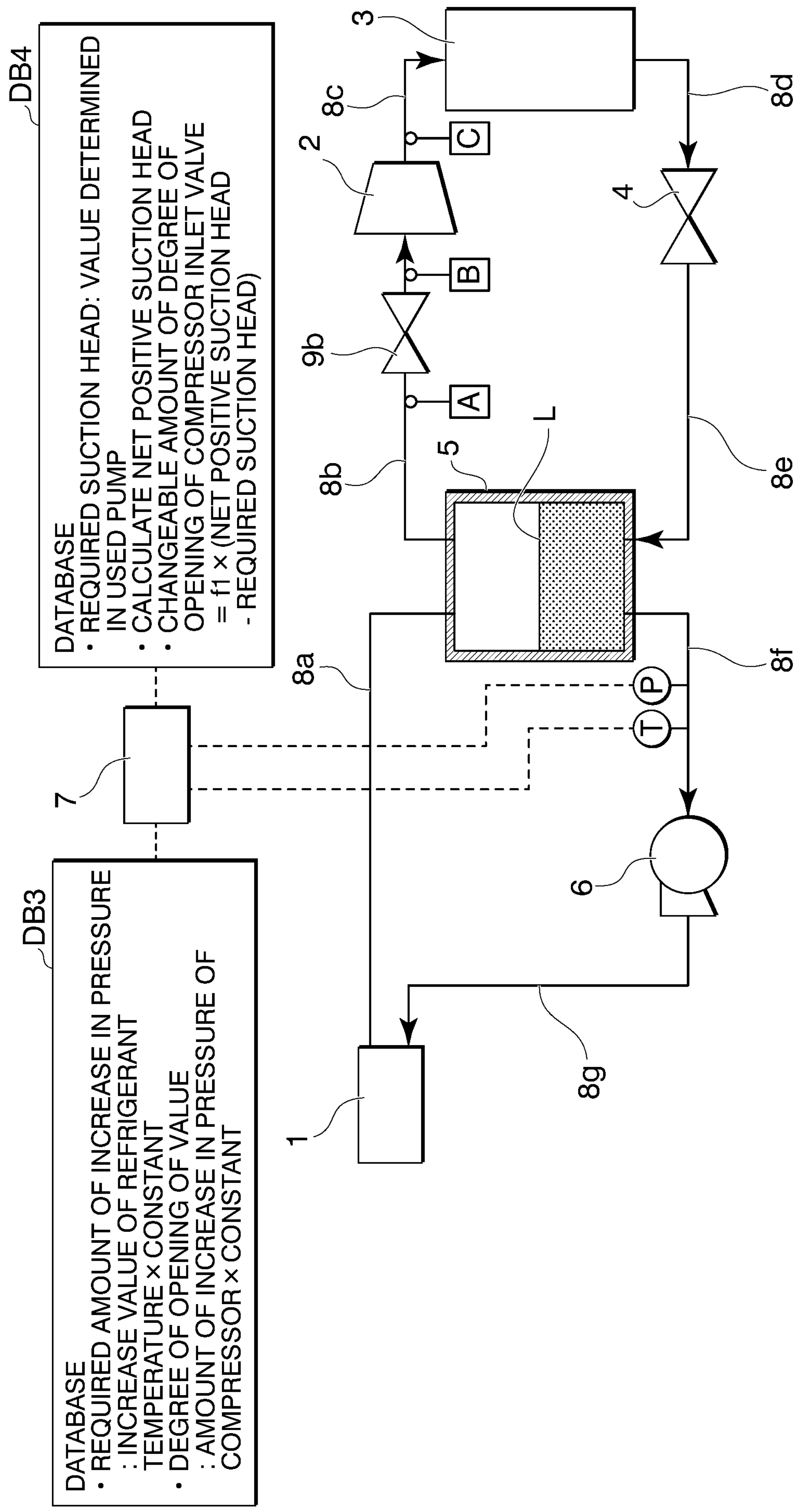

DB4
DATABASE
• REQUIRED SUCTION HEAD: VALUE DETERMINED IN USED PUMP
• CALCULATE NET POSITIVE SUCTION HEAD
• CHANGEABLE AMOUNT OF DEGREE OF OPENING OF COMPRESSOR INLET VALVE = f1 × (NET POSITIVE SUCTION HEAD - REQUIRED SUCTION HEAD)
DB3
DATABASE
• REQUIRED AMOUNT OF INCREASE IN PRESSURE : INCREASE VALUE OF REFRIGERANT TEMPERATURE × CONSTANT
• DEGREE OF OPENING OF VALUE : AMOUNT OF INCREASE IN PRESSURE OF COMPRESSOR × CONSTANT
7
1
2
3
4
5
6
L
8a
8b
8c
8d
8e
8f
8g
9b
A
B
C
P
T

FIG. 11

	DEGREE OF OPENING OF VALVE [%]	PRESSURE [kPa]			AMOUNT OF INCREASE IN PRESSURE (COMPRESSION RATIO)
		COMPRESSOR INLET		COMPRESSOR OUTLET	
		A BEFORE VALVE	B AFTER VALVE	C	
COMPARATIVE EXAMPLE	100	100	100	150	1.5
INCREASE IN PRESSURE (NO VALVE CONTROL)	100	75	75	150	2.0
INCREASE IN PRESSURE (VALVE CONTROL)	60	95	75	150	2.0

