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(71) Applicant: **Panasonic Intellectual Property Management Co., Ltd.**
Osaka-shi, Osaka 540-6207 (JP)

(72) Inventor: **KUSAKA, Michiyoshi**
Kadoma-shi, Osaka 571-0057 (JP)

(74) Representative: **Eisenführ Speiser Patentanwälte Rechtsanwälte PartGmbB**
Postfach 31 02 60
80102 München (DE)

(54) **SHELL-AND-TUBE HEAT EXCHANGER, REFRIGERATION CYCLE DEVICE, AND HEAT EXCHANGE METHOD**

(57) An evaporator 101 is configured as a shell-and-tube heat exchanger. The evaporator 101 includes a plurality of heat transfer tubes 22 in which a first fluid flows, and a plurality of nozzles 24 for spraying a second fluid toward the plurality of heat transfer tubes 22. When a direction parallel to the longitudinal direction of the heat transfer tubes 22 is defined as X direction, the vertical direction perpendicular to the X direction is defined as Y direction, and a direction perpendicular to the X direction and the Y direction is defined as Z direction, the plurality of nozzles 24 include a plurality of first nozzles 24a that spray the second fluid from a first side toward a second side in the Z direction, and a plurality of second nozzles 24b that spray the second fluid from the first side toward the second side in the Z direction. On a projected image obtained by projecting the plurality of first nozzles 24a and the plurality of second nozzles 24b in the Z direction, the plurality of first nozzles 24a and the plurality of second nozzles 24b form a staggered arrangement pattern.

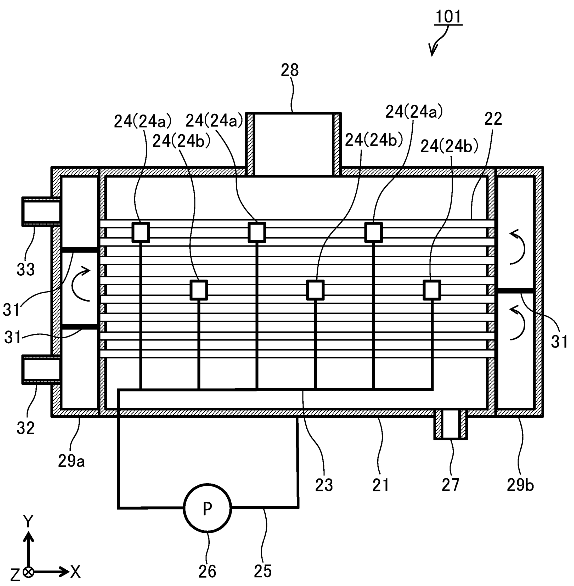

FIG. 2

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Description

TECHNICAL FIELD

[0001] The present disclosure relates to a shell-and-tube heat exchanger, a refrigeration cycle device, and a heat exchange method.

BACKGROUND ART

[0002] A technique for cooling a refrigerant inside a heat transfer tube by sprinkling cooling water toward the heat transfer tube, has been known. FIG. 19 illustrates a conventional evaporative condenser described in Patent Literature 1 (FIG. 9). A water spraying portion 330 of an evaporative condenser 300 has a plurality of water spraying nozzles 334 for spraying cooling water CW toward condenser coils 326. Through heat exchange between the cooling water CW and a refrigerant R circulating in the condenser coils 326, the cooling water CW evaporates and the refrigerant R is cooled and condensed.

CITATION LIST

Patent Literature

[0003] Patent Literature 1: WO2017/073367

SUMMARY OF INVENTION

Technical Problem

[0004] According to the present disclosure, a shell-and-tube heat exchanger that is advantageous in that dryout is inhibited on outer surfaces of a plurality of heat transfer tubes, is provided.

Solution to Problem

[0005] A shell-and-tube heat exchanger of the present disclosure includes:

a shell;
a plurality of heat transfer tubes disposed inside the shell; and
a nozzle, wherein
the shell-and-tube heat exchanger satisfies the following conditions (Ia), (Ib), (Ic), and (Id) or the following conditions (IIa), (IIb), (IIc), and (IId),
(Ia) the plurality of heat transfer tubes is disposed inside the shell in a manner that the heat transfer tubes are parallel to each other, and a first fluid flows in the plurality of heat transfer tubes,
(Ib) the nozzle includes a plurality of nozzles that is disposed inside the shell, and that spray a second fluid toward the plurality of heat transfer tubes,
(Ic) when a direction parallel to a longitudinal direction of the plurality of heat transfer tubes is defined as an X direction, a direction perpendicular to the X direction is defined as a Y direction, and a direction perpendicular to the X direction and the Y direction is defined as a Z direction,
the plurality of nozzles includes a plurality of first nozzles that sprays the second fluid from a first side toward a second side in the Z direction, and a plurality of second nozzles that sprays the second fluid from the first side toward the second side in the Z direction,
(Id) on a projected image obtained by projecting the plurality of first nozzles and the plurality of second nozzles in the Z direction, the plurality of first nozzles and the plurality of second nozzles form a staggered arrangement pattern,
(IIa) the plurality of heat transfer tubes constitutes a heat transfer tube group,
(IIb) the nozzle sprays liquid toward the heat transfer tube group,
(IIc) the heat transfer tube group includes a first tier having a plurality of heat transfer tubes arranged along a first plane, and a second tier that has a plurality of heat transfer tubes arranged along a second plane parallel to the first plane and that is adjacent to the first tier in a direction perpendicular to the first plane, and
(IId) the nozzle sprays the liquid to form a flat spray pattern that has a spray axis passing between a first end portion, which is close to the second tier in the direction perpendicular to the first plane, of the plurality of heat transfer tubes in the first tier and a second end portion, which is close to the first tier in the direction perpendicular to the first plane, of the plurality of heat transfer tubes in the second tier and that passes between the first tier and the second tier.

[0006] Furthermore, a heat exchange method of the present disclosure includes:

causing a heat medium to pass in a heat transfer tube group that includes a first tier having a plurality of heat transfer tubes arranged along a first plane, and a second tier that has a plurality of heat transfer tubes arranged along a second plane parallel to the first plane and that is adjacent to the first tier in a direction perpendicular to the first plane; and
spraying a liquid toward the heat transfer tube group to form a flat spray pattern that has a spray axis passing between a first end portion, which is close to the second tier in the direction perpendicular to the first plane, the plurality of heat transfer tubes in the first tier and a second end portion, which is close to the first tier in the direction perpendicular to the first plane, of the plurality of heat transfer tubes in the second tier and that passes between the first tier and the second tier, and causing heat exchange between the heat medium and the liquid.

Advantageous Effects of Invention

[0007] In the shell-and-tube heat exchanger of the present disclosure, in a case where the conditions (Ia), (Ib), (Ic), and (Id) are satisfied, the surfaces of the plurality of heat transfer tubes can be made uniformly wet with the second fluid sprayed from the plurality of first nozzles to fourth nozzles. Thus, dryout can be inhibited. Furthermore, in a case where the conditions (IIa), (IIb), (IIc), and (IId) are satisfied, liquid can be sprayed toward the heat transfer tube group to form a flat spray pattern having a spray axis that passes between the first end portions of the plurality of heat transfer tubes in the first tier and the second end portions of the plurality of heat transfer tubes in the second tier. The spray pattern passes between the first tier and the second tier. In the heat exchange method of the present disclosure, liquid can be sprayed toward the heat transfer tube group to form such a spray pattern. Thus, dryout can be inhibited.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008]

