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(54) HEAT EXCHANGER EVALUATING DEVICE, HEAT EXCHANGER EVALUATING METHOD, HEAT EXCHANGER MANUFACTURING METHOD, AND HEAT EXCHANGER DESIGNING METHOD

(57) The present invention prevents a refrigerant from accumulating in a refrigerant flow path in a heat exchanger as much as possible. This evaluating device is for a heat exchanger (100, 200) including a heat exchanging unit (10) that causes a refrigerant to circulate through a plurality of multistage refrigerant flow paths (11, 12, 13, 14) arranged in a vertical direction, and performs heat exchange between the refrigerant and air; a refrigerant header (40) that allows a gas phase refrigerant to circulate therethrough and is connected to a first end side of each of the plurality of refrigerant flow paths (11, 12, 13, 14); a plurality of capillary tubes (21_{c1}, 21_{c2}, 21_{ci},..., $21_{cbottom}$) that are connected to respective second end sides of the plurality of refrigerant flow paths (11, 12, 13, 14); and a distributor (50) that joins the plurality of capillary tubes (21_{c1}, 21_{c2}, 21_{ci},..., $21_{cbottom}$) at a joining position. The evaluating device is provided with a determination unit that determines, for each of the refrigerant flow paths (11, 12, 13, 14), whether the refrigerant has accumulated in the heat exchanging unit (10) on the basis of a relationship between a vertical height of the refrigerant flow path (11, 12, 13, 14) at an outlet of the heat exchanging unit (10), a first pressure loss (Pri) of the refrigerant in the refrigerant flow path (11, 12, 13, 14) of the heat exchanging unit (10), a second pressure loss (Pci) of the refrigerant in the corresponding capillary tube (21_{c1}, 21_{c2}, 21_{ci},..., $21_{cbottom}$), and a vertical height (hi) from a bottom edge of the heat exchanging unit (10) to the vertically lowermost refrigerant flow path (14).

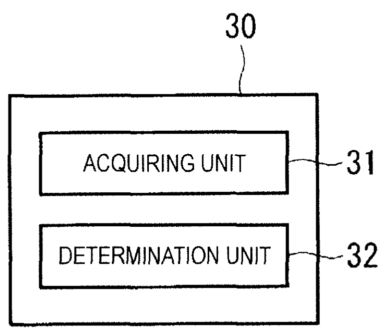

FIG. 2

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Description

Technical Field

[0001] The present invention relates to a heat exchanger evaluating device, a heat exchanger evaluating method, a heat exchanger manufacturing method, and a heat exchanger designing method.

Background Art

[0002] A known heat exchanger is provided with a plurality of multistage refrigerant flow paths arranged independently in a vertical direction, and a refrigerant distributor to which a first end side of each of the plurality of refrigerant flow paths is connected via a capillary tube (refer to Patent Document 1, for example).

[0003] Patent Document 1 discloses a method of adjusting a height from a bottom edge of a lowermost refrigerant flow path to a top edge of a lowermost capillary tube to prevent a liquid refrigerant from accumulating in the lowermost refrigerant flow path and causing an excessive increase in the degree of subcooling when the heat exchanger functions as a condenser.

Citation List

Patent Document

[0004] Patent Document 1: JP 3985831 A

Summary of Invention

Problem to be Solved by the Invention

[0005] In Patent Document 1, the connecting positions of the plurality of refrigerant flow paths and the capillary tubes connected thereto are spaced apart at a constant interval across an entire region of the overall height of the heat exchanger in the vertical direction. As a result, a distance in the vertical direction between the connecting position of the uppermost refrigerant flow path and the capillary tube, and the connecting position of the lowermost refrigerant flow path and the capillary tube substantially matches the overall height of the heat exchanger.

[0006] Thus, a large difference exists between the pressure of the liquid refrigerant from the connecting position of the uppermost refrigerant flow path to the refrigerant distributor caused by its own weight, and the pressure of the liquid refrigerant from the connecting position of the lowermost refrigerant flow path to the refrigerant distributor caused by its own weight. In consequence, the equalized pressure achieved after the liquid refrigerants from the plurality of capillary tubes join together in the refrigerant distributor increases, making it difficult for the liquid refrigerant to discharge from the lowermost refrigerant flow path to the capillary tube and resulting in problematic accumulation of liquid refrigerant in the interior of the refrigerant flow path.

[0007] In light of the foregoing, an object of the present invention is to provide a heat exchanger evaluating device, a heat exchanger evaluating method, a heat exchanger manufacturing method, and a heat exchanger designing method capable of significantly preventing a refrigerant from accumulating in a refrigerant flow path of a heat exchanger.

Solution to Problem

[0008] A first aspect of the present invention is a heat exchanger evaluating device for a heat exchanger including a heat exchanging unit that causes a refrigerant to circulate through a plurality of multistage refrigerant flow paths arranged in a vertical direction, and performs heat exchange between the refrigerant and air, a refrigerant header that allows the refrigerant in a gas phase to circulate therethrough and is connected to a first end side of each of the plurality of refrigerant flow paths, a plurality of refrigerant distribution tubes connected to respective second end sides of the plurality of refrigerant flow paths, and a refrigerant distributor that joins the plurality of refrigerant distribution tubes at a joining position. The heat exchanger evaluating device is provided with a determination unit that determines, for each of the refrigerant flow paths, whether the refrigerant has accumulated in the heat exchanging unit on the basis of a relationship between a vertical height of the refrigerant flow path at an outlet of the heat exchanging unit, a first pressure loss of the refrigerant in the refrigerant flow path of the heat exchanging unit, a second pressure loss of the refrigerant in the corresponding refrigerant distribution tube, and a vertical height from a bottom edge of the heat exchanging unit to the vertically lowermost refrigerant flow path.

[0009] According to the first aspect of the present invention, it is determined, for each of the plurality of multistage refrigerant flow paths arranged in the vertical direction, whether the refrigerant has accumulated in the heat exchanging unit on the basis of a relationship between the vertical height of the refrigerant flow path at the outlet of the heat exchanging unit, the first pressure loss of the refrigerant in the refrigerant flow path of the heat exchanging unit that performs heat exchange between the air and the refrigerant, the second pressure loss of the refrigerant in the refrigerant distribution tube, and the vertical height from the bottom edge of the heat exchanging unit to the vertically lowermost multistage refrigerant flow path.

[0010] Thus, whether the refrigerant has accumulated in the heat exchanging unit can be simply determined using the information of each location through which the refrigerant passes.

[0011] When the heat exchanging unit is made to function as a condenser and subcooled liquid is determined to have accumulated in the heat exchanging unit, the accumulation in the heat exchanging unit can be eliminated and a decrease in a condensing capacity of the condenser can be prevented by adjusting the relationship between the height of the refrigerant flow path of the heat exchanging unit, the pressure loss of the refrigerant in the heat exchanging unit, the pressure loss of the refrigerant in the refrigerant distribution tubes, and the height of the lowermost refrigerant flow path.

[0012] The determination unit of the heat exchanger evaluating device according to the first aspect of the present invention may determine whether the refrigerant has accumulated in the heat exchanging unit on the basis of an expression below, given hi as the vertical height at the outlet of the heat exchanging unit, Pri as the first pressure loss, Pci as the second pressure loss, h_{bottom} as the vertical height from the bottom edge of the heat exchanging unit to the vertically lowermost refrigerant flow path, p as a refrigerant density, and g as a gravitational acceleration.