FIG. 12

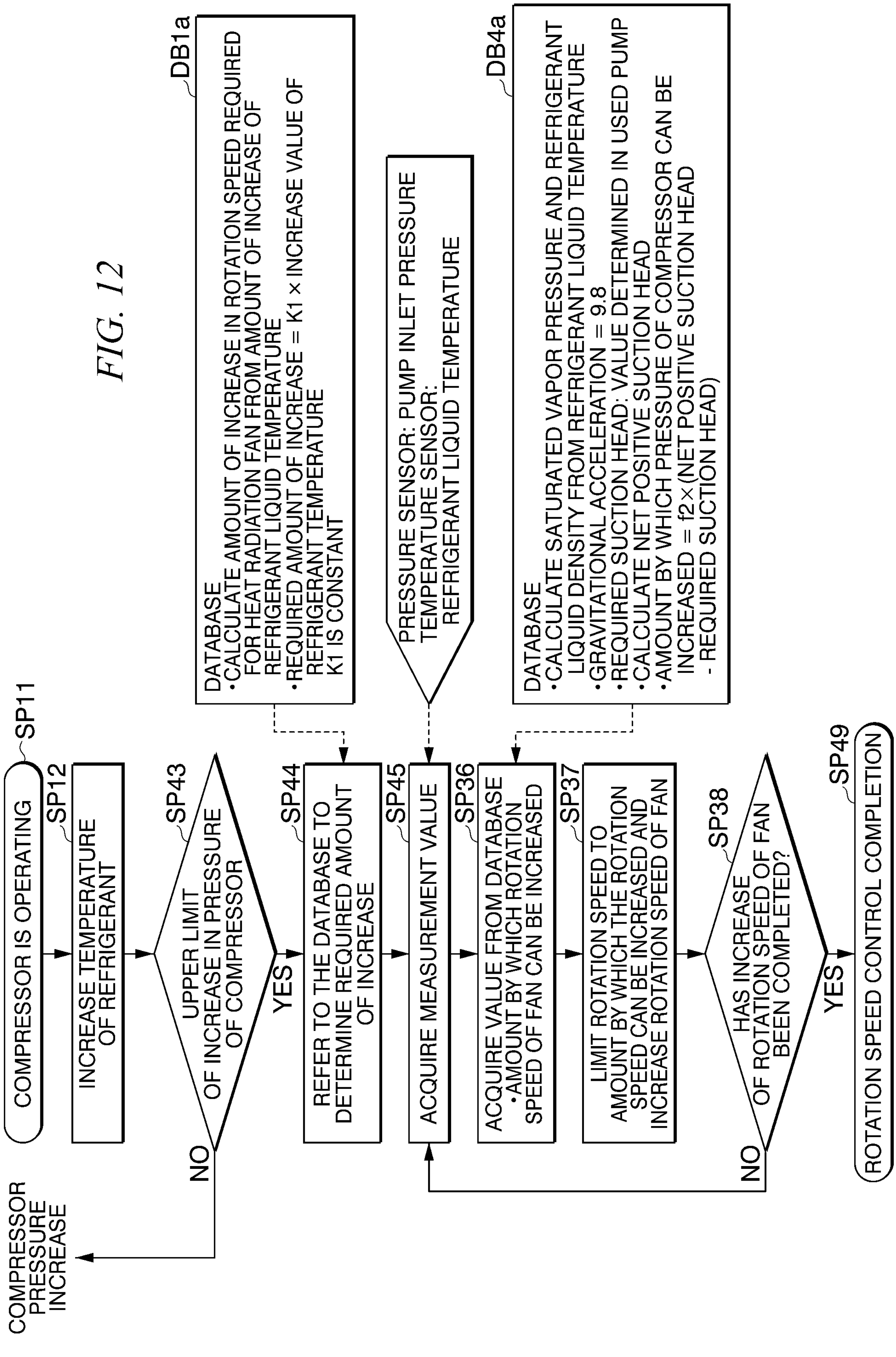

SP11
COMPRESSOR IS OPERATING
SP12
INCREASE TEMPERATURE OF REFRIGERANT
SP43
UPPER LIMIT OF INCREASE IN PRESSURE OF COMPRESSOR
NO
COMPRESSOR PRESSURE INCREASE
YES
SP44
REFER TO THE DATABASE TO DETERMINE REQUIRED AMOUNT OF INCREASE
DB1a
DATABASE
•CALCULATE AMOUNT OF INCREASE IN ROTATION SPEED REQUIRED FOR HEAT RADIATION FAN FROM AMOUNT OF INCREASE OF REFRIGERANT LIQUID TEMPERATURE
•REQUIRED AMOUNT OF INCREASE = K1 × INCREASE VALUE OF REFRIGERANT TEMPERATURE K1 IS CONSTANT
SP45
ACQUIRE MEASUREMENT VALUE
PRESSURE SENSOR: PUMP INLET PRESSURE
TEMPERATURE SENSOR: REFRIGERANT LIQUID TEMPERATURE
SP36
ACQUIRE VALUE FROM DATABASE
•AMOUNT BY WHICH ROTATION SPEED OF FAN CAN BE INCREASED
DB4a
DATABASE
•CALCULATE SATURATED VAPOR PRESSURE AND REFRIGERANT LIQUID DENSITY FROM REFRIGERANT LIQUID TEMPERATURE
•GRAVITATIONAL ACCELERATION = 9.8
•REQUIRED SUCTION HEAD: VALUE DETERMINED IN USED PUMP
•CALCULATE NET POSITIVE SUCTION HEAD
•AMOUNT BY WHICH PRESSURE OF COMPRESSOR CAN BE INCREASED = f2×(NET POSITIVE SUCTION HEAD - REQUIRED SUCTION HEAD)
SP37
LIMIT ROTATION SPEED TO AMOUNT BY WHICH THE ROTATION SPEED CAN BE INCREASED AND INCREASE ROTATION SPEED OF FAN
SP38
HAS INCREASE OF ROTATION SPEED OF FAN BEEN COMPLETED?
NO
YES
SP49
ROTATION SPEED CONTROL COMPLETION