FIG. 1 is a configuration diagram illustrating a refrigeration cycle device according to Embodiment 1 of the present disclosure;
FIG. 2 is a longitudinal cross-sectional view of an evaporator as taken along a line II-II in FIG. 1;
FIG. 3 is a transverse cross-sectional view of the evaporator as taken along a line III-III in FIG. 1;
FIG. 4A is a side view of the evaporator as taken along a line IVA-IVA in FIG. 2;
FIG. 4B is a side view of the evaporator as taken along a line IVB-IVB in FIG. 2;
FIG. 5A is a cross-sectional view of the evaporator as taken along a line VA-VA in FIG. 2;
FIG. 5B is a cross-sectional view of the evaporator as taken along a line VB-VB in FIG. 2;
FIG. 6 is a diagram illustrating moving directions and a dropping state of a refrigerant sprayed from a first nozzle and a third nozzle toward a plurality of heat transfer tubes;
FIG. 7A is a diagram illustrating a position relationship between a nozzle plane defined by the first nozzle and the third nozzle, and a nozzle plane defined by a second nozzle and a fourth nozzle;
FIG. 7B is a diagram illustrating a state of the refrigerant at each nozzle plane after the refrigerant is sprayed;
FIG. 8 is a transverse cross-sectional view of an evaporator according to Embodiment 2 of the present disclosure;
FIG. 9 is a side view of the evaporator as taken along a line IX-IX in FIG. 8;
FIG. 10A is a cross-sectional view of the evaporator as taken along a line XA-XA in FIG. 8;
FIG. 10B is a cross-sectional view of the evaporator as taken along a line XB-XB in FIG. 8;
FIG. 11 is a diagram illustrating a configuration of a refrigeration cycle device according to Embodiment 3 of the present disclosure;
FIG. 12 is a longitudinal cross-sectional view of an evaporator as taken at a line II-II in FIG. 11 as a cutting plane line;
FIG. 13A is a diagram illustrating a spray pattern of a liquid phase refrigerant sprayed from a nozzle;
FIG. 13B is a diagram illustrating a spray pattern of the liquid phase refrigerant sprayed from the nozzle;
FIG. 14 is a longitudinal cross-sectional view of the evaporator as taken at a line IV-IV in FIG. 11 as a cutting plane line;
FIG. 15 is a diagram illustrating a region over which the liquid phase refrigerant is sprayed;
FIG. 16 is a diagram illustrating a state where the liquid phase refrigerant is sprayed and flows;
FIG. 17 is a diagram illustrating a region over which a liquid phase refrigerant is sprayed in Embodiment 4 of the present disclosure;
FIG. 18 is a diagram illustrating a state where a liquid phase refrigerant is sprayed and flows in Embodiment 5 of the present disclosure; and
FIG. 19 is a cross-sectional view of a conventional evaporative condenser.

DESCRIPTION OF EMBODIMENTS

(Findings on which the present disclosure is based, and the like)

[0009] If a conventional configuration of nozzles is applied to a shell-and-tube heat exchanger, dryout is likely to occur at specific positions. Heat exchange does not occur at a surface on which dryout has occurred, and the shell-and-tube heat exchanger cannot sufficiently exhibit its performance. If occurrence of dryout can be prevented, the shell-and-tube heat exchanger can sufficiently exhibit its performance. Based on such findings, the present inventor has configured the subject of the present disclosure. The "dryout surface" refers to a surface on which liquid films of a refrigerant do not exist.

[0010] At the time when the present inventor has conceived of the present disclosure, liquid such as cooling water has been attempted to be sprayed toward heat transfer tubes by using nozzles in a shell-and-tube heat exchanger. In such a situation, the present inventor has obtained an idea that performance of a shell-and-tube heat exchanger can be enhanced, by obtaining a hint from a flow of liquid sprayed from nozzles. The present inventor has found that, in realizing the idea, there is a problem that, for example, if a spray pattern of a liquid phase refrigerant has a conical shape, the liquid phase refrigerant, which is in the form of mist, is unlikely to reach an outer surface of a heat transfer tube that is far from a nozzle, and dryout is thus likely to occur. The present inventor has configured the subject of the present disclosure in order to solve the problem.

[0011] Therefore, according to the present disclosure, a shell-and-tube heat exchanger that is advantageous in that dryout is inhibited on outer surfaces of a plurality of heat transfer tubes, is provided.

[0012] Embodiments will be described below in detail with reference to the drawings. However, unnecessarily detailed description may be omitted. For example, detailed description for well-known matter, or repeated description for substantially the same components may be omitted. This is for the purpose of preventing the following description from being unnecessarily redundant, and allowing a person skilled in the art to easily understand the present disclosure.

[0013] The accompanying drawings and the following description are provided for allowing a person skilled in the art to sufficiently understand the present disclosure, and are not intended to limit the subject of claims.

(Embodiment 1)

[0014] Embodiment 1 will be described below with reference to FIG. 1 to FIG. 7B.

[1-1. Configuration]

[0015] FIG. 1 illustrates a configuration of a refrigeration cycle device in which a shell-and-tube heat exchanger is used. A refrigeration cycle device 100 includes an evaporator 101, a compressor 102, a condenser 103, a flow valve 104, a flow path 110a, a flow path 110b, a flow path 110c, and a flow path 11 0d. The outlet of the evaporator 101 is connected to the inlet of the compressor 102 through the flow path 110a. The outlet of the compressor 102 is connected to the inlet of the condenser 103 through the flow path 110b. The outlet of the condenser 103 is connected to the inlet of the flow valve 104 through the flow path 110c. The outlet of the flow valve 104 is connected to the inlet of the evaporator 101 through the flow path 110d. The flow paths 110a and 110b are vapor paths. The flow path 110c and the flow path 110d are liquid paths. Each path is, for example, formed of at least one metal tube.

[0016] The evaporator 101 is configured by a shell-and-tube heat exchanger as described below.

[0017] The compressor 102 may be a dynamic compressor such as a centrifugal compressor, or may be a positive displacement compressor such as a scroll compressor.

[0018] The type of the condenser 103 is not particularly limited. A heat exchanger such as a plate heat exchanger and a shell-and-tube heat exchanger can be used for the condenser 103.

[0019] The refrigeration cycle device 100 is, for example, a business-use or home-use air conditioner. A heat medium cooled by the evaporator 101 is supplied through a circuit 105 into a room, and used for cooling the room. Alternatively, a heat medium heated by the condenser 103 is supplied through a circuit 106 into a room, and used for heating the room. The heat medium is, for example, water. However, the refrigeration cycle device 100 is not limited to an air conditioner, and may be another device such as a chiller and a heat storage device. The refrigeration cycle device 100 may be an absorption refrigerator that includes an evaporator, an absorber, a regenerator, and a condenser.

[0020] The circuit 105 is a circuit for circulating a heat medium in the evaporator 101. The circuit 106 is a circuit for circulating a heat medium in the condenser 103. The circuit 105 and the circuit 106 may be sealed circuits isolated from outside air.

[0021] The heat medium is a first fluid that flows in each of the circuit 105 and the circuit 106. The heat medium is not limited to water, and may be liquid such as oil or brine, or may be gas such as air. A composition of the heat medium in the circuit 105 may be different from a composition of the heat medium in the circuit 106.

[0022] By actuating the compressor 102, a refrigerant is heated and evaporated in the evaporator 101. Thus, a gas phase refrigerant is generated. The gas phase refrigerant is suctioned into the compressor 102 and compressed. The compressed gas phase refrigerant is supplied from the compressor 102 to the condenser 103. The gas phase refrigerant is cooled, and condensed and liquefied in the condenser 103. Thus, a liquid phase refrigerant is generated. The liquid phase refrigerant is returned from the condenser 103 through the flow valve 104 to the evaporator 101.

[0023] The type of the refrigerant is not particularly limited. Examples of the refrigerant include a fluorocarbon refrigerant, a low GWP (global warming potential) refrigerant, and a natural refrigerant. Examples of the fluorocarbon refrigerant include HCFC (hydrochlorofluorocarbon) and HFC (hydrofluorocarbon). Examples of the low GWP refrigerant include HFO-1234yf and water. Examples of the natural refrigerant include carbon dioxide and water.

[0024] The refrigerant may be a refrigerant that contains, as a main component, a substance of which the saturated vapor pressure is a negative pressure at ordinary temperature. Examples of such a refrigerant include a refrigerant that contains water, alcohol, or ether as a main component. The "main component" represents a component having the largest content at a mass ratio. The "negative pressure" represents a pressure which is lower than atmospheric pressure on an absolute pressure basis. The "ordinary temperature" represents a temperature in a range of 20°C±15°C according to the Japanese Industrial Standard (JIS Z8703).