[Expression 1]

$$hi < \frac{P_{ri} + P_{ci}}{\rho g} + h_{bottom}$$

[0013] This determination is simply made on the basis of the conditional expression.

[0014] A second aspect of the present invention is a heat exchanger evaluating method of a heat exchanger including a heat exchanging unit that causes a refrigerant to circulate through a plurality of multistage refrigerant flow paths arranged in a vertical direction, and performs heat exchange between the refrigerant and air, a refrigerant header that allows the refrigerant in a gas phase to circulate therethrough and is connected to a first end side of each of the plurality of refrigerant flow paths, a plurality of refrigerant distribution tubes connected to respective second end sides of the plurality of refrigerant flow paths, and a refrigerant distributor that joins the plurality of refrigerant distribution tubes at a joining position. The heat exchanger evaluating method includes a first step of acquiring information on a vertical height of each of the refrigerant flow paths at an outlet of the heat exchanging unit of the heat exchanger to be evaluated, a first pressure loss of the refrigerant in the refrigerant flow paths of the heat exchanging unit, and a second pressure loss of the refrigerant in the refrigerant distribution tubes; and a second step of determining, for each of the refrigerant flow paths, whether the refrigerant has accumulated in the heat exchanging unit on the basis of a relationship between the vertical height of the refrigerant flow path of the heat exchanging unit, the first pressure loss, the second pressure loss, and a vertical height from a bottom edge of the heat exchanging unit to the vertically lowermost refrigerant flow path.

[0015] The heat exchanger evaluating method may determine whether the refrigerant has accumulated in the heat exchanging unit on the basis of an expression below, given hi as the vertical height at the outlet of the heat exchanging unit, Pri as the first pressure loss, Pci as the second pressure loss, h_{bottom} as the vertical height from the bottom edge of the heat exchanging unit to the vertically lowermost refrigerant flow path, p as a refrigerant density, and g as a gravitational acceleration.

[Expression 2]

$$hi < \frac{P_{ri} + P_{ci}}{\rho g} + h_{bottom}$$

[0016] A third aspect of the present invention is a heat exchanger manufacturing method for a heat exchanger including a heat exchanging unit that causes a refrigerant to circulate through a plurality of multistage refrigerant flow paths arranged in a vertical direction, and performs heat exchange between the refrigerant and air, a refrigerant header that allows the refrigerant in a gas phase to circulate therethrough and is connected to a first end side of each of the plurality of refrigerant flow paths, a plurality of refrigerant distribution tubes connected to respective second end sides of the plurality of refrigerant flow paths, and a refrigerant distributor that joins the plurality of refrigerant distribution tubes at a joining position. The heat exchanger manufacturing method includes manufacturing the heat exchanger that satisfies an expression below, given hi as a vertical height of the refrigerant flow path at an outlet of the heat exchanging unit, Pri as a first pressure loss of the refrigerant in the refrigerant flow paths of the heat exchanging unit, Pci as a second pressure loss of the refrigerant in the refrigerant distribution tubes, h_{bottom} as a vertical height from a bottom edge of the heat exchanging unit to the vertically lowermost refrigerant flow path, ρ as a refrigerant density, and g as a gravitational acceleration.

[Expression 3]

$$hi < \frac{P_{ri} + P_{ci}}{\rho g} + h_{bottom}$$

[0017] A fourth aspect of the present invention is a heat exchanger designing method for a heat exchanger including a heat exchanging unit that causes a refrigerant to circulate through a plurality of multistage refrigerant flow paths arranged in a vertical direction, and performs heat exchange between the refrigerant and air, a refrigerant header that allows the refrigerant in a gas phase to circulate therethrough and is connected to a first end side of each of the plurality of refrigerant flow paths, a plurality of refrigerant distribution tubes connected to respective second end sides of the plurality of refrigerant flow paths, and a refrigerant distributor that joins the plurality of refrigerant distribution tubes at a joining position. The heat exchanger designing method includes designing the heat exchanger that satisfies an expression below, given hi as a vertical height of the refrigerant flow path at the outlet of the heat exchanging unit, Pri as a first pressure loss of the refrigerant in the refrigerant flow paths of the heat exchanging unit, Pci as a second pressure loss of the refrigerant in the refrigerant distribution tubes, h_{bottom} as a vertical height from the bottom edge of the heat exchanging unit to the vertically lowermost refrigerant flow path, ρ as a refrigerant density, and g as a gravitational acceleration.

[Expression 4]

$$hi < \frac{P_{ri} + P_{ci}}{\rho g} + h_{bottom}$$

Advantageous Effects of Invention

[0018] The present invention achieves the effect of preventing a refrigerant from accumulating in a refrigerant flow path of a heat exchanger to the extent possible.

Brief Description of Drawings

[0019]

FIG. 1 is a system configuration diagram of a heat exchanging system according to the present invention.
FIG. 2 is a function block diagram of an evaluating device according to the present invention.
FIG. 3 illustrates an example of a heat exchange model during use as a condenser in a case where a distributer is below a bottom surface of a heat exchanger.
FIG. 4 illustrates an example of a heat exchange model during use as a condenser in a case where the distributer is above the bottom surface of the heat exchanger.

Description of Embodiments

[0020] A heat exchanger evaluating device, a heat exchanger evaluating method, a heat exchanger manufacturing method, and a heat exchanger designing method according to the present invention is described below with reference to the drawings.

[0021] FIG. 1 illustrates a system configuration diagram of an evaluation system 3 of the present embodiment. The evaluation system 3 includes a heat exchanging system 1 and an evaluating device 30. While the evaluating device 30 according to the present embodiment may be used to evaluate an outdoor heat exchanger (heat exchanger) 100 or an indoor heat exchanger (heat exchanger) 200, the example described below is for evaluation of the outdoor heat exchanger 100.

[0022] The heat exchanging system 1 is a system that connects the outdoor heat exchanger 100 and the indoor heat exchanger 200 by a refrigerant system to circulate the refrigerant.

[0023] Examples of the heat exchanging system 1 include an air conditioning system in which one or a plurality of indoor heat exchangers are connected to a single outdoor heat exchanger. Other examples of the heat exchanging system 1 include a heat pump type hot water supply system that uses a CO2 refrigerant.

[0024] As illustrated in the system configuration diagram in FIG. 1, the heat exchanging system 1 includes the outdoor heat exchanger 100, the indoor heat exchanger 200, a compressor 210 that compresses a refrigerant, an accumulator 220 that removes liquid components contained in a high-temperature, high-pressure refrigerant gas, a four-way valve 230, and an expansion valve 240, with these being connected by refrigerant piping.

[0025] The heat exchanging system 1 illustrated in FIG. 1 allows selective execution of a cooling operation that cools an indoor area and a heating operation that heats an indoor area by switching a circulation direction of the refrigerant by the four-way valve 230.

[0026] When the heating operation is performed, the four-way valve 230 sets the circulation direction of the refrigerant so that the refrigerant compressed by the compressor 210 is introduced into the indoor heat exchanger 200, causing the indoor heat exchanger 200 to function as a condenser, and the refrigerant heat-blocked and expanded by the expansion valve 240 is introduced into the outdoor heat exchanger 100, causing the outdoor heat exchanger 100 to function as an evaporator (the direction indicated by the solid arrows in FIG. 1).