FIG. 13

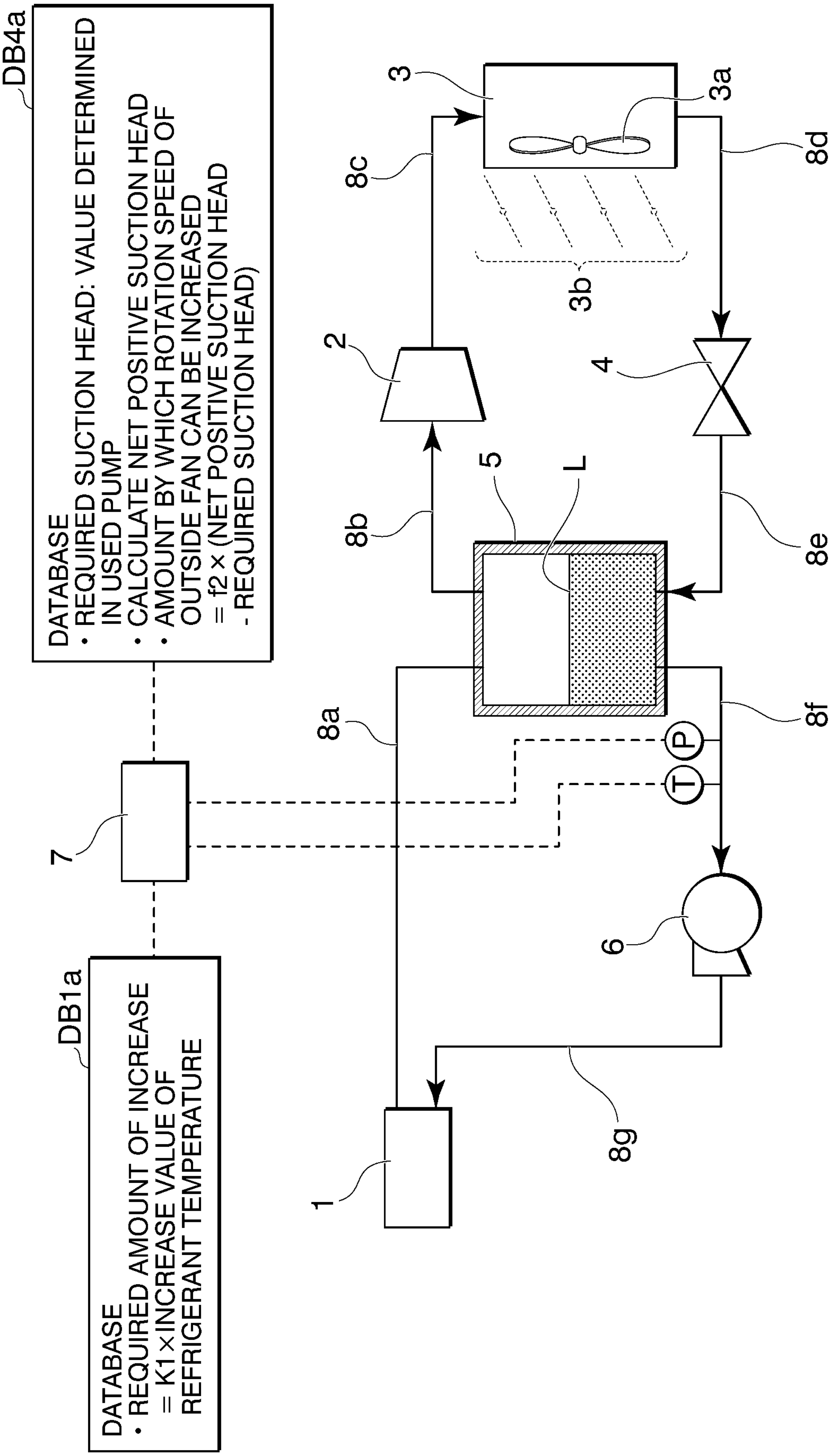

DB4a
DATABASE
• REQUIRED SUCTION HEAD: VALUE DETERMINED IN USED PUMP
• CALCULATE NET POSITIVE SUCTION HEAD
• AMOUNT BY WHICH ROTATION SPEED OF OUTSIDE FAN CAN BE INCREASED = f2 × (NET POSITIVE SUCTION HEAD - REQUIRED SUCTION HEAD)
DB1a
DATABASE
• REQUIRED AMOUNT OF INCREASE = K1×INCREASE VALUE OF REFRIGERANT TEMPERATURE
7
1
2
3
3a
3b
4
5
L
6
8a
8b
8c
8d
8e
8f
8g
P
T