[0025] The refrigerant is an example of a second fluid that is to exchange heat with a heat medium as the first fluid.

[0026] FIG. 2 is a longitudinal cross-sectional view of the evaporator 101 as taken along a line II-II. FIG. 3 is a transverse cross-sectional view of the evaporator 101 as taken along a line III-III. As shown in FIG. 2 and FIG. 3, the evaporator 101 is configured as a shell-and-tube heat exchanger. The evaporator 101 includes a shell 21, a plurality of heat transfer tubes 22, a plurality of nozzles 24, a circulation circuit 25, and a circulation pump 26. The plurality of heat transfer tubes 22 and the plurality of nozzles 24 are disposed inside the shell 21. The plurality of nozzles 24 include a plurality of first nozzles 24a, a plurality of second nozzles 24b, a plurality of third nozzles 24c, and a plurality of fourth nozzles 24d. The plurality of heat transfer tubes 22 are disposed between a nozzle group including the plurality of first nozzles 24a and the plurality of second nozzles 24b, and a nozzle group including the plurality of third nozzles 24c and the plurality of fourth nozzles 24d. The refrigerant is efficiently evaporated in the evaporator 101, whereby a coefficient of performance (COP) of a refrigerating cycle can be enhanced.

[0027] The plurality of heat transfer tubes 22 includes a round tube having a round cross-section. In FIG. 2 and FIG. 3, all of the heat transfer tubes 22 are round tubes having a round cross-section. A heat medium as the first fluid flows from the inlet of the heat transfer tube 22 toward the outlet thereof. Each of the heat transfer tubes 22 penetrates through faces of the shell 21 which are opposite each other.

[0028] The heat transfer tubes 22 are disposed parallel to each other inside the shell 21. More specifically, the heat transfer tubes 22 are regularly aligned in a plurality of lines at a plurality of tiers inside the shell 21. The regular alignment is advantageous in that the liquid film is made uniformly thin on the surface of the heat transfer tube 22.

[0029] In the present embodiment, the direction parallel to the longitudinal direction of the heat transfer tube 22 is defined as X direction. The vertical direction perpendicular to the X direction is defined as Y direction. The direction perpendicular to the X direction and the Y direction is defined as Z direction. The Y direction and the Z direction represent a tier direction and a line direction, respectively. The Y direction can be the direction parallel to the gravitational direction. The X direction and the Z direction can be directions parallel to the horizontal direction.

[0030] As shown in FIG. 3, on a cross-section perpendicular to the X direction and parallel to the Y direction and the Z direction, the heat transfer tubes 22 are located on grid points of a square grid. More specifically, the center of each heat transfer tube 22 is located at the grid point of the square grid. However, the manner in which the heat transfer tubes 22 are aligned is not limited to a particular one. The plurality of heat transfer tubes 22 may be, for example, disposed such that the center of each heat transfer tube 22 is located at a grid point of a rectangular grid. In FIG. 2 and FIG. 3, the heat transfer tubes 22 are aligned at eight tiers in twelve lines. The number of tiers and the number of lines are not limited to specific values.

[0031] A tube that forms the heat transfer tube 22 may be a machined tube in which grooves are formed at the inner portion of the tube, the outer portion of the tube, or both of them.

[0032] Inside the heat transfer tube 22, a heat medium that exchanges heat with a refrigerant flow. The heat medium is fluid such as water, ethylene glycol, or propylene glycol. For example, the heat medium absorbs heat in the atmosphere through a heat exchanger such as a fin-and-tube heat exchanger, and flows into each heat transfer tube 22 of the evaporator 101. In each heat transfer tube 22, the heat medium is cooled by the refrigerant.

[0033] Examples of a material of the heat transfer tube 22 include metal materials such as aluminium, aluminium alloys, stainless steel, and copper.

[0034] As shown in FIG. 2 and FIG. 3, the refrigerant is sprayed from each of the first nozzles 24a to the fourth nozzles 24d toward the plurality of heat transfer tubes 22. The plurality of first nozzles 24a and the plurality of second nozzles 24b spray the refrigerant from the first side toward the second side in the Z direction. The plurality of third nozzles 24c and the plurality of fourth nozzles 24d spray the refrigerant from the second side toward the first side in the Z direction. The "first side" represents, for example, one side in the width direction of the heat transfer tube 22. The "second side" represents the other side in the width direction of the heat transfer tube 22. The width direction of the heat transfer tube 22 can be the width direction with respect to the horizontal direction.

[0035] The nozzle 24 is, for example, a pressure-injection type spray nozzle. The pressure-injection-type spray nozzle is configured to receive a pressurized refrigerant through the inlet, apply a swirl force to the refrigerant by a swirl mechanism inside the nozzle, and inject the refrigerant into a space. Thus, the injected refrigerant spreads to form a conical shape by a centrifugal force according to a swirl speed, and is formed into a thin film and a liquid thread, and thereafter split into droplet groups.

[0036] The same type of spray nozzles can be used for the first nozzles 24a to the fourth nozzles 24d. The term "same" means that the structure and characteristics are the same in design. However, the structures and sizes may be different among the first nozzles 24a to the fourth nozzles 24d.

[0037] In the present embodiment, the plurality of first nozzles 24a and the plurality of second nozzles 24b are located at the same position in the Z direction. The plurality of third nozzles 24c and the plurality of fourth nozzles 24d are located at the same position in the Z direction. The plurality of first nozzles 24a and the plurality of third nozzles 24c are located at the same position in the Y direction. The plurality of second nozzles 24b and the plurality of fourth nozzles 24d are located at the same position in the Y direction. In FIG. 2 and FIG. 3, the plurality of first nozzles 24a and the plurality of second nozzles 24b are each disposed at one tier. The plurality of third nozzles 24c and the plurality of fourth nozzles 24d are each disposed at one tier. The first nozzles 24a and the second nozzles 24b may be arranged in the X direction and the Y direction in the form of a matrix. The third nozzles 24c and the fourth nozzles 24d may be arranged in the X direction and the Y direction in the form of a matrix.

[0038] FIG. 4A is a side view of the evaporator 101 as taken along a line IVA-IVA. In FIG. 4A, components other than the heat transfer tubes 22 and the nozzles 24 are omitted. As shown in FIG. 4A, on a projected image obtained by projecting the plurality of first nozzles 24a and the plurality of second nozzles 24b in the Z direction, the plurality of first nozzles 24a and the plurality of second nozzles 24b form a staggered arrangement pattern. The projected image is specifically an image obtained by orthogonal projection of the plurality of first nozzles 24a and the plurality of second nozzles 24b onto any projection plane perpendicular to the Z direction.

[0039] FIG. 4B is a side view of the evaporator 101 as taken along a line IVB-IVB. In FIG. 4B, components other than the heat transfer tubes 22 and the nozzles 24 are omitted. As shown in FIG. 4B, on a projected image obtained by projecting the plurality of third nozzles 24c and the plurality of fourth nozzles 24d in the Z direction, the plurality of third nozzles 24c and the plurality of fourth nozzles 24d form a staggered arrangement pattern. The projected image is specifically an image obtained by orthogonal projection of the plurality of third nozzles 24c and the plurality of fourth nozzles 24d onto any projection plane perpendicular to the Z direction.

[0040] As shown in FIG. 4A, the plurality of first nozzles 24a are arranged in the X direction. The plurality of second nozzles 24b are arranged in the X direction. The position of the first nozzle 24a in the Y direction is different from the position of the second nozzle 24b in the Y direction. The plurality of first nozzles 24a and the plurality of second nozzles 24b are located on the same plane perpendicular to the Z direction.