[0027] On the other hand, when the cooling operation is performed, the four-way valve 230 sets the circulation direction of the refrigerant so that the refrigerant compressed by the compressor 210 is introduced into the outdoor heat exchanger 100, causing the outdoor heat exchanger 100 to function as a condenser, and the refrigerant heat-blocked and expanded by the expansion valve 240 is introduced into the indoor heat exchanger 200, causing the indoor heat exchanger 200 to function as an evaporator (the direction indicated by the dashed arrows in FIG. 1).

[0028] As illustrated in FIG. 2, the evaluating device 30 includes an acquiring unit 31 and a determination unit 32. FIG. 3 illustrates a refrigerant system of the outdoor heat exchanger 100 as viewed from the side.

[0029] The acquiring unit 31 acquires information on vertical heights h_1, h_2, h_i, h_{bottom} of refrigerant flow paths 11, 12, 13, 14 at an outlet of the heat exchanging unit 10 of the heat exchanger (outdoor heat exchanger or indoor heat exchanger) to be evaluated from a bottom edge of a heat exchanging unit 10, a first pressure loss of the refrigerant in the refrigerant flow paths 11, 12, 13, 14 of the heat exchanging unit 10, and a second pressure loss of the refrigerant in capillary tubes 21_{c1}, 21_{c2}, 21_{c1} ... $21_{cbottom}$.

[0030] The determination unit 32 determines, for each of the refrigerant flow paths 11, 12, 13, 14, whether refrigerant has accumulated in the heat exchanging unit 10 on the basis of the relationship of the vertical heights of the refrigerant flow paths 11, 12, 13, 14 at the outlet of the heat exchanging unit 10 from the bottom edge of the heat exchanging unit 10, the first pressure loss, the second pressure loss, and a vertical height from the bottom edge of the heat exchanging unit 10 to the vertically lowermost refrigerant flow path 14. Specifically, the determination unit 32 determines whether refrigerant has accumulated in the heat exchanging unit on the basis of an expression below, given Pri as the first pressure loss, Pci as the second pressure loss, h_{bottom} as the vertical height from the bottom edge of the heat exchanging unit 10 to the vertically lowermost refrigerant flow path 14, p as a refrigerant density, and g as a gravitational acceleration.

[Expression 5]

$$hi < \frac{P_{ri} + P_{ci}}{\rho g} + h_{bottom}$$

[0031] The basis for use of the formula above is explained below.

[0032] When the Distributer is Below the Bottom Surface of the Heat Exchanging Unit:

As illustrated in FIG. 3, the outdoor heat exchanger 100 includes the heat exchanging unit 10, the refrigerant distribution tubes 21, a refrigerant header 40, and a distributor (refrigerant distributor) 50.

[0033] The heat exchanging unit 10 causes the refrigerant to circulate through the plurality of refrigerant flow paths (circuits) 11, 12, 13, 14 arranged in a vertical direction, and performs heat exchange with air blown by a blowing fan (not illustrated) provided to the outdoor heat exchanger 100.

[0034] The refrigerant flow paths 11, 12, 13, 14 are tubular members formed by a metal member made of copper for example, and flow paths that circulate the refrigerant are formed in the interiors thereof.

[0035] The heat exchanging unit 10 can be, for example, configured as a fin and tube type heat exchanger in which the plurality of refrigerant flow paths 11, 12, 13, 14 are inserted through insertion holes in a plurality of fins (not illustrated) having plate-like shapes, being made from aluminum, and being disposed consecutively in the horizontal direction.

[0036] The refrigerant header 40 is piping that allows the refrigerant in a gas phase to circulate therethrough and is connected to a first end side of each of the plurality of refrigerant flow paths 11, 12, 13, 14 at a first connecting position C1.

[0037] When the outdoor heat exchanger 100 functions as a condenser, the refrigerant header 40 supplies the refrigerant in a gas phase to each of the plurality of refrigerant flow paths 11, 12, 13, 14. On the other hand, when the outdoor heat exchanger 100 functions as an evaporator, the refrigerant in a gas phase is supplied from each of the plurality of refrigerant flow paths 11, 12, 13, 14 to the refrigerant header 40.

[0038] The refrigerant distribution tubes 21 include capillary tubes 21_{c1}, 21_{c2}, 21_{ci}... $21_{cbottom}$, each being connected to a second end side of the plurality of refrigerant flow paths 11, 12, 13, 14 at a second connecting position C2.

[0039] The distributor 50 is a device that joins the capillary tubes 21_{c1}, 21_{c2}, 21_{ci}... $21_{cbottom}$ at a joining position C3. The joining position C3 is disposed below the bottom edge of the heat exchanging unit 10 in a vertical direction (that is, up-down direction in FIG. 3) orthogonal to a mounting surface of the outdoor heat exchanger 100.

[0040] When the outdoor heat exchanger 100 functions as a condenser, subcooled liquid discharged from the second connecting positions C2 of the plurality of refrigerant flow paths 11, 12, 13, 14 is supplied to the capillary tubes 21_{c1}, 21_{c2}, 21_{ci}... $21_{cbottom}$, and guided to the joining position C3 of the distributor 50.

[0041] On the other hand, when the outdoor heat exchanger 100 functions as an evaporator, subcooled liquid discharged from the joining position C3 of the distributor 50 is guided to the capillary tubes 21_{c1}, 21_{c2}, 21_{ci}... $21_{cbottom}$, and supplied to the second connecting positions C2 of the plurality of refrigerant flow paths 11, 12, 13, 14.

[0042] As illustrated in FIG. 3, the vertical heights of each of the refrigerant flow paths 11, 12, 13, 14 at the outlets of the heat exchanging unit 10 from the bottom surface of the heat exchanging unit 10 in the vertical direction (up-down direction in FIG. 3) orthogonal to the mounting surface of the outdoor heat exchanger 100 are set as heights h_1, h_2, h_i, h_{bottom}.

[0043] FIG. 3 illustrates an example of a heat exchange model when the heat exchanger is used as a condenser. The up-down direction in FIG. 3 matches the vertical direction given the mounting surface on which the outdoor heat exchanger 100 is mounted as a reference.

[0044] In the present embodiment, the heat exchanger is used as a condenser and therefore the refrigerant flows from left to right as viewed on the paper surface of FIG. 3. The refrigerant passes through the refrigerant header 40 in a gas state, subsequently passes through the heat exchanging unit 10 in a two-phase state, and lastly passes through the capillary tubes 21_{c1}, 21_{c2}, 21_{ci}... $21_{cbottom}$ in a liquid state, with the refrigerant from each of the refrigerant flow paths joining at the joining position C3 of the distributor 50.

[0045] In FIG. 3, each subscript represents the number of refrigerant flow paths (circuits), and "bottom" refers to the lowermost refrigerant flow path. Here, Pri denotes the pressure loss (Pa) in each of the refrigerant flow paths, Pci denotes the pressure loss (Pa) in each of the capillary tubes, h denotes the height (m) from the outlet of each of the refrigerant flow paths to the bottom edge of the heat exchanging unit 10, h_D denotes the height (m) from the bottom edge of the heat exchanging unit 10 to the bottom edge of the distributor 50, Pin denotes the inlet pressure (Pa), and Pout denotes the outlet pressure (Pa).