FIG. 14

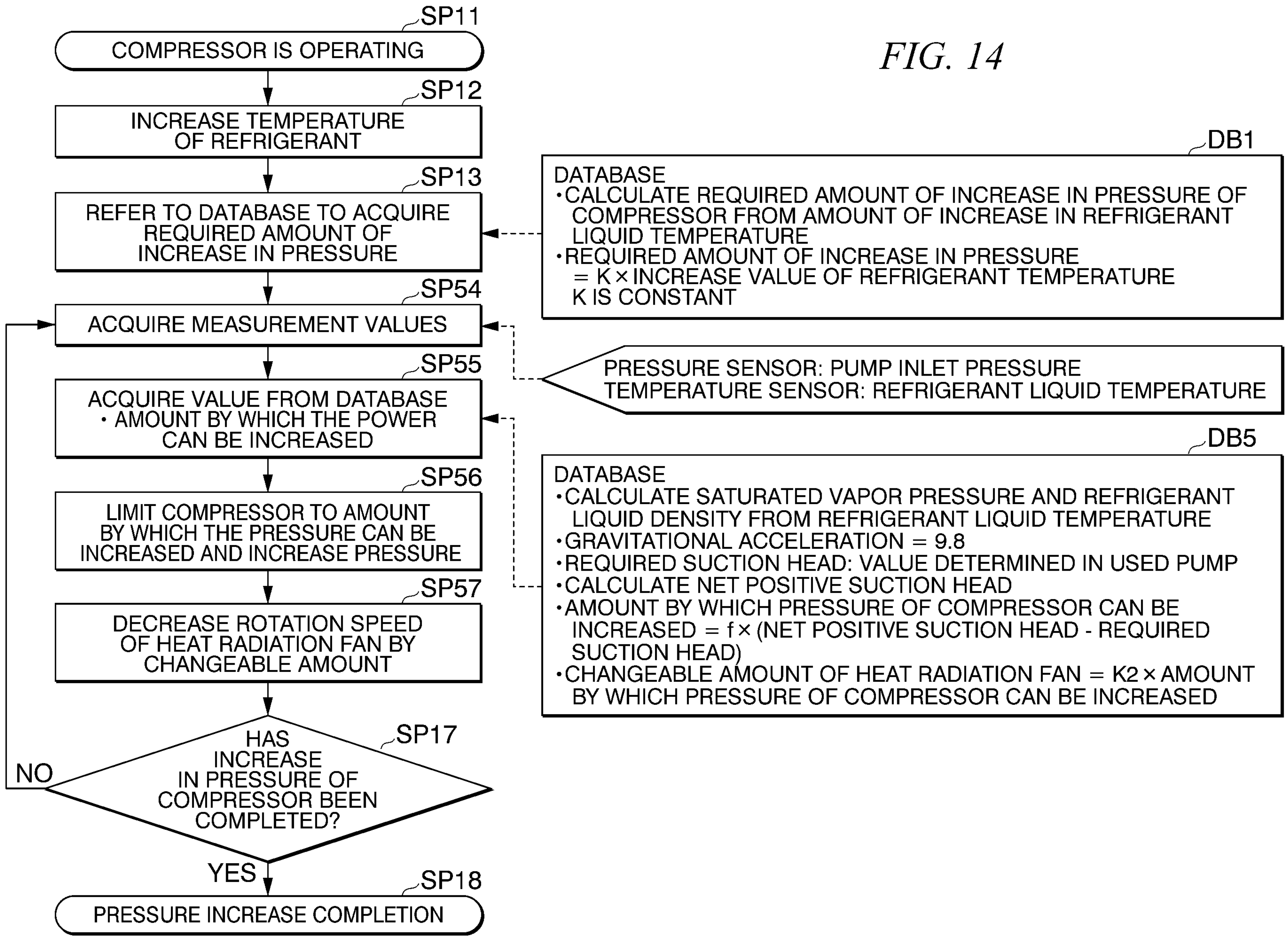

SP11
COMPRESSOR IS OPERATING
SP12
INCREASE TEMPERATURE OF REFRIGERANT
SP13
REFER TO DATABASE TO ACQUIRE REQUIRED AMOUNT OF INCREASE IN PRESSURE
SP54
ACQUIRE MEASUREMENT VALUES
SP55
ACQUIRE VALUE FROM DATABASE
• AMOUNT BY WHICH THE POWER CAN BE INCREASED
SP56
LIMIT COMPRESSOR TO AMOUNT BY WHICH THE PRESSURE CAN BE INCREASED AND INCREASE PRESSURE
SP57
DECREASE ROTATION SPEED OF HEAT RADIATION FAN BY CHANGEABLE AMOUNT
SP17
HAS INCREASE IN PRESSURE OF COMPRESSOR BEEN COMPLETED?
NO
YES
SP18
PRESSURE INCREASE COMPLETION
DB1
DATABASE
•CALCULATE REQUIRED AMOUNT OF INCREASE IN PRESSURE OF COMPRESSOR FROM AMOUNT OF INCREASE IN REFRIGERANT LIQUID TEMPERATURE
•REQUIRED AMOUNT OF INCREASE IN PRESSURE = K × INCREASE VALUE OF REFRIGERANT TEMPERATURE
K IS CONSTANT
PRESSURE SENSOR: PUMP INLET PRESSURE
TEMPERATURE SENSOR: REFRIGERANT LIQUID TEMPERATURE
DB5
DATABASE
•CALCULATE SATURATED VAPOR PRESSURE AND REFRIGERANT LIQUID DENSITY FROM REFRIGERANT LIQUID TEMPERATURE
•GRAVITATIONAL ACCELERATION = 9.8
•REQUIRED SUCTION HEAD: VALUE DETERMINED IN USED PUMP
•CALCULATE NET POSITIVE SUCTION HEAD
•AMOUNT BY WHICH PRESSURE OF COMPRESSOR CAN BE INCREASED = f × (NET POSITIVE SUCTION HEAD - REQUIRED SUCTION HEAD)
•CHANGEABLE AMOUNT OF HEAT RADIATION FAN = K2 × AMOUNT BY WHICH PRESSURE OF COMPRESSOR CAN BE INCREASED