[0041] As shown in FIG. 4B, the plurality of third nozzles 24c are arranged in the X direction. The plurality of fourth nozzles 24d are arranged in the X direction. The position of the third nozzle 24c in the Y direction is different from the position of the fourth nozzle 24d in the Y direction. The plurality of third nozzles 24c and the plurality of fourth nozzles 24d are located on the same plane perpendicular to the Z direction.

[0042] FIG. 5A is a cross-sectional view of the evaporator 101 as taken along a line VA-VA. FIG. 5B is a cross-sectional view of the evaporator 101 as taken along a line IVB-IVB. In FIG. 5A and FIG. 5B, components other than the heat transfer tubes 22 and the nozzles 24 are omitted.

[0043] A spray axis O1 of the first nozzle 24a and a spray axis O2 of the second nozzle 24b are parallel to a direction inclined relative to both the X direction and the Z direction. The spray axis O1 represents the central axis of a refrigerant spray flow which is generated by the first nozzle 24a. The spray axis O2 represents the central axis of a refrigerant spray flow which is generated by the second nozzle 24b. The spray axis O1 and the spray axis O2 are each inclined relative to the line direction (Z direction). In such a configuration, the refrigerant can be sprayed over a wide range by the first nozzle 24a and the second nozzle 24b. This also contributes to forming a liquid film as a uniform thin film on the surface of the heat transfer tube 22.

[0044] A spray axis O3 of the third nozzle 24c and a spray axis O4 of the fourth nozzle 24d are parallel to a direction inclined relative to both the X direction and the Z direction. The spray axis O3 represents the central axis of a refrigerant spray flow which is generated by the third nozzle 24c. The spray axis O4 represents the central axis of a refrigerant spray flow which is generated by the fourth nozzle 24d. The spray axis O3 and the spray axis O4 are each inclined relative to the line direction (Z direction). In such a configuration, the refrigerant can be sprayed over a wide range by the third nozzle 24c and the fourth nozzle 24d.

[0045] The "spray axis O1" can be regarded as the central axis of the first nozzle 24a. The spray axis O1 can be an axis that passes through the center of the opening of the first nozzle 24a. The "spray axis O2" can be regarded as the central axis of the second nozzle 24b. The spray axis O2 can be an axis that passes through the center of the opening of the second nozzle 24b. The "spray axis O3" can be regarded as the central axis of the third nozzle 24c. The spray axis O3 can be an axis that passes through the center of the opening of the third nozzle 24c. The "spray axis O4" can be regarded as the central axis of the fourth nozzle 24d. The spray axis O4 can be an axis that passes through the center of the opening of the fourth nozzle 24d.

[0046] In a planar view in the Y direction, the spray axis O1 of the first nozzle 24a is inclined clockwise relative to a first reference line L1 that passes through the center of the opening of the first nozzle 24a and is parallel to the Z direction. The spray axis O2 of the second nozzle 24b is inclined counterclockwise relative to a second reference line L2 that passes through the center of the opening of the second nozzle 24b and is parallel to the Z direction. In such a configuration, the refrigerant can be sprayed over a wide range by the minimum number of the first nozzles 24a and the second nozzles 24b.

[0047] In a planar view in the Y direction, the spray axis O3 of the third nozzle 24c is inclined clockwise relative to a third reference line L3 that passes through the center of the opening of the third nozzle 24c and is parallel to the Z direction. The spray axis O4 of the fourth nozzle 24d is inclined counterclockwise relative to a fourth reference line L4 that passes through the center of the opening of the fourth nozzle 24d and is parallel to the Z direction. In such a configuration, the refrigerant can be sprayed over a wide range by the minimum number of the first nozzles 24a and the second nozzles 24b.

[0048] In a planar view in the Y direction, an angle $\theta 1$ between the spray axis O1 of the first nozzle 24a and the first reference line L1 is equal to an angle $\theta 2$ between the spray axis O2 of the second nozzle 24b and the second reference line L2.

[0049] In a planar view in the Y direction, an angle θ3 between the spray axis O3 of the third nozzle 24c and the third reference line L3 is equal to an angle θ4 between the spray axis O4 of the fourth nozzle 24d and the fourth reference line L4.

[0050] The angle θ1, the angle θ2, the angle θ3, and the angle θ4 may be equal to each other, or may be different from each other. Each of the angle θ1, the angle θ2, the angle θ3, and the angle θ4 may be such an angle that at least one of outer edges of the spray flow of the refrigerant is not parallel to the longitudinal direction (X direction) of the heat transfer tube 22. For example, the angle θ1, the angle θ2, the angle θ3, and the angle θ4 are each from 30° to 40°, and typically 30°. In FIG. 5A and FIG. 5B, the dashed lines represent an angle α at which the spray flow of the refrigerant spreads. The spray flow spread angle α represents a spread that is symmetric with respect to each of the spray axes O1, O2, O3, and O4. The spray flow spread angle α may be an acute angle, and is, for example, 60°. The angle θ1, the angle θ2, the angle θ3, and the angle θ4 can be half the spray flow spread angle α. In such a configuration, one of the outer edges of the spray flow of the refrigerant is substantially parallel to the reference lines L1, L2, L3, and L4. Thus, a refrigerant flow component in the direction opposite to the moving direction of the refrigerant that moves along the surface of the heat transfer tube 22 is inhibited from being generated. Since the movement of the refrigerant on the surface of the heat transfer tube 22 is promoted, a heat transfer rate is expected to be increased by enhancement of the moving speed. The angle θ1, the angle θ2, the angle θ3, and the angle θ4 are determined according to conditions such as the number of the nozzles 24, and a distance between the adjacent nozzles 24.

[0051] The first nozzles 24a are arranged at predetermined intervals in the X direction. A distance between the first nozzles 24a adjacent to each other in the X direction is a distance W. The second nozzles 24b are arranged at predetermined intervals in the X direction. A distance between the second nozzles 24b adjacent to each other in the X direction is a distance W. The third nozzles 24c are arranged at predetermined intervals in the X direction. A distance between the third nozzles 24c adjacent to each other in the X direction is a distance W. The fourth nozzles 24d are arranged at predetermined intervals in the X direction. A distance between the fourth nozzles 24d adjacent to each other in the X direction is a distance W. That is, the distance between the first nozzles 24a adjacent to each other in the X direction, the distance between the second nozzles 24b adjacent to each other in the X direction, the distance between the third nozzles 24c adjacent to each other in the X direction, and the distance between the fourth nozzles 24d adjacent to each other in the X direction are equal to each other. The distance W is appropriately determined according to the angle θ of the nozzle 24, and a distance from the nozzle 24 to the heat transfer tube 22. The distance between the nozzles 24 adjacent to each other in the X direction is defined as a distance between the centers of the openings of the adjacent nozzles 24.

[0052] A distance between the first nozzle 24a and the second nozzle 24b in the X direction is half the distance between the first nozzles 24a adjacent to each other in the X direction. A distance between the third nozzle 24c and the fourth nozzle 24d in the X direction is half the distance between the third nozzles 24c adjacent to each other in the X direction. That is, the distance between the first nozzle 24a and the second nozzle 24b in the X direction is W/2. The distance between the third nozzle 24c and the fourth nozzle 2 in the X direction is W/2.

[0053] In a planar view in the Y direction, the positions of the plurality of third nozzles 24c are offset relative to the positions of the plurality of first nozzles 24a in the X direction. In a planar view in the Y direction, the positions of the plurality of fourth nozzles 24d are offset relative to the positions of the plurality of second nozzles 24b in the X direction. Such a configuration is advantageous in that overlap of flow of the refrigerant in the Z direction is avoided.

[0054] The spray axis O1 of each of the first nozzles 24a passes between the heat transfer tube 22 and the heat transfer tube 22 adjacent to each other in the Y direction. In other words, the positions of the plurality of first nozzles 24a are defined such that each spray axis O1 passes through a space between the heat transfer tube 22 and the heat transfer tube 22 adjacent to each other in the Y direction. The spray axis O2 of each of the second nozzles 24b passes between the heat transfer tube 22 and the heat transfer tube 22 adjacent to each other in the Y direction. In other words, the positions of the plurality of second nozzles 24b are defined such that each spray axis O2 passes through a space between the heat transfer tube 22 and the heat transfer tube 22 adjacent to each other in the Y direction In such a configuration, a spray flow travel increases in the line direction (Z direction). This contributes to reducing the size of the evaporator 101, and further contributes to forming a liquid film as a uniform thin film on the surface of the heat transfer tube 22.