[0046] In the refrigerant header 40, the refrigerant is in a gas state and therefore has low density. As a result, a position head pressure ρgh is negligibly small compared to the pressure loss Pri in the refrigerant flow paths 11, 12, 13, 14 and the pressure loss Pci in the capillary tubes. Further, upon comparison with the refrigerant flow paths 11, 12, 13, 14, the refrigerant header 40 has a shorter piping length and a larger inner diameter than those of the refrigerant flow paths 11, 12, 13, 14, making the pressure loss in the refrigerant header 40 also negligibly small. Thus, the inlet pressures Pin of each of the refrigerant flow paths 11, 12, 13, 14 can be assumed as equal.

[0047] Further, the outlet pressures Pout of each of the refrigerant flow paths 11, 12, 13, 14 are designed as equal, and therefore the outlet pressures Pout can also be assumed as equal for the refrigerant flow paths 11, 12, 13, 14. Furthermore, as long as heat is suitably exchanged in the heat exchanging unit 10, the refrigerant in the capillary tubes 21_{c1}, 21_{c2}, 21_{ci},..., $21_{cbottom}$, is in a liquid state, and thus the refrigerant density ρ can be assumed as equal in the refrigerant flow paths 11, 12, 13, 14.

[0048] From the above assumed conditions, the relationship between the inlet pressure Pin and the outlet pressure Pout is expressed as Formula (2) below from Formula (1). Here, ρ is the refrigerant density (kg/m^3), and g is gravitational acceleration (m/s^2).

[0049] [Expression 6]

$$P_{out} = P_{in} - \{P_{r1} + P_{c1} - \rho g(h_1 + h_D)\} \quad (1)$$
$$= P_{in} - \{P_{r2} + P_{c2} - \rho g(h_2 + h_D)\}$$
$$\vdots$$
$$= P_{in} - \{P_{ri} + P_{ci} - \rho g(h_i + h_D)\}$$
$$\vdots$$
$$= P_{in} - \{P_{rbottom} + P_{cbottom} - \rho g(h_{bottom} + h_D)\} \quad (2)$$

[0050] Here, the relationship between the uppermost refrigerant flow path 11 and the lowermost refrigerant flow path 14 will be examined. Because the outlet outputs Pout are equal for each of the refrigerant flow paths, Formulas (1) and (2) above are equal. Thus, Formula (3) below holds.
[Expression 7]

$$P_{in} - \{P_{r1} + P_{c1} - \rho g(h_1 + h_D)\} = P_{in} - \{P_{rbottom} + P_{cbottom} - \rho g(h_{bottom} + h_D)\}$$
$$P_{r1} + P_{c1} - \rho g(h_1 - h_{bottom}) = P_{rbottom} + P_{cbottom} \quad (3)$$

[0051] Here, the pressure loss is a function proportionate to the square of the refrigerant flow path Gr (kg/h) as shown below. Note that λ is a friction coefficient, L is a piping length (m), d is a piping inner diameter (m), A is a piping cross-sectional area (m^2), φ_L is a two-phase multiplier coefficient, and x is a dryness.

[Expression 8]

$$P = \lambda \frac{L}{d} \frac{Gr^2}{2\rho A^2} \quad \text{(Single phase region, capillary tube portion)}$$

$$P = \phi_L^2 \lambda \frac{L}{d} \frac{(1-x)^2}{2\rho A^2} Gr^2 \quad \text{(Two-phase region, refrigerant flow path portion)}$$

[0052] Thus, the refrigerant flows to the lowermost refrigerant flow path 14 as long as $P_{rbottom} > 0$, and to the lowermost capillary tube $21_{cbottom}$ as long as $P_{cbottom} > 0$. As a result, the conditional expression for the flow of refrigerant without liquid accumulation in the lowermost refrigerant flow path 14 is Formula (4) below.
[Expression 9]

$$P_{rbottom} + P_{cbottom} > 0 \quad (\text{Where, } P_{rbottom} > 0 \quad \text{And} \quad P_{cbottom} > 0) \quad (4)$$

[0053] When Formula (3) is substituted into Formula (4) described above, Formula (5) below is achieved.
[Expression 10]

$$P_{r1} + P_{c1} - \rho g(h_1 - h_{bottom}) > 0$$
$$P_{r1} + P_{c1} > \rho g(h_1 - h_{bottom}) \quad (5)$$

[0054] From Formula (5) above, it is understood that a flow of refrigerant will exist in the lowermost refrigerant flow path 14 and liquid accumulation will not occur as long as the sum of the pressure loss of the uppermost refrigerant flow path 11 and the pressure loss of the capillary tube 21_{c1} is greater than a liquid head pressure differential of the uppermost refrigerant flow path 11 and the lowermost refrigerant flow path 14. The relationships between the second and subsequent refrigerant flow paths 12, 13 from the uppermost stage and the lowermost refrigerant flow path 14 can also each be found using a similar procedure. From this, it is understood that liquid accumulation will not occur in the lowermost refrigerant flow path 14 as long as Formula (6) below (Formula (7) upon conversion) is satisfied in all of the refrigerant flow paths 11, 12, 13.
[Expression 11]

$$P_{ri} + P_{ci} > \rho g(h_i - h_{bottom}) \tag{6}$$

$$hi < \frac{P_{ri} + P_{ci}}{\rho g} + h_{bottom} \tag{7}$$

[0055] When the Distributer is Above the Bottom Surface of the Heat Exchanging Unit:
[0056] FIG. 4 illustrates an example of a heat exchange model when the heat exchanger is used as a condenser. Unlike FIG. 3, the distributor 50 is disposed in a position above the bottom edge of the heat exchanging unit 10 in a vertical direction (that is, up-down direction in FIG. 4) orthogonal to the mounting surface of the outdoor heat exchanger 100. In the following, descriptions of locations having the same configuration as that in FIG. 3 will be omitted, and differences therebetween will be mainly described.
[0057] Here, the liquid head of the refrigerant at the capillary tube $21_{cbottom}$ of the lowermost refrigerant flow path 14 will be examined. In the lowermost refrigerant flow path 14, the refrigerant moves upward and thus the liquid head works to decrease pressure. While the refrigerant is positioned higher than a top edge of the distributor 50 at this time, the position decreases to the top edge of the distributor 50, causing the pressure to eventually increase by h_D - h_{bottom}. Thus, the relationship between the inlet pressure Pin and the outlet pressure Pout is expressed as follows.
[0058] [Expression 12]

$$P_{out} = P_{in} - \{P_{r1} + P_{c1} - \rho g(h_1 - h_D)\} \tag{8}$$

$$\vdots$$

$$= P_{in} - \{P_{ri} + P_{ci} - \rho g(h_i - h_D)\}$$

$$\vdots$$

$$= P_{in} - \{P_{rbottom} + P_{cbottom} + \rho g(h_D - h_{bottom})\} \tag{9}$$

[0059] Similar to the case where the distributor 50 is below the bottom edge of the heat exchanging unit 10, the outlet pressure Pout are equal for each of the refrigerant flow paths 11, 12, 13, 14, and thus Formulas (8) and (9) above are equal. As a result, Formula (10) below holds.
[Expression 13]

$$P_{in} - \{P_{r1} + P_{c1} - \rho g(h_1 - h_D)\} = P_{in} - \{P_{rbottom} + P_{cbottom} + \rho g(h_D - h_{bottom})\}$$

$$P_{r1} + P_{c1} - \rho g(h_1 - h_D + h_D - h_{bottom}) = P_{rbottom} + P_{cbottom}$$

$$P_{r1} + P_{c1} - \rho g(h_1 - h_{bottom}) = P_{rbottom} + P_{cbottom} \tag{10}$$

[0060] Here, Formula (10) is equal to Formula (3) above. Accordingly, the exact same procedure as the process for deriving Formula (6) is used. When Formula (10) is substituted into Formula (4), the formula becomes Formula (11) below, and Formula (11) and Formula (5) are exactly the same.