FIG. 15

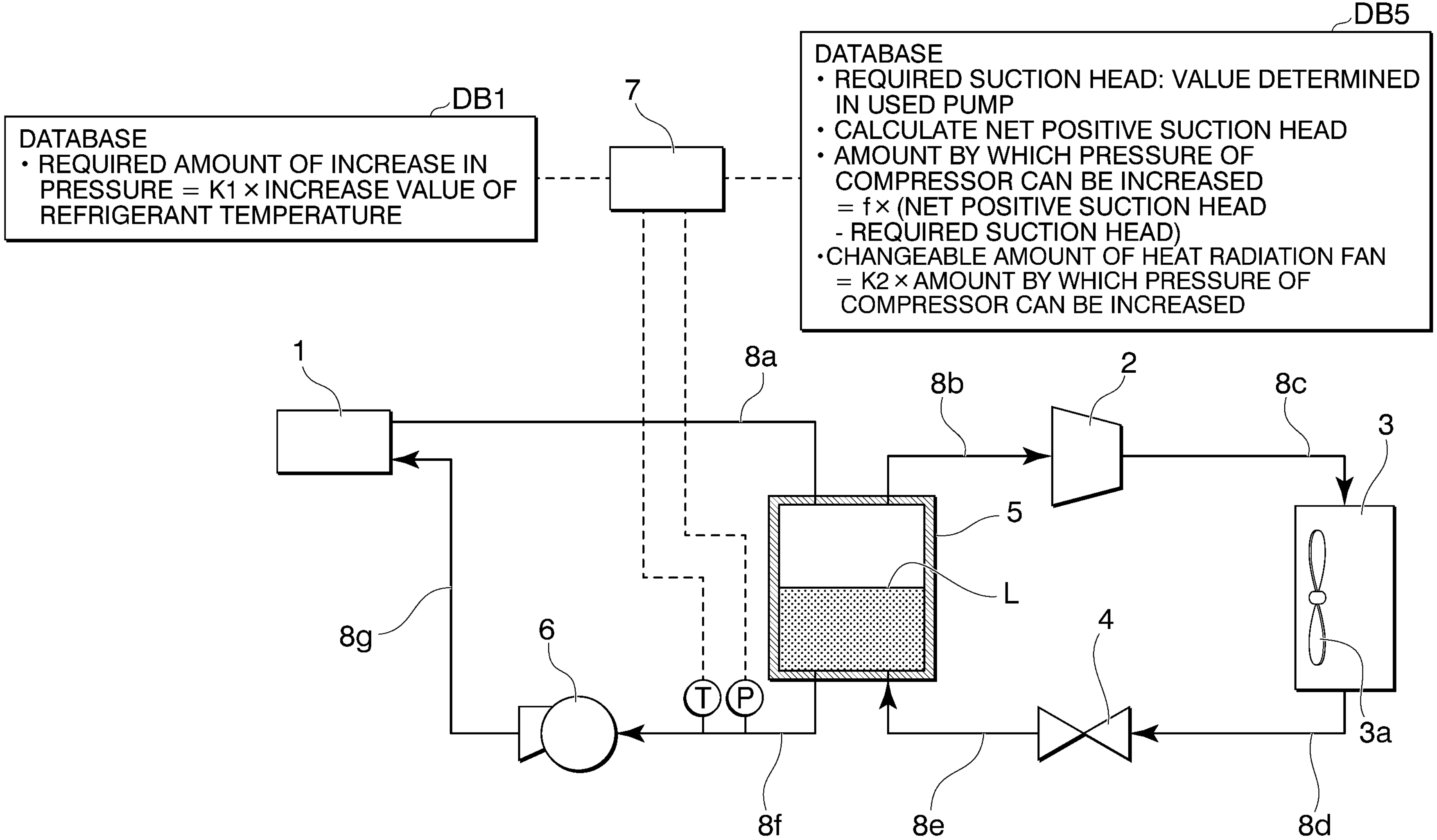

DB1
DATABASE
• REQUIRED AMOUNT OF INCREASE IN PRESSURE = K1 × INCREASE VALUE OF REFRIGERANT TEMPERATURE
7
DB5
DATABASE
• REQUIRED SUCTION HEAD: VALUE DETERMINED IN USED PUMP
• CALCULATE NET POSITIVE SUCTION HEAD
• AMOUNT BY WHICH PRESSURE OF COMPRESSOR CAN BE INCREASED = f × (NET POSITIVE SUCTION HEAD - REQUIRED SUCTION HEAD)
•CHANGEABLE AMOUNT OF HEAT RADIATION FAN = K2 × AMOUNT BY WHICH PRESSURE OF COMPRESSOR CAN BE INCREASED
1
8a
8b
2
8c
3
5
L
8g
6
T
P
4
3a
8f
8e
8d