[0055] The spray axis O3 of each of the third nozzles 24c passes between the heat transfer tube 22 and the heat transfer tube 22 adjacent to each other in the Y direction. In other words, the positions of the third nozzles 24c are defined in the Y direction such that each spray axis O3 passes through a space between the heat transfer tube 22 and the heat transfer tube 22 adjacent to each other in the Y direction. The spray axis O4 of each of the fourth nozzles 24d passes between the heat transfer tube 22 and the heat transfer tube 22 adjacent to each other in the Y direction. In other words, the positions of the fourth nozzles 24d are defined in the Y direction such that each spray axis O4 passes through a space between the heat transfer tube 22 and the heat transfer tube 22 adjacent to each other in the Y direction. In such a configuration, a spray flow travel increases in the line direction (Z direction).

[0056] As shown in FIG. 4A, at least one tier of the heat transfer tubes 22 is disposed between the plurality of first nozzles 24a and the plurality of second nozzles 24b in the Y direction. As shown in FIG. 4B, at least one tier of the heat transfer tubes 22 is disposed between the plurality of third nozzles 24c and the plurality of fourth nozzles 24d in the Y direction. In the present embodiment, three tiers of the heat transfer tubes 22 are disposed between the plurality of first nozzles 24a and the plurality of second nozzles 24b in the Y direction. Three tiers of the heat transfer tubes 22 are disposed between the plurality of third nozzles 24c and the plurality of fourth nozzles 24d in the Y direction.

[0057] As shown in FIG. 2, the shell 21 is configured to store a liquid phase refrigerant at the bottom thereof. The circulation circuit 25 connects the bottom of the shell 21 and each of the nozzles 24. The circulation pump 26 is disposed in the circulation circuit 25. Through the operation of the circulation pump 26, the liquid phase refrigerant stored at the bottom of the shell 21 is supplied through the circulation circuit 25 to the plurality of nozzles 24. In such a configuration, the liquid phase refrigerant is easily collected, and energy consumption for supplying the liquid phase refrigerant to the plurality of nozzles 24 can be reduced.

[0058] The shell 21 has an inflow tube 27 and a discharge tube 28. The inflow tube 27 defines a flow path for introducing the refrigerant into the shell 21. The discharge tube 28 defines a flow path for introducing the refrigerant evaporated on the surfaces of the plurality of heat transfer tubes 22 to the outside of the shell 21. The flow path 110d and the flow path 110a can be connected to the inflow tube 27 and the discharge tube 28, respectively.

[0059] The nozzles 24 are connected to the circulation circuit 25 through a header 23.

[0060] A flow path cover 29a is attached to the shell 21 to cover one end portion of the plurality of heat transfer tubes 22. A flow path cover 29b is attached to the shell 21 to cover the other end portion of the plurality of heat transfer tubes 22. The flow path cover 29a has two partitions 31 thereinside. The flow path cover 29b has one partition 31 thereinside. The flow path cover 29a has a secondary-side inflow port 32 and a secondary-side outflow port 33. The secondary-side inflow port 32 may be disposed at the flow path cover 29b. The secondary-side outflow port 33 may be disposed at the flow path cover 29b. In the evaporator 101 of the present embodiment, the number of passes is incremented by "1" each time the refrigerant flowing direction is inverted at the flow path cover 29a or 29b. In the present embodiment, the secondary-side inflow port 32 and the secondary-side outflow port 33 are disposed in the flow path cover 29a such that the number of passes is "4".

[0061] In the present embodiment, the shell 21 has a rectangular cross-sectional shape. However, the shape of the shell 21 is not limited. The shell 21 may have a round cross-sectional shape. The shell 21 may be a pressure-resistant container.

[1-2. Operation]

[0062] An operation and an effect of the evaporator 101 having the above-described configuration will be described below.

[0063] By actuating the circulation pump 26, a liquid phase refrigerant is supplied from the bottom of the shell 21 through the header 23 to the plurality of nozzles 24. The liquid phase refrigerant is sprayed from each of the first nozzles 24a and the second nozzles 24b to the plurality of heat transfer tubes 22. Furthermore, the liquid phase refrigerant is sprayed from each of the third nozzles 24c and the fourth nozzles 24d to the plurality of heat transfer tubes 22. A heat medium flows into the flow path cover 29a through the secondary-side inflow port 32 and flows through the heat transfer tube 22.
Subsequently, the flowing direction of the heat medium is inverted at the flow path cover 29b, and the heat medium flows through the heat transfer tube 22. Subsequently, the flowing direction of the heat medium is inverted again at the flow path cover 29a, and the heat medium flows through the heat transfer tube 22. The flowing direction of the heat medium is inverted again at the flow path cover 29b, and the heat medium flows through the heat transfer tube 22. Thereafter, the heat medium flows out through the secondary-side outflow port 33, and is discharged to the outside of the evaporator 101. By spraying the liquid phase refrigerant toward the heat transfer tubes 22 while the heat medium is caused to flow in the heat transfer tubes 22, heat exchange is made between the heat medium and the liquid phase refrigerant at the heat transfer tubes 22, the refrigerant evaporates, and a gas phase refrigerant is generated.

[0064] Components of the refrigerant sprayed from each nozzle 24 will be described with reference to FIG. 5A and FIG. 5B. In FIG. 5A and FIG. 5B, arrows on the heat transfer tubes 22 represent main moving directions of the sprayed refrigerant.

[0065] The spray flow of the refrigerant sprayed from the first nozzle 24a has a flow component C1 along the spray axis O1, and a flow component C2 along the surface of the heat transfer tube 22. The component C1 is a component of flow of the refrigerant sprayed and spread from the first nozzle 24a. The component C1 is a component of flow of the refrigerant moving along the spray axis O1 in a space between the heat transfer tube 22 and the heat transfer tube 22 adjacent to each other in the Y direction. The component C2 is a component of flow of the refrigerant moving on the surface of the heat transfer tube 22 with a velocity component in the X direction. The spray flow of the refrigerant sprayed from the second nozzle 24b has a flow component C3 along the spray axis O2 and a flow component C4 along the surface of the heat transfer tube 22. The spray flow of the refrigerant sprayed from the third nozzle 24c has a flow component C5 along the spray axis O3, and a flow component C6 along the surface of the heat transfer tube 22. The spray flow of the refrigerant sprayed from the fourth nozzle 24d has a flow component C7 along the spray axis O4 and a flow component C8 along the surface of the heat transfer tube 22.

[0066] The flows of the refrigerant which have the component C1, the component C3, the component C5, and the component C7 each advance in a space between the heat transfer tube 22 and the heat transfer tube 22 adjacent to each other in the Y direction. At this time, the refrigerant moves to be in contact with the lower surface of the heat transfer tube 22 located on the upper side, and the upper surface of the heat transfer tube 22 located on the lower side. The flows of the refrigerant which have the component C2 and the component C8 each move on the surface of the heat transfer tube 22 along the X direction. The flows of the refrigerant which have the component C4 and the component C6 each move on the surface of the heat transfer tube 22 in the direction opposite to the direction of the flows of the refrigerant which have the component C2 and the component C8. The refrigerant having these components makes heat exchange with the heat medium flowing inside the heat transfer tubes 22, on the surfaces of the heat transfer tubes 22, and evaporates. Unevaporated refrigerant drops toward the heat transfer tubes 22 located on the lower side.