[Expression 14]

$$P_{r1}+P_{c1}-\rho g(h_1-h_{bottom})>0$$

$$P_{r1}+P_{c1}>\rho g(h_1-h_{bottom}) \qquad (11)$$

[0061] When the second and subsequent refrigerant flow paths 12, 13 from the uppermost stage and the lowermost refrigerant flow path 14 are treated in the same manner, Formula (12) is found, and Formulas (12) and (6) are the same. It is then understood that liquid accumulation will not occur in the lowermost refrigerant flow path 14 as long as Formula (12) (Formula (13) upon conversion) is satisfied in all of the refrigerant flow paths 11, 12, 13.
[Expression 15]

$$P_{ri}+P_{ci}>\rho g(h_i-h_{bottom}) \qquad (12)$$

$$hi<\frac{P_{ri}+P_{ci}}{\rho g}+h_{bottom} \qquad (13)$$

[0062] Neither Formula (6) derived when the distributor 50 is assumed to be below the bottom edge of the heat exchanging unit 10 nor Formula (12) derived when the distributor 50 is assumed to be above the bottom edge of the heat exchanging unit 10 includes ho which represents the height from bottom edge of the heat exchanging unit 10 to the top edge of the distributor 50.

[0063] This indicates that liquid accumulation is not related to the height position of the distributor 50 when the heat exchanger is used as a condenser, and liquid accumulation will not occur as long as the sum of the pressure loss of each of the refrigerant flow paths 11, 12, 13, 14 and the pressure loss of each of the capillary tubes 21_{c1}, 21_{c2}, 21_{ci}... $21_{cbottom}$ is greater than a liquid head pressure differential of each of the refrigerant flow paths 11, 12, 13, 14 and the lowermost refrigerant flow path 14.

[0064] The action of the evaluating device 30 of an air-conditioning device according to the present embodiment will be described below with reference to FIGS. 1 to 4.

[0065] A heat exchanger already manufactured serves as the evaluation target, and the information acquired include the vertical height of the refrigerant flow paths 11, 12, 13, 14 at the outlets of the heat exchanging unit 10 of the heat exchanger to be evaluated, from the bottom edge of the heat exchanging unit 10, as well as the first pressure loss of the refrigerant in the refrigerant flow paths of the heat exchanging unit, and the second pressure loss of the refrigerant in the capillary tubes 21_{c1}, 21_{c2}, 21_{ci}... $21_{cbottom}$.

[0066] Whether refrigerant has accumulated in the heat exchanging unit 10 is determined in accordance with whether Formula (7) (Formula (13)) holds on the basis of the acquired information.

[0067] When Formula (7) holds, it is determined that refrigerant has not accumulated in the heat exchanging unit 10. When Formula (7) does not hold, it is determined that refrigerant has accumulated in the heat exchanging unit 10.

[0068] When it has been determined that refrigerant has accumulated in the heat exchanging unit 10, the value of each location may be adjusted so that Formula (7) holds. Examples of ways for remedying accumulation include changing the path assembly method of the refrigerant flow paths 11, 12, 13 of the heat exchanging unit 10 (that is, changing the circuit lengths of the heat exchanging unit 10), and adjusting the lengths of the capillary tubes 21_{c1}, 21_{c2}, 21_{ci}... $21_{cbottom}$.

[0069] As described above, according to the heat exchanger (outdoor heat exchanger 100 and indoor heat exchanger 200) evaluating device, the heat exchanger evaluating method, the heat exchanging manufacturing method, and the heat exchanger designing method according to the present embodiment, whether refrigerant has accumulated in the heat exchanging unit 10 is determined on the basis of the relationship between the vertical heights h_1, h_2, h_i of the plurality of multistage refrigerant flow paths 11, 12, 13, arranged in the vertical direction, at the outlets of the heat exchanging unit 10, the first pressure loss of the refrigerant in the refrigerant flow paths 11, 12, 13, 14 in the heat exchanging unit 10 that performs heat exchange between the air and the refrigerant, the second pressure loss of the refrigerant in the capillary tubes 21_{c1}, 21_{c2}, 21_{ci}... $21_{cbottom}$, and the vertical height from the bottom edge of the heat exchanging unit 10 to the vertically lowermost multistage refrigerant flow path 14.

[0070] Thus, whether refrigerant has accumulated in the heat exchanging unit 10 can be simply determined using the information of each location through which the refrigerant passes.

[0071] Further, the outlet heights of the heat exchanging unit 10 for the refrigerant flow paths 11, 12, 13 above the refrigerant flow path 14 can be simply determined on the basis of the lowermost refrigerant flow path 14 using the expression for determining refrigerant accumulation.

[0072] When the heat exchanger is made to function as a condenser and subcooled liquid is determined to have accumulated in the heat exchanging unit 10, the accumulation in the heat exchanging unit can be eliminated and a decrease in a condensing capacity of the condenser can be prevented by adjusting the relationship between the heights of the refrigerant flow paths 11, 12, 13 of the heat exchanging unit 10, the pressure loss of the refrigerant in the heat exchanging unit 10, the pressure loss of the refrigerant in the refrigerant distribution tubes (capillary tubes) 21, and the height $h_{cbottom}$ of the lowermost refrigerant flow path 14.

[0073] While the evaluating device in the above embodiment has been described as a device that evaluates whether refrigerant has accumulated in the heat exchanging unit 10 for a heat exchanger that has already been manufactured, the present invention is not limited thereto. For example, the evaluating device may be used in the stage of designing the heat exchanger.

[0074] Specifically, when the information on the height h_i of each of the refrigerant flow paths 11, 12, 13, 14, the first pressure loss in the refrigerant flow paths 11, 12, 13, 14, the second pressure loss in the capillary tubes 21_{c1}, 21_{c2}, 21_{ci}... $21_{cbottom}$, and the height $h_{cbottom}$ of the lowermost refrigerant flow path 14 from the heat exchanging unit 10 derived in the design stage is substituted into Formula (7) above and Formula (7) holds, no refrigerant accumulation is assumed, and the design process transitions to another design process or the like. When Formula (7) above does not hold, refrigerant accumulation is assumed to have occurred, and the accumulation can be remedied by returning to the design procedure, adjusting the heights h_1, h_2, h_i, h_{bottom} of each of the refrigerant flow paths 11, 12, 13, 14 at the outlets of the heat exchanging unit 10, adjusting the circuit lengths, and reselecting the capillary tubes 21_{c1}, 21_{c2}, 21_{ci}... $21_{cbottom}$.