FIG. 16

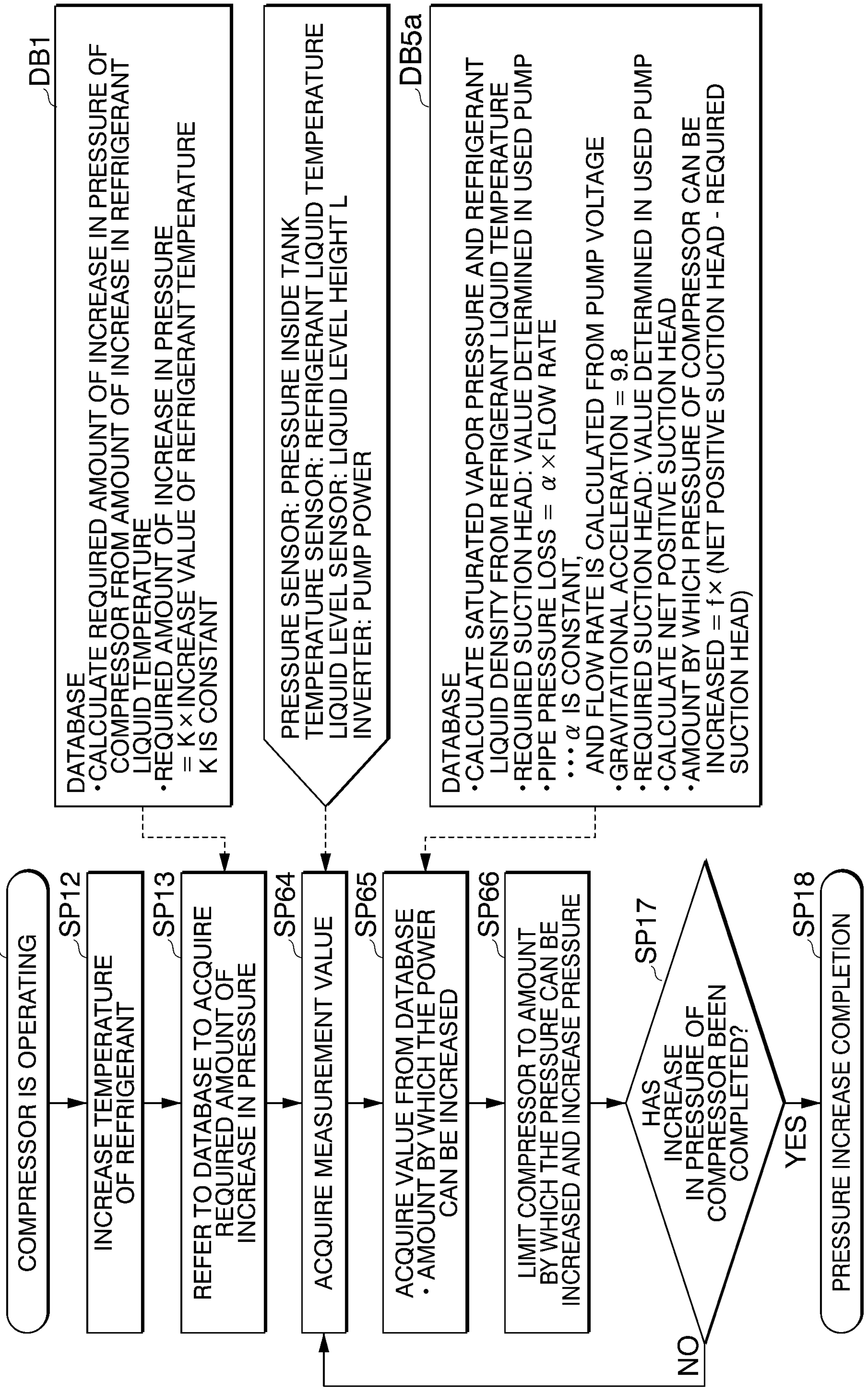

SP11
COMPRESSOR IS OPERATING
SP12
INCREASE TEMPERATURE OF REFRIGERANT
SP13
REFER TO DATABASE TO ACQUIRE REQUIRED AMOUNT OF INCREASE IN PRESSURE
SP64
ACQUIRE MEASUREMENT VALUE
SP65
ACQUIRE VALUE FROM DATABASE
• AMOUNT BY WHICH THE POWER CAN BE INCREASED
SP66
LIMIT COMPRESSOR TO AMOUNT BY WHICH THE PRESSURE CAN BE INCREASED AND INCREASE PRESSURE
SP17
HAS INCREASE IN PRESSURE OF COMPRESSOR BEEN COMPLETED?
YES
NO
SP18
PRESSURE INCREASE COMPLETION
DB1
DATABASE
•CALCULATE REQUIRED AMOUNT OF INCREASE IN PRESSURE OF COMPRESSOR FROM AMOUNT OF INCREASE IN REFRIGERANT LIQUID TEMPERATURE
•REQUIRED AMOUNT OF INCREASE IN PRESSURE = K × INCREASE VALUE OF REFRIGERANT TEMPERATURE
K IS CONSTANT
PRESSURE SENSOR: PRESSURE INSIDE TANK
TEMPERATURE SENSOR: REFRIGERANT LIQUID TEMPERATURE
LIQUID LEVEL SENSOR: LIQUID LEVEL HEIGHT L
INVERTER: PUMP POWER
DB5a
DATABASE
•CALCULATE SATURATED VAPOR PRESSURE AND REFRIGERANT LIQUID DENSITY FROM REFRIGERANT LIQUID TEMPERATURE
•REQUIRED SUCTION HEAD: VALUE DETERMINED IN USED PUMP
•PIPE PRESSURE LOSS = α × FLOW RATE
••• α IS CONSTANT, AND FLOW RATE IS CALCULATED FROM PUMP VOLTAGE
•GRAVITATIONAL ACCELERATION = 9.8
•REQUIRED SUCTION HEAD: VALUE DETERMINED IN USED PUMP
•CALCULATE NET POSITIVE SUCTION HEAD
•AMOUNT BY WHICH PRESSURE OF COMPRESSOR CAN BE INCREASED = f × (NET POSITIVE SUCTION HEAD - REQUIRED SUCTION HEAD)