[0067] FIG. 6 is a diagram illustrating moving directions and a dropping state of the refrigerant sprayed from the first nozzle 24a and the third nozzle 24c toward the plurality of heat transfer tubes 22. FIG. 6 illustrates a state as viewed in the Z direction, and illustrates a portion seen in front of the plane including the forefront heat transfer tubes 22, and a part of a portion seen behind the plane including the rearmost heat transfer tubes 22. In FIG. 6, arrows on the heat transfer tubes 22 represent a main moving direction of the sprayed refrigerant.

[0068] The spray flow of the refrigerant sprayed from the first nozzle 24a advances from the first side toward the second side in a direction between the Z direction and the X direction in a space between the heat transfer tube 22 and the heat transfer tube 22 adjacent to each other in the Y direction. The spray axis O1 is located between the heat transfer tube 22 and the heat transfer tube 22 in the Y direction. The spray flow of the refrigerant sprayed from the third nozzle 24c advances from the second side toward the first side in a direction between the Z direction and the X direction in a space between the heat transfer tube 22 and the heat transfer tube 22 adjacent to each other in the Y direction. The spray axis O3 is located between the heat transfer tube 22 and the heat transfer tube 22 in the Y direction.

[0069] At this time, a part (the component C2) of the refrigerant sprayed from the first nozzle 24a moves on the surface of the heat transfer tube 22 along the X direction. A part (the component C6) of the refrigerant sprayed from the third nozzle 24c moves on the surface of the heat transfer tube 22 along the X direction. The component C2 of flow of the refrigerant is a component in the direction opposite to the direction of the component C6 of flow of the refrigerant. When a moving speed in the X direction is reduced, dropping of the refrigerant toward the heat transfer tubes 22 located on the lower side is started. Meanwhile, components (the component C1 and the component C5) of flow of the refrigerant sprayed from the first nozzle 24a and the third nozzle 24c hardly reach the heat transfer tubes 22 located lower than these heat transfer tubes 22. Therefore, heat exchange is made by dropping of the refrigerant which has not been evaporated at the heat transfer tubes 22 located on the upper side. The same description can apply to the second nozzle 24b and the fourth nozzle 24d.

[0070] FIG. 7A is a diagram illustrating a positional relationship between a nozzle plane defined by the first nozzle 24a and the third nozzle 24c, and a nozzle plane defined by the second nozzle 24b and the fourth nozzle 24d. In FIG. 7A, for easy understanding, one of the first nozzles 24a, one of the second nozzles 24b, one of the third nozzles 24c, and one of the fourth nozzles 24d are merely illustrated. The third nozzle 24c and the second nozzle 24b are on the same nozzle plane. The three tiers of the heat transfer tubes 22 are disposed between the first nozzle 24a and the second nozzle 24b in the Y direction. Similarly, three tiers of the heat transfer tubes 22 are disposed between the third nozzle 24c and the fourth nozzle 24d in the Y direction.

[0071] The n-th nozzle plane is defined as an XZ plane that is defined by the spray axis O1 (not shown in FIG. 7A) of the first nozzle 24a and the spray axis O3 (not shown in FIG. 7A) of the third nozzle 24c. The heat transfer tube 22 positioned above the spray axis O1 of the first nozzle 24a is defined as a heat transfer tube 22a. The heat transfer tube 22 positioned below the spray axis O1 of the first nozzle 24a is defined as a heat transfer tube 22b. The heat transfer tube 22a and the heat transfer tube 22b are adjacent to each other in the Y direction. The n-th nozzle plane includes the lower surface of the heat transfer tube 22a and the upper surface of the heat transfer tube 22b. The (n+1)-th nozzle plane is defined as an XZ plane that is defined by the spray axis O2 (not shown in FIG. 7A) of the second nozzle 24b and the spray axis O4 (not shown in FIG. 7A) of the fourth nozzle 24d. The heat transfer tube 22 positioned above the spray axis O2 of the second nozzle 24b is defined as a heat transfer tube 22c. The heat transfer tube 22 positioned below the spray axis O2 of the second nozzle 24b is defined as a heat transfer tube 22d. The heat transfer tube 22c and the heat transfer tube 22d are adjacent to each other in the Y direction. The (n+1)-th nozzle plane includes the lower surface of the heat transfer tube 22c and the upper surface of the heat transfer tube 22d.

[0072] A predetermined number of tiers of the heat transfer tubes 22 are disposed between the n-th nozzle plane and the (n+1)-th nozzle plane.

[0073] FIG. 7B is a diagram illustrating a state of the refrigerant at each of the n-th nozzle plane and the (n+1)-th nozzle plane after the refrigerant is sprayed. In FIG. 7B, arrows represent a direction in which the refrigerant drops. By spraying the refrigerant from each of the first nozzle 24a, the second nozzle 24b, the third nozzle 24c, and the fourth nozzle 24d, a refrigerant sparse-dense state is generated on the n-th nozzle plane and the (n+1)-th nozzle plane, as shown in FIG. 7B. Specifically, on the n-th nozzle plane and the (n+1)-th nozzle plane, dense regions and sparse regions of the refrigerant are generated to be staggered.

[0074] More specifically, on the n-th nozzle plane, the refrigerant sufficiently reaches a region including the heat transfer tubes 22 near the first nozzle 24a and the third nozzle 24c by the components (the component C1 and the component C5) of flow of the refrigerant. The refrigerant sufficiently moves on the surfaces of the heat transfer tubes 22 by the components (the component C2 and the component C6) of flow of the refrigerant. Thus, as shown in FIG. 7B, a dense region of the refrigerant is generated on the n-th nozzle plane, and a liquid film of the refrigerant is formed. Similarly, on the (n+1)-th nozzle plane, the refrigerant sufficiently reaches a region including the heat transfer tubes 22 near the second nozzle 24b and the fourth nozzle 24d by the components (the component C3 and the component C7) of flow of the refrigerant. The refrigerant sufficiently moves on the surfaces of the heat transfer tubes 22 by the components (the component C4 and the component C8) of flow of the refrigerant. Thus, as shown in FIG. 7B, a dense region of the refrigerant is generated on the (n+1)-th nozzle plane, and a liquid film of the refrigerant is formed.

[0075] Meanwhile, on the n-th nozzle plane, an amount of the refrigerant reaching a region including the heat transfer tubes 22 located far from the first nozzle 24a and the third nozzle 24c is not sufficient, or the refrigerant does not reach the region. Therefore, as shown in FIG. 7B, a sparse region of the refrigerant is generated. Similarly, on the (n+1)-th nozzle plane, an amount of the refrigerant reaching a region including the heat transfer tubes 22 located far from the second nozzle 24b and the fourth nozzle 24d is not sufficient, or the refrigerant does not reach the region. Therefore, as shown in FIG. 7B, a sparse region of the refrigerant is generated. However, by dropping the unevaporated refrigerant from the dense region on the n-th nozzle plane to the sparse region on the (n+1)-th nozzle plane, the wet state in the sparse region is improved.

[1-3. Effect and the like]

[0076] As described above, in the present embodiment, on a projected image obtained by projecting the plurality of first nozzles 24a and the plurality of second nozzles 24b in the Z direction, the plurality of first nozzles 24a and the plurality of second nozzles 24b form a staggered arrangement pattern. On a projected image obtained by projecting the plurality of third nozzles 24c and the plurality of fourth nozzles 24d in the Z direction, the plurality of third nozzles 24c and the plurality of fourth nozzles 24d form a staggered arrangement pattern.

[0077] In such a configuration, the surfaces of the plurality of heat transfer tubes 22 can be made uniformly wet with the refrigerant sprayed by the plurality of first nozzles 24a to the fourth nozzles 24d. Thus, a dryout surface which is not reached by the refrigerant can be prevented from being generated. Therefore, the heat transfer performance of the evaporator 101 can be enhanced.

[0078] The present embodiment is particularly effective in a case where the number of lines of the heat transfer tubes 22 is large, and an amount of the refrigerant reaching some of the heat transfer tubes 22 from the nozzle 24 is small. According to the present embodiment, differences in a sparse/dense wet state on each nozzle plane can be improved by a superimposing effect of spray-type supply of the refrigerant and falling liquid film-type supply of the refrigerant, from both sides of the plurality of heat transfer tubes 22. Thus, generation of the dryout surface can be prevented. Furthermore, in a region where a spray flow of the refrigerant directly reaches and the heat transfer tubes 22 having surfaces on which the refrigerant moves is included, a heat transfer coefficient is increased by forced convection, whereby heat exchange efficiency can be further enhanced.