[0075] Additionally, as another example, the evaluating device may be used in the stage of manufacturing the heat exchanger.

[0076] Specifically, when the information on the height h_i of each of the refrigerant flow paths 11, 12, 13, 14, the first pressure loss in each of the refrigerant flow paths 11, 12, 13, 14, the second pressure loss in the capillary tubes 21_{c1}, 21_{c2}, 21_{ci}... $21_{cbottom}$, and the height $h_{cbottom}$ of the lowermost refrigerant flow path 14 from the heat exchanging unit 10 obtained in the manufacturing stage is substituted into Formula (7) above and Formula (7) holds, no refrigerant accumulation is assumed and the manufacturing process proceeds.

[0077] When Formula (7) above does not hold, it is determined that refrigerant accumulation has occurred. The heat exchanger can then be manufactured so that Formula (7) above holds by adjusting the heights h_1, h_2, h_i, h_{bottom} of each of the refrigerant flow paths 11, 12, 13, 14 at the outlets of the heat exchanging unit 10, adjusting the circuit lengths, and reselecting the capillary tubes 21_{c1}, 21_{c2}, 21_{ci}... $21_{cbottom}$.

[0078] The embodiment of the present invention has been described above in detail with reference to the drawings, but the specific configurations are not limited to the embodiment, and design changes and the like that do not depart from the scope of the present invention are also included.

Reference Signs List

[0079]

1 Heat exchanging system
10 Heat exchanging unit
11, 12, 13, 14 Refrigerant flow path
21_{c1}, 21_{c2}, 21_{ci}... $21_{cbottom}$ Capillary tube
40 Refrigerant header
50 Distributor (refrigerant distributor)
100 Outdoor heat exchanger (heat exchanger)
200 Indoor heat exchanger (heat exchanger)

Claims

1. A heat exchanger evaluating device for a heat exchanger comprising:

a heat exchanging unit that causes a refrigerant to circulate through a plurality of multistage refrigerant flow paths arranged in a vertical direction, and performs heat exchange between the refrigerant and air;
a refrigerant header that allows the refrigerant in a gas phase to circulate therethrough and is connected to a first end side of each of the plurality of refrigerant flow paths;
a plurality of refrigerant distribution tubes connected to respective second end sides of the plurality of refrigerant flow paths; and

a refrigerant distributor that joins the plurality of refrigerant distribution tubes at a joining position; the heat exchanger evaluating device comprising:

a determination unit that determines, for each of the refrigerant flow paths, whether the refrigerant has accumulated in the heat exchanging unit on the basis of a relationship between a vertical height of the refrigerant flow path at an outlet of the heat exchanging unit, a first pressure loss of the refrigerant in the refrigerant flow path of the heat exchanging unit, a second pressure loss of the refrigerant in the corresponding refrigerant distribution tube, and a vertical height from a bottom edge of the heat exchanging unit to the vertically lowermost refrigerant flow path.

2. The heat exchanger evaluating device according to claim 1, wherein the determination unit determines whether the refrigerant has accumulated in the heat exchanging unit on the basis of an expression below, given hi as the vertical height at the outlet of the heat exchanging unit, Pri as the first pressure loss, Pci as the second pressure loss, h_{bottom} as the vertical height from the bottom edge of the heat exchanging unit to the vertically lowermost refrigerant flow path, p as a refrigerant density, and g as a gravitational acceleration:

[Expression 1]

$$hi < \frac{P_{ri} + P_{ci}}{\rho g} + h_{bottom}$$

.

3. A heat exchanger evaluating method of a heat exchanger comprising a heat exchanging unit that causes a refrigerant to circulate through a plurality of multistage refrigerant flow paths arranged in a vertical direction, and performs heat exchange between the refrigerant and air, a refrigerant header that allows the refrigerant in a gas phase to circulate therethrough and is connected to a first end side of each of the plurality of refrigerant flow paths, a plurality of refrigerant distribution tubes connected to respective second end sides of the plurality of refrigerant flow paths, and a refrigerant distributor that joins the plurality of refrigerant distribution tubes at a joining position, the heat exchanger evaluating method comprising:

a first step of acquiring information on a vertical height of each of the refrigerant flow paths at an outlet of the heat exchanging unit of the heat exchanger to be evaluated, a first pressure loss of the refrigerant in the refrigerant flow paths of the heat exchanging unit, and a second pressure loss of the refrigerant in the refrigerant distribution tubes; and
a second step of determining, for each of the refrigerant flow paths, whether the refrigerant has accumulated in the heat exchanging unit on the basis of a relationship between the vertical height of the refrigerant flow path of the heat exchanging unit, the first pressure loss, the second pressure loss, and a vertical height from a bottom edge of the heat exchanging unit to the vertically lowermost refrigerant flow path.

4. The heat exchanger evaluating method according to claim 3, wherein whether the refrigerant has accumulated in the heat exchanging unit is determined on the basis of an expression below, given hi as the vertical height at the outlet of the heat exchanging unit, Pri as the first pressure loss, Pci as the second pressure loss, h_{bottom} as the vertical height from the bottom edge of the heat exchanging unit to the vertically lowermost refrigerant flow path, p as a refrigerant density, and g as a gravitational acceleration:

[Expression 2]

$$hi < \frac{P_{ri} + P_{ci}}{\rho g} + h_{bottom}$$

5. A heat exchanger manufacturing method for a heat exchanger comprising a heat exchanging unit that causes a refrigerant to circulate through a plurality of multistage refrigerant flow paths arranged in a vertical direction, and performs heat exchange between the refrigerant and air, a refrigerant header that allows the refrigerant in a gas phase to circulate therethrough and is connected to a first end side of each of the plurality of refrigerant flow paths, a plurality of refrigerant distribution tubes connected to respective second end sides of the plurality of refrigerant flow paths, and a refrigerant distributor that joins the plurality of refrigerant distribution tubes at a joining position, the heat exchanger manufacturing method comprising:

manufacturing the heat exchanger that satisfies an expression below, given hi as a vertical height of the refrigerant flow path at an outlet of the heat exchanging unit, Pri as a first pressure loss of the refrigerant in the refrigerant flow paths of the heat exchanging unit, Pci as a second pressure loss of the refrigerant in the refrigerant distribution tubes, h_{bottom} as a vertical height from the bottom edge of the heat exchanging unit to the vertically lowermost refrigerant flow path, ρ as a refrigerant density, and g as a gravitational acceleration:

[Expression 3]

$$hi < \frac{P_{ri} + P_{ci}}{\rho g} + h_{bottom}$$

.

6. A heat exchanger designing method for a heat exchanger comprising a heat exchanging unit that causes a refrigerant to circulate through a plurality of multistage refrigerant flow paths arranged in a vertical direction, and performs heat exchange between the refrigerant and air, a refrigerant header that allows the refrigerant in a gas phase to circulate therethrough and is connected to a first end side of each of the plurality of refrigerant flow paths, a plurality of refrigerant distribution tubes connected to respective second end sides of the plurality of refrigerant flow paths, and a refrigerant distributor that joins the plurality of refrigerant distribution tubes at a joining position, the heat exchanger designing method comprising:

designing the heat exchanger that satisfies an expression below, given hi as a vertical height of the refrigerant flow path at an outlet of the heat exchanging unit, Pri as a first pressure loss of the refrigerant in the refrigerant flow paths of the heat exchanging unit, Pci as a second pressure loss of the refrigerant in the refrigerant distribution tubes, h_{bottom} as a vertical height from the bottom edge of the heat exchanging unit to the vertically lowermost refrigerant flow path, ρ as a refrigerant density, and g as a gravitational acceleration:

[Expression 4]

$$hi < \frac{P_{ri} + P_{ci}}{\rho g} + h_{bottom}$$

.