FIG. 17

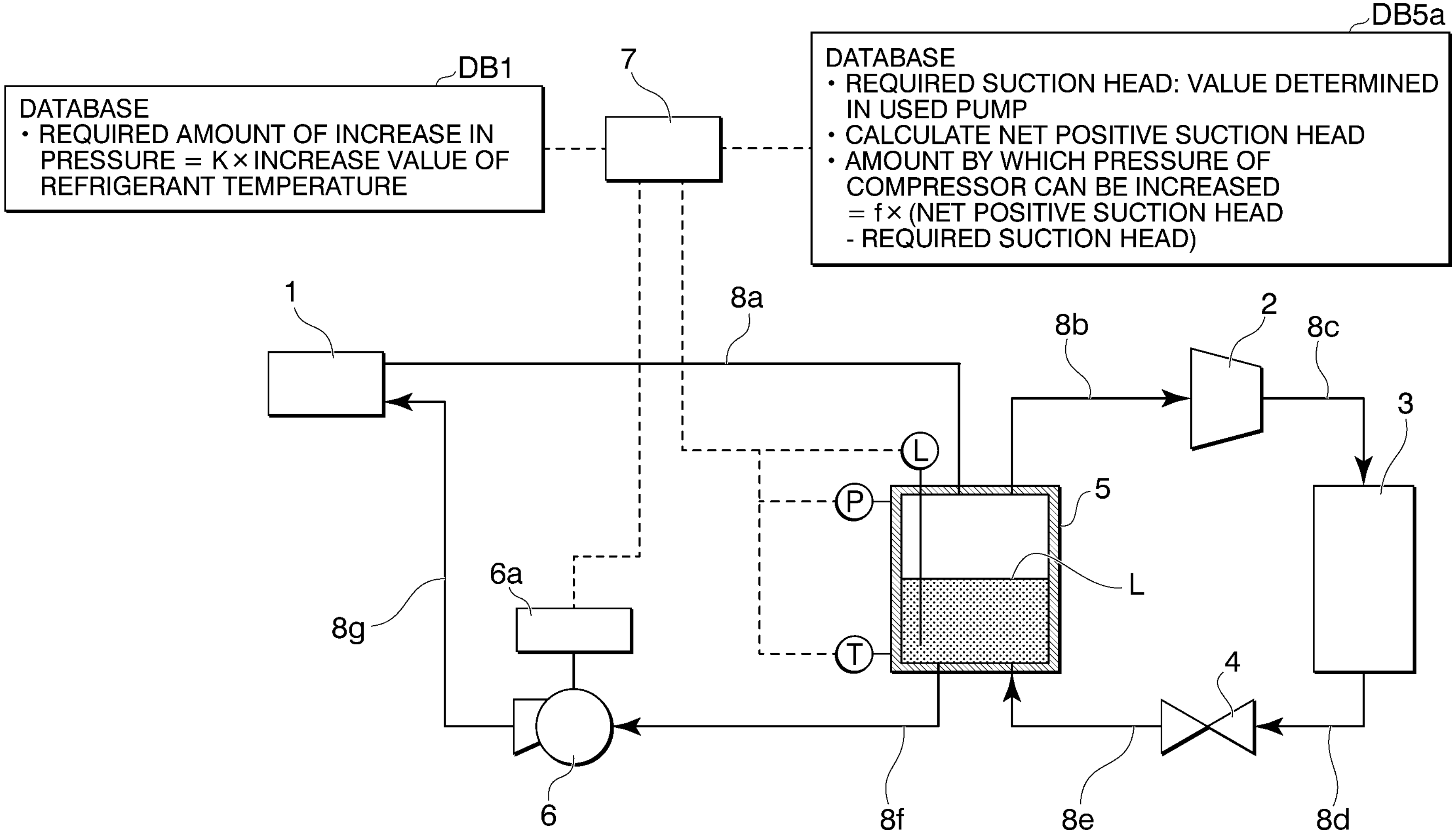

DB1
DATABASE
• REQUIRED AMOUNT OF INCREASE IN PRESSURE = K×INCREASE VALUE OF REFRIGERANT TEMPERATURE
7
DB5a
DATABASE
• REQUIRED SUCTION HEAD: VALUE DETERMINED IN USED PUMP
• CALCULATE NET POSITIVE SUCTION HEAD
• AMOUNT BY WHICH PRESSURE OF COMPRESSOR CAN BE INCREASED = f×(NET POSITIVE SUCTION HEAD - REQUIRED SUCTION HEAD)
1
8a
8b
2
8c
3
L
P
T
5
L
6a
8g
4
6
8f
8e
8d

FIG. 18

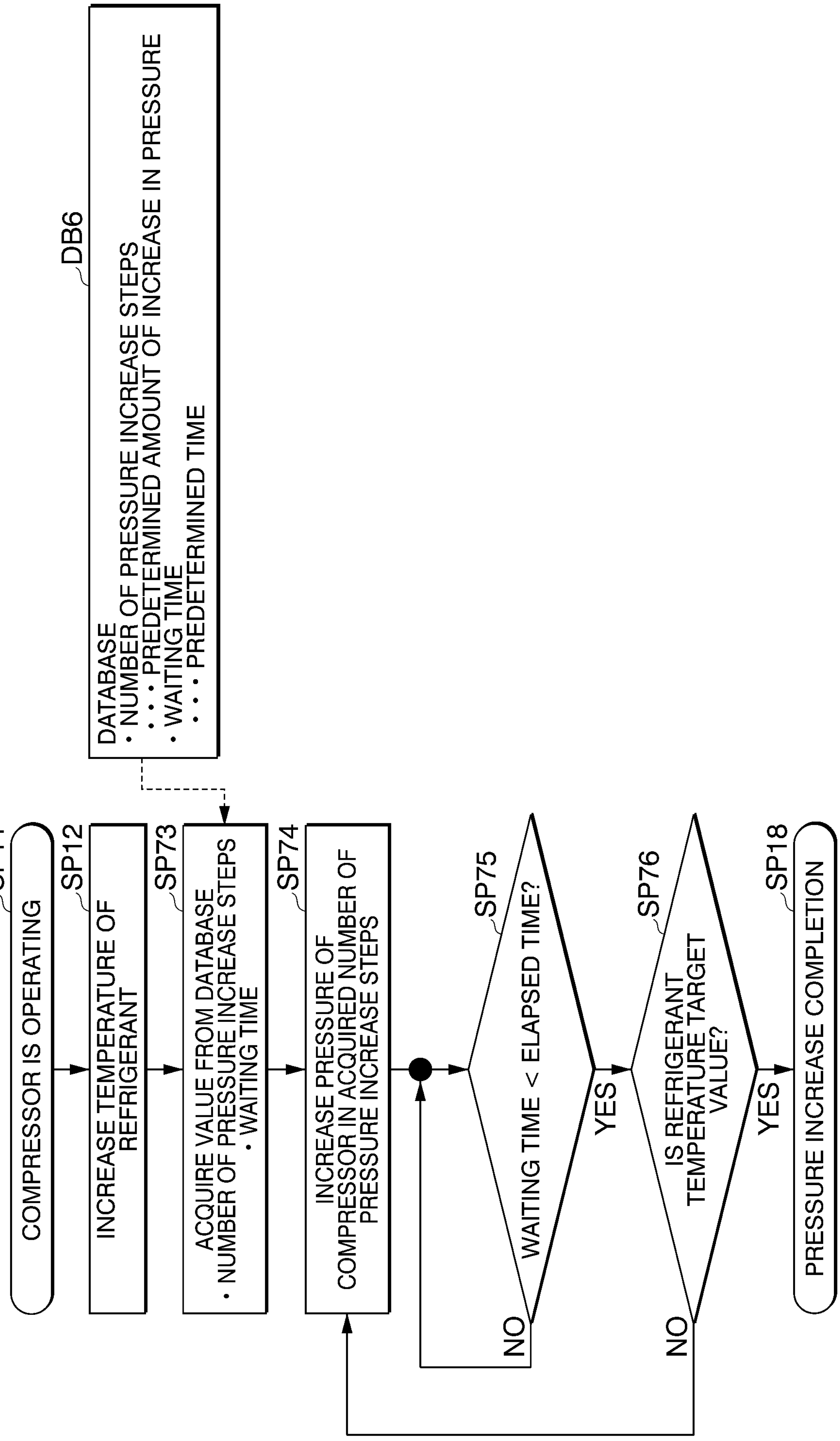
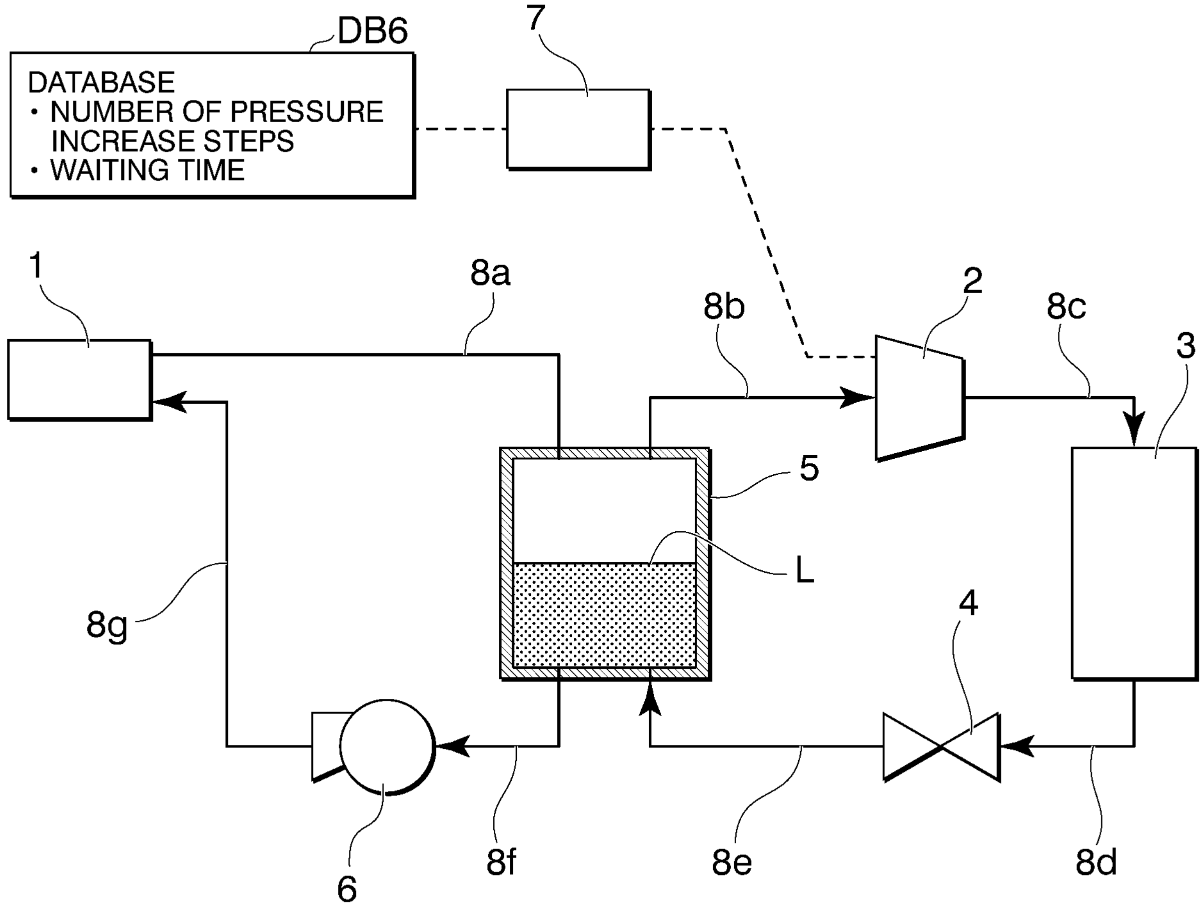