[0079] In the present embodiment, a plurality of tiers of the first nozzles 24a may be disposed. A plurality of tiers of the second nozzles 24b may be disposed. The number of tiers of the first nozzles 22a may be equal to or not equal to the number of tiers of the second nozzles 24b. A plurality of tiers of the third nozzles 24a may be disposed. A plurality of tiers of the second nozzles 24b may be disposed. The number of tiers of the third nozzles 22c may be equal to or not equal to the number of tiers of the fourth nozzles 24d. In such a configuration, even in a case where the number of tiers of the plurality of heat transfer tubes 22 is large, generation of a region where the refrigerant does not reach can be more sufficiently inhibited by dropping of the refrigerant to a nozzle plane located on the lower side.

[0080] In a case where three or more tiers of the plurality of first nozzles 24a are disposed along the Y direction, the distances between the first nozzles 24a adjacent to each other in the Y direction may be equal to each other, or may be different from each other. Such a configuration can apply also to the second nozzles 24b, the third nozzles 24c, and the fourth nozzles 24d. A distance between the first nozzle 24a and the second nozzle 24b in the Y direction may be half a distance between the first nozzles 24a adjacent to each other in the Y direction. A distance between the third nozzle 24c and the fourth nozzle 24d in the Y direction may be half a distance between the third nozzles 24c adjacent to each other in the Y direction.

[0081] In a planar view in the Z direction, the first nozzles 24a and the second nozzles 24b may be arranged in the form of a matrix. In a planar view in the Z direction, when four first nozzles 24a that form four vertexes of a quadrangular shape having the smallest area are selected, the second nozzle 24b can be positioned at the center portion of the quadrangular shape formed by the four first nozzles 24a. Similarly, in a planar view in the Z direction, when four second nozzles 24b are selected to form four vertexes of a quadrangular shape having the smallest area, the first nozzle 24a can be positioned at the center portion of the quadrangular shape formed by the four second nozzles 24b.

[0082] In a planar view in the Z direction, the third nozzles 24c and the fourth nozzles 24d may be arranged in the form of a matrix. In a planar view in the Z direction, when four third nozzles 24c that form four vertexes of a quadrangular shape having the smallest area are selected, the fourth nozzle 24d can be positioned at the center portion of the quadrangular shape formed by the four third nozzles 24c. Similarly, in a planar view in the Z direction, when four fourth nozzles 24d are selected to form four vertexes of a quadrangular shape having the smallest area, the third nozzle 24c can be positioned at the center portion of the quadrangular shape formed by the four fourth nozzles 24d.

[0083] Two or more tiers of the plurality of first nozzles 24a and two or more tiers of the plurality of second nozzles 24b may be disposed along the Y direction. In this case, a distance between the first nozzles 24a adjacent to each other in the Y direction may be greater than the distance W between the first nozzles 24a adjacent to each other in the X direction. A distance between the second nozzles 24b adjacent to each other in the Y direction may be greater than the distance W between the second nozzles 24b adjacent to each other in the X direction. Such a configuration is advantageous in that overlap of flow of the refrigerant in the Y direction is avoided.

[0084] Two or more tiers of the plurality of third nozzles 24c and two or more tiers of the plurality of fourth nozzles 24d may be disposed along the Y direction. In this case, a distance between the third nozzles 24c adjacent to each other in the Y direction may be greater than the distance W between the third nozzles 24c adjacent to each other in the X direction. A distance between the fourth nozzles 24d adjacent to each other in the Y direction may be greater than the distance W between the fourth nozzles 24d adjacent to each other in the X direction. Such a configuration is advantageous in that overlap of flow of the refrigerant in the Y direction is avoided.

[0085] Two or more tiers of the plurality of first nozzles 24a and two or more tiers of the plurality of second nozzles 24b may be disposed along the Y direction. In this case, a distance between the first nozzles 24a adjacent to each other in the Y direction may be equal to a distance between the second nozzles 24b adjacent to each other in the Y direction. A distance between the first nozzle 24a and the second nozzle 24b in the Y direction may be half a distance between the first nozzles 24a adjacent to each other in the Y direction. In such a configuration, the above-described effects can be more sufficiently obtained.

[0086] Two or more tiers of the plurality of third nozzles 24c and two or more tiers of the plurality of fourth nozzles 24d may be disposed along the Y direction. In this case, a distance between the third nozzles 24c adjacent to each other in the Y direction may be equal to a distance between the fourth nozzles 24d adjacent to each other in the Y direction. A distance between the third nozzle 24c and the fourth nozzle 24d in the Y direction may be half a distance between the third nozzles 24c adjacent to each other in the Y direction. In such a configuration, the above-described effects can be more sufficiently obtained.

[0087] The refrigeration cycle device 100 of the present embodiment includes the shell-and-tube heat exchanger of the present embodiment. The shell-and-tube heat exchanger may be used for the evaporator 101 or may be used for the condenser 103. By using the shell-and-tube heat exchanger of the present embodiment, the efficiency of the refrigeration cycle device 100 can be enhanced.

(Embodiment 2)

[0088] Embodiment 2 will be described below with reference to FIG. 8 to FIG. 10. The same components as those in Embodiment 1 are denoted by the same reference characters, and detailed description thereof is omitted.

[2-1. Configuration of evaporator]

[0089] FIG. 8 is a transverse cross-sectional view of an evaporator 111 according to Embodiment 2 of the present disclosure. FIG. 8 corresponds to FIG. 3 for Embodiment 1. The evaporator 111 of the present embodiment has the same configuration as the evaporator 101 of Embodiment 1 except that the evaporator 111 does not include the plurality of third nozzles 24c and the plurality of fourth nozzles 24d, and the number of lines of the plurality of heat transfer tubes 22 is six.

[0090] FIG. 9 is a side view of the evaporator 111 as taken along a line IX-IX. In FIG. 9, components other than the heat transfer tubes 22 and the nozzles 24 are omitted. As shown in FIG. 9, on a projected image obtained by projecting the plurality of first nozzles 24a and the plurality of second nozzles 24b in the Z direction, the plurality of first nozzles 24a and the plurality of second nozzles 24b form a staggered arrangement pattern.

[0091] FIG. 10A is a cross-sectional view of the evaporator 111 as taken along a line XA-XA. FIG. 10B is a cross-sectional view of the evaporator 111 as taken along a line XB-XB. In FIG. 10A and FIG. 10B, components other than the heat transfer tubes 22 and the nozzles 24 are omitted.

[2-2. Operation]

[0092] As described for Embodiment 1, by actuating the circulation pump 26, a liquid phase refrigerant is supplied from the bottom of the shell 21 through the header 23 to the plurality of first nozzles 24a and the plurality of second nozzles 24b. The liquid phase refrigerant is sprayed from each of first nozzles 24a and the second nozzles 24b to the plurality of heat transfer tubes 22.

[0093] The moving direction and the dropping state of the refrigerant sprayed from each of the first nozzles 24a and the plurality of second nozzles 24b are as described for Embodiment 1.

[2-3. Effect and the like]

[0094] The present embodiment is effective also in a case where the number of lines of the heat transfer tubes 22 is small. According to the present embodiment, differences in a sparse/dense wet state on each nozzle plane can be improved by a superimposing effect of spray-type supply of the refrigerant and falling liquid film-type supply of the refrigerant. Thus, generation of the dryout surface can be prevented.

[0095] In the present embodiment, a plurality of tiers of the first nozzles 24a may be disposed. A plurality of tiers of the second nozzles 24b may be disposed. The number of tiers of the first nozzles 22a may be equal to or not equal to the number of tiers of the second nozzles 24b. For such a configuration, the same description as for Embodiment 1 can be applied.