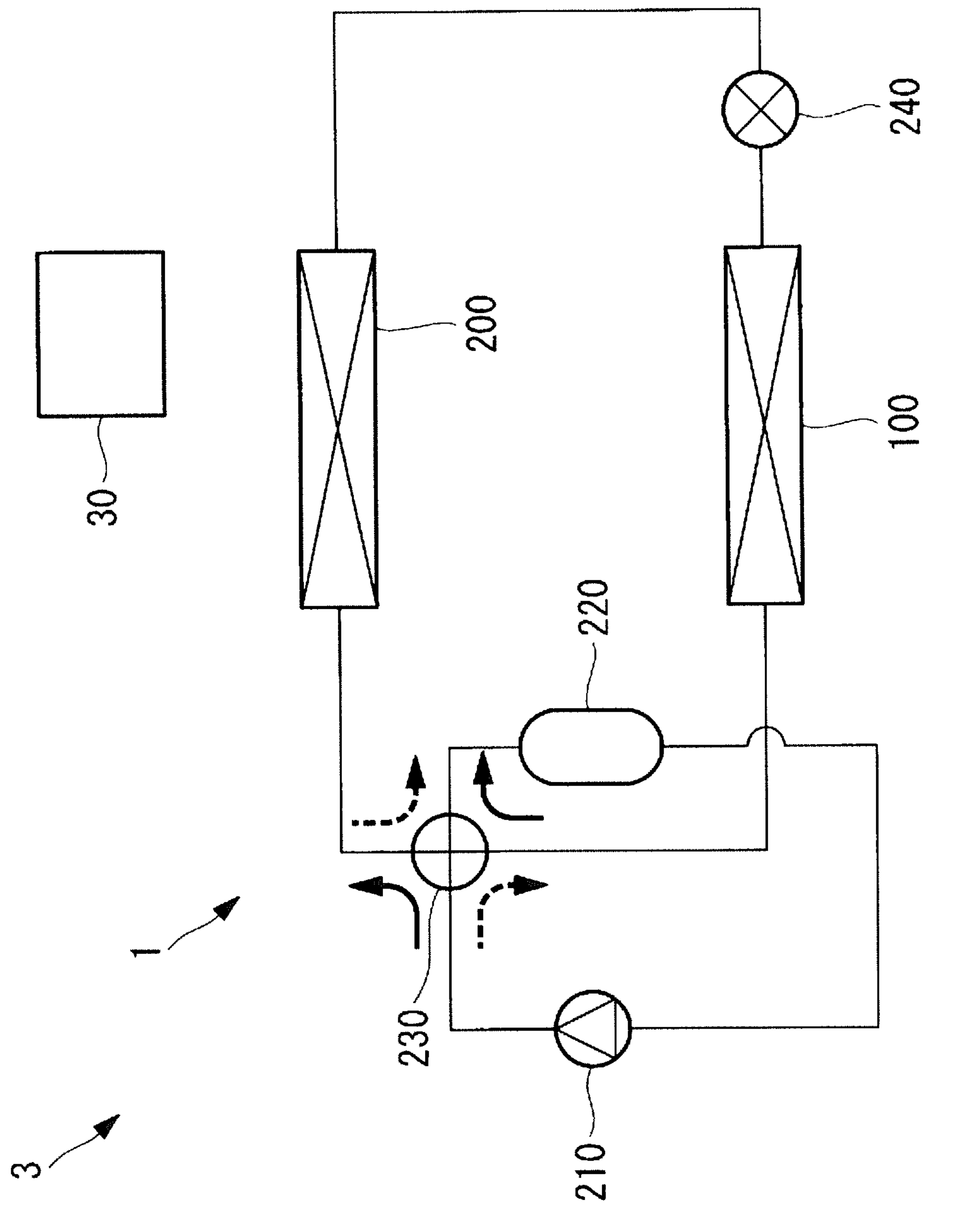

FIG. 1

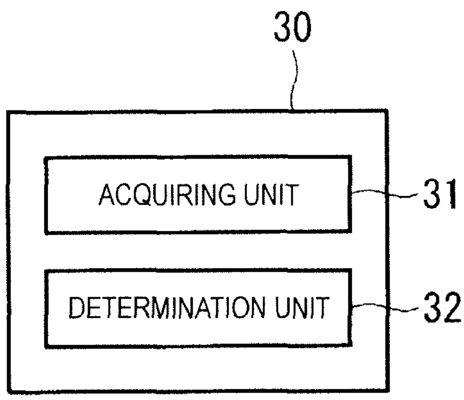

FIG. 2

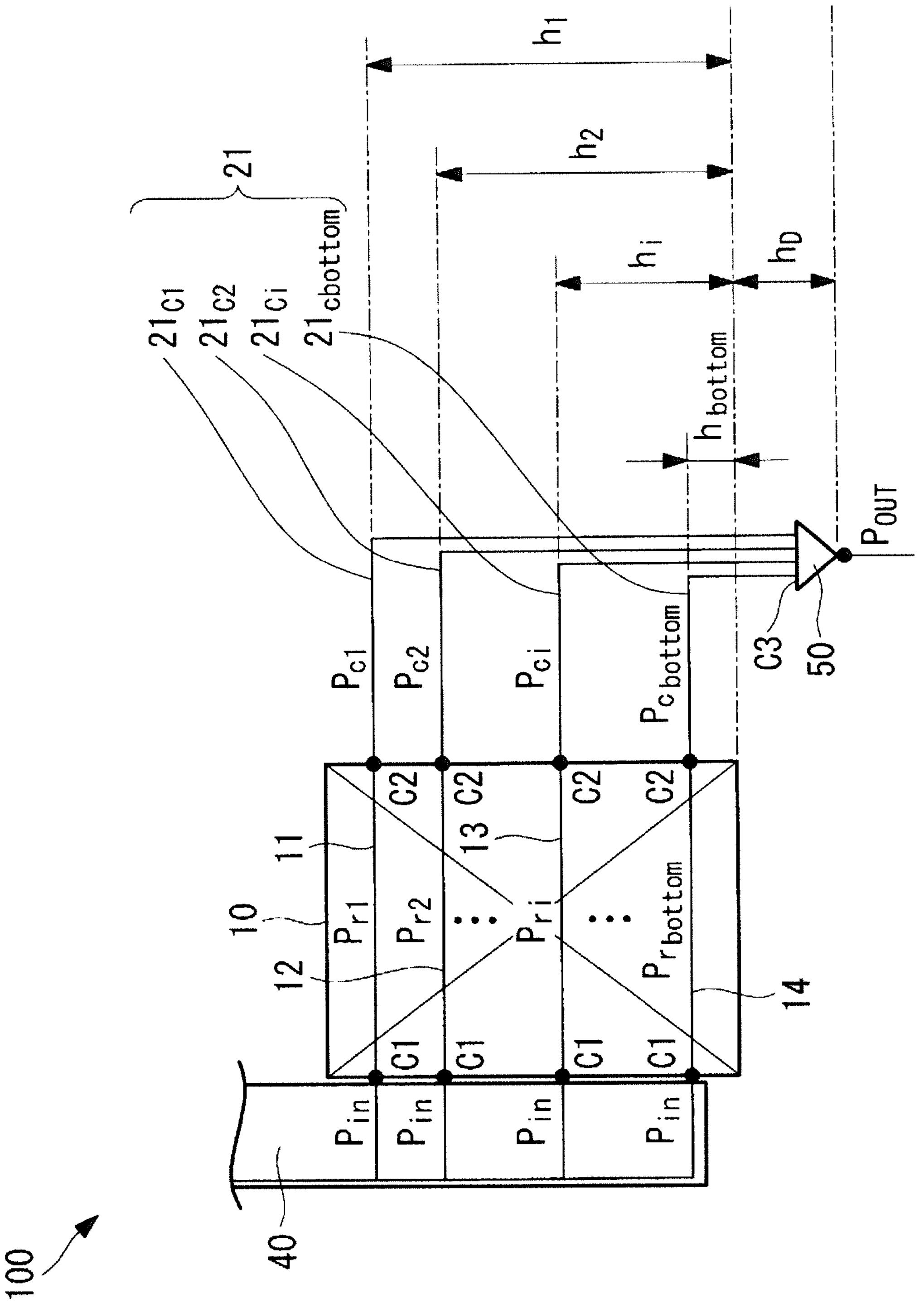

FIG. 3

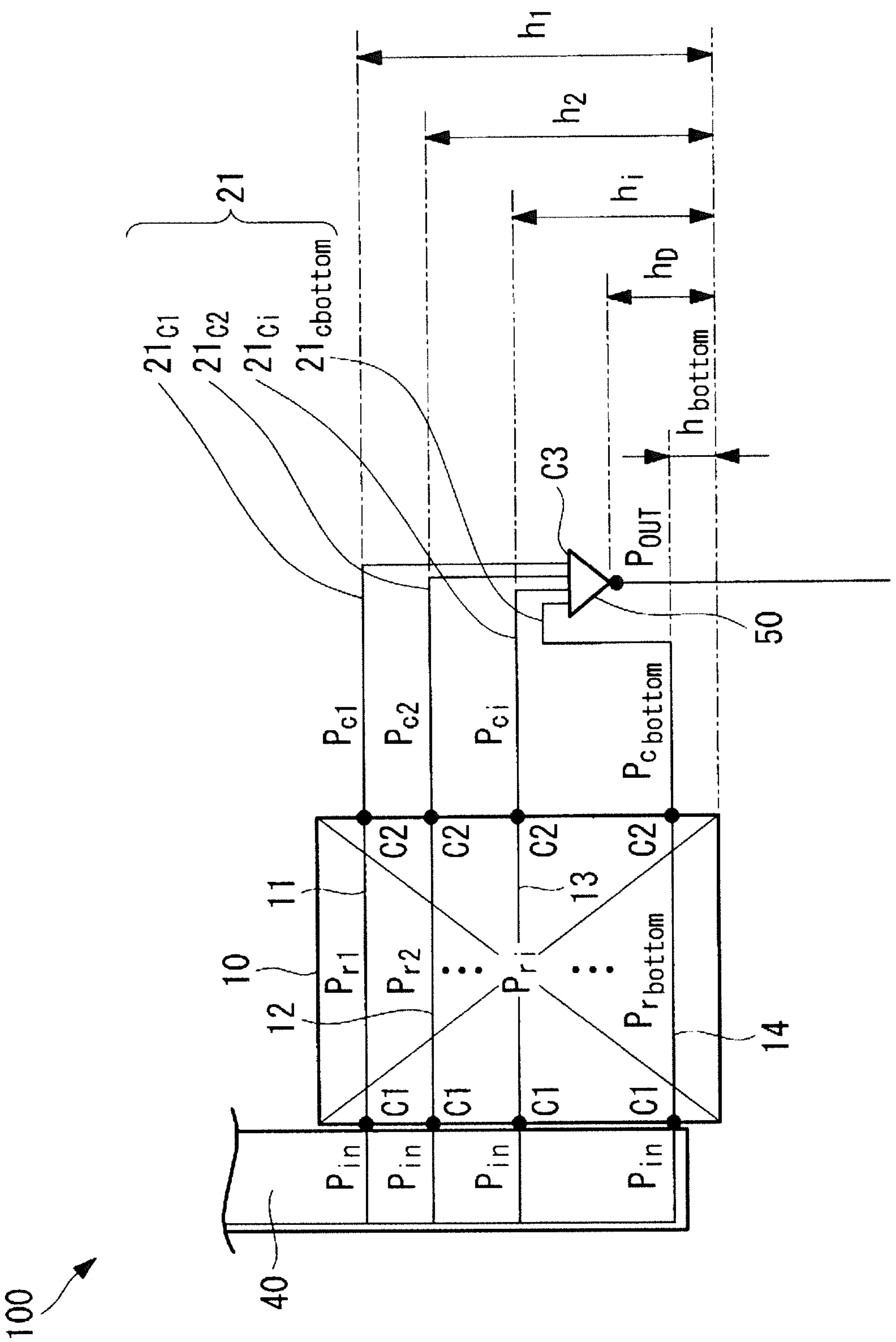
100
40
10
11
12
13
14
21
21_{C1}
21_{C2}
21_{Ci}
$21_{cbottom}$
h_1
h_2
h_i
h_D
h_{bottom}
C3
P_{OUT}
50
P_{c1}
P_{c2}
P_{ci}
$P_{c\,bottom}$
C2
C1
P_{r1}
P_{r2}
P_{ri}
$P_{r\,bottom}$
P_{in}

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/009351

A. CLASSIFICATION OF SUBJECT MATTER
F25B39/00(2006.01)i, *F25B41/00*(2006.01)i, *F25B49/02*(2006.01)i, *F28D1/04* (2006.01)i

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)
F25B39/00-49/02, F28D1/04, G01L7/00-23/32, G01L27/00-27/02

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2017
Kokai Jitsuyo Shinan Koho	1971-2017	Toroku Jitsuyo Shinan Koho	1994-2017

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014/080496 A1 (Mitsubishi Electric Corp.), 30 May 2014 (30.05.2014), paragraphs [0027] to [0032]; fig. 2 & US 2015/0276290 A1 paragraphs [0037] to [0043]; fig. 2 & EP 2924368 A1	1-6
A	JP 2014-25673 A (Fujitsu General Ltd.), 06 February 2014 (06.02.2014), paragraph [0078] & US 2014/0026603 A1 paragraphs [0110] to [0111] & EP 2693130 A2 & AU 2013206682 A & CN 103574855 A	1-6

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

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Date of the actual completion of the international search	Date of mailing of the international search report
18 May 2017 (18.05.17)	30 May 2017 (30.05.17)

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

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/009351

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	JP 3985831 B2 (Daikin Industries, Ltd.), 03 October 2007 (03.10.2007), paragraph [0045]; fig. 4 & WO 2007/052515 A1 & EP 1953480 A1 paragraph [0056]; fig. 4 & ES 2386733 T	1-6

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