DB6
DATABASE
· NUMBER OF PRESSURE INCREASE STEPS
· · · PREDETERMINED AMOUNT OF INCREASE IN PRESSURE
· WAITING TIME
· · · PREDETERMINED TIME
SP11
COMPRESSOR IS OPERATING
SP12
INCREASE TEMPERATURE OF REFRIGERANT
SP73
ACQUIRE VALUE FROM DATABASE
· NUMBER OF PRESSURE INCREASE STEPS
· WAITING TIME
SP74
INCREASE PRESSURE OF COMPRESSOR IN ACQUIRED NUMBER OF PRESSURE INCREASE STEPS
SP75
WAITING TIME < ELAPSED TIME?
NO
YES
SP76
IS REFRIGERANT TEMPERATURE TARGET VALUE?
NO
YES
SP18
PRESSURE INCREASE COMPLETION

FIG. 19


DB6
DATABASE
・NUMBER OF PRESSURE INCREASE STEPS
・WAITING TIME
7
1
8a
8b
2
8c
3
5
L
4
8g
6
8f
8e
8d

INTERNATIONAL SEARCH REPORT

International application No. **PCT/JP2021/030413**

A. CLASSIFICATION OF SUBJECT MATTER

F25B 43/00(2006.01)i; ***F25B 1/00***(2006.01)i; ***F25B 41/40***(2021.01)i
FI: F25B43/00 B; F25B41/40 Z; F25B1/00 399A

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)

F25B1/00-49/04; H05K7/20; G06F1/20

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2021
Registered utility model specifications of Japan 1996-2021
Published registered utility model applications of Japan 1994-2021

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2017-20687 A (PANASONIC IP MAN CORP) 26 January 2017 (2017-01-26) paragraphs [0018], [0022], [0036], [0047], fig. 1	1-8
A	JP 2011-196607 A (TOYO ENG WORKS LTD) 06 October 2011 (2011-10-06) paragraphs [0038], [0043]-[0045], fig. 1	1, 8
A	WO 2005/050104 A1 (MAYEKAWA MFG.CO.,LTD.) 02 June 2005 (2005-06-02) p. 18, lines 16-22, fig. 3	4
A	JP 2021-76364 A (MAYEKAWA MFG.CO.,LTD.) 20 May 2021 (2021-05-20) paragraph [0029]	1, 8

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 October 2021	**19 October 2021**

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

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2021/030413

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2017-20687 A	26 January 2017	(Family: none)	
JP 2011-196607 A	06 October 2011	(Family: none)	
WO 2005/050104 A1	02 June 2005	US 2006/0266058 A1 paragraph [0116], fig. 3 EP 1688685 A1 CA 2545370 A1 KR 10-2006-0116009 A CN 1902448 A JP 2005-172416 A	
JP 2021-76364 A	20 May 2021	(Family: none)	

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

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2018056201 A **[0007]**
- JP 2019174001 A **[0007]**
- JP 2021076364 A **[0007]**