(Another embodiment)

[0096] In the above-described Embodiment 1, the plurality of first nozzles 24a and the plurality of third nozzles 24c are disposed to define the same nozzle plane. The plurality of second nozzles 24b and the plurality of fourth nozzles 24d are disposed to define the same nozzle plane. The plurality of first nozzles 24a and the plurality of third nozzles 24c may be disposed on different nozzle planes. The plurality of second nozzles 24b and the plurality of fourth nozzles 24d may be disposed on different nozzle planes. That is, the position of the first nozzle 24a in the Y direction may be different from the position of the third nozzle 24c in the Y direction. The position of the second nozzle 24b in the Y direction may be different from the position of the fourth nozzle 24d in the Y direction. On a projected image obtained by projecting the plurality of first nozzles 24a, the plurality of third nozzles 24c, the plurality of second nozzles 24b, and the plurality of fourth nozzles 24d in the Z direction, the plurality of first nozzles 24a, the plurality of third nozzles 24c, the plurality of second nozzles 24b, and the plurality of fourth nozzles 24d may form a staggered arrangement pattern.

(Embodiment 3)

[0097] Embodiment 3 will be described below with reference to FIG. 11 to FIG. 16.

[3-1. Configuration]

[0098] FIG. 11 illustrates a configuration of a refrigeration cycle device 200 including a shell-and-tube heat exchanger. As shown in FIG. 11, the refrigeration cycle device 200 includes an evaporator 201, a compressor 202, a condenser 203, a flow valve 204, a flow path 210a, a flow path 210b, a flow path 210c, and a flow path 210d. The outlet of the evaporator 201 is connected to the inlet of the compressor 202 through the flow path 210a. The outlet of the compressor 202 is connected to the inlet of the condenser 203 through the flow path 210b. The outlet of the condenser 203 is connected to the inlet of the flow valve 204 through the flow path 210c. The outlet of the flow valve 204 is connected to the inlet of the evaporator 201 through the flow path 210d. The flow paths 210a and 210b are paths through which a gas phase refrigerant passes. The flow path 210c and the flow path 210d are paths through which a liquid phase refrigerant passes. Each path is, for example, formed of at least one metal tube.

[0099] In the evaporator 201, a liquid phase refrigerant is heated and evaporated, and a gas phase refrigerant is generated. The gas phase refrigerant is suctioned into the compressor 202 and compressed. The compressed gas phase refrigerant is supplied from the compressor 202 to the condenser 203. The gas phase refrigerant is cooled, and condensed and liquefied in the condenser 203. Thus, a liquid phase refrigerant is generated. The liquid phase refrigerant is returned from the condenser 203 through the flow valve 204 to the evaporator 201.

[0100] The refrigerant for the refrigeration cycle device 200 is not limited to a specific refrigerant. Examples of the refrigerant include a fluorocarbon refrigerant, a low GWP (global warming potential) refrigerant, and a natural refrigerant. Examples of the fluorocarbon refrigerant include hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC). Examples of the low GWP refrigerant include HFO-1234yf and water. Examples of the natural refrigerant include carbon dioxide and water.

[0101] The refrigerant may be a refrigerant that contains, as a main component, a substance of which the saturated vapor pressure is a negative pressure at ordinary temperature. Examples of such a refrigerant include a refrigerant that contains water, alcohol, or ether as a main component. The "main component" represents a component having the largest content at a mass ratio. The "negative pressure" represents a pressure which is lower than atmospheric pressure on an absolute pressure basis. The "ordinary temperature" represents a temperature in a range of 20°C±15°C according to the Japanese Industrial Standard (JIS Z8703).

[0102] The evaporator 201 is configured by a shell-and-tube heat exchanger as described below.

[0103] The compressor 202 may be a dynamic compressor such as a centrifugal compressor or a positive displacement compressor such as a scroll compressor,

[0104] The type of the condenser 203 is not limited to a specific type. A heat exchanger such as a plate heat exchanger and a shell-and-tube heat exchanger can be used for the condenser 203.

[0105] The refrigeration cycle device 200 is, for example, a business-use or home-use air conditioner. A heat medium cooled by the evaporator 201 is supplied through a circuit 205 into a room, and used for cooling the room. Alternatively, a heat medium heated by the condenser 203 is supplied through a circuit 206 into a room, and used for heating the room. The heat medium is, for example, water. The refrigeration cycle device 200 is not limited to an air conditioner, and may be another device such as a chiller and a heat storage device. The refrigeration cycle device 200 may be an absorption refrigerator that includes an evaporator, an absorber, a regenerator, and a condenser.

[0106] The circuit 205 is a circuit for circulating a heat medium in the evaporator 201. The circuit 206 is a circuit for circulating a heat medium in the condenser 203. The circuit 205 and the circuit 206 may be sealed circuits isolated from outside air.

[0107] The heat medium is a fluid that flows in each of the circuit 205 and the circuit 206. The heat medium is not limited to water, and may be liquid such as oil or brine, or may be gas such as air. A composition of the heat medium in the circuit 205 may be different from a composition of the heat medium in the circuit 206.

[0108] FIG. 12 is a longitudinal cross-sectional view of the evaporator 201 as taken at a line II-II in FIG. 11 as a cutting plane line. As shown in FIG. 12, the evaporator 201 is configured as a shell-and-tube heat exchanger. The evaporator 201 includes a shell 221, a heat transfer tube group 222, and nozzles 224. The heat transfer tube group 222 is disposed inside the shell 221. The nozzle 224 sprays a liquid phase refrigerant toward the heat transfer tube group 222. The heat transfer tube group 222 is, for example, formed by heat transfer tubes 222p disposed in parallel with each other. For example, the cross-section perpendicular to the longitudinal direction of the heat transfer tube 222p has a round shape. Grooves may be formed at the inner surface of the heat transfer tube 222p, the outer surface of the heat transfer tube 222p, or both of them.

[0109] As shown in FIG. 12, the shell 221 has, for example, a rectangular cross-sectional shape. The shell 221 may have a round cross-sectional shape. The shell 221 may be a pressure-resistant container.

[0110] For example, the evaporator 201 further includes a header 223, a circulation circuit 225, a pump 226, an inflow tube 227a, an outflow tube 227b, a first cover 229a, and a second cover 229b.

[0111] The nozzle 224 is connected to the circulation circuit 225 through the header 223. The pump 226 is disposed in the circulation circuit 225. A liquid phase refrigerant is stored at the bottom of the shell 221. By operation of the pump 226, the liquid phase refrigerant stored at the bottom of the shell 221 is supplied through the circulation circuit 225 and the header 223 to the nozzle 224.

[0112] The inflow tube 227a and the outflow tube 227b are attached to the shell 221. The inflow tube 227a forms a flow path for introducing the refrigerant into the shell 221. The discharge tube 227b forms a flow path for introducing a gas phase refrigerant generated in the evaporator 201, to the outside of the shell 221. The flow path 210d and the flow path 210a can be connected to flow paths formed by the inflow tube 227a and the discharge tube 227b, respectively.

[0113] The first cover 229a is attached to the shell 221 and covers one end portion of the heat transfer tube group 222 in the longitudinal direction (X-axis direction) of the heat transfer tube 222p. The second cover 229b is attached to the shell 221 and covers the other end portion of the heat transfer tube group 222 in the longitudinal direction of the heat transfer tube 222p. The first cover 229a has two partitions 229c thereinside. The second cover 229b has one partition 229d thereinside. The first cover 229a has, for example, a secondary-side inflow port 228a and a secondary-side outflow port 228b. Each of the secondary-side inflow port 228a and the secondary-side outflow port 228b may be formed at the second cover 229b. The number of passes in the evaporator 201 is incremented by "1" each time the flowing direction of the heat medium in the heat transfer tube 222p is inverted at the flow path cover 229a or 229b. In the present embodiment, the flow path cover 229a has the secondary-side inflow port 228a and the secondary-side outflow port 228b such that the number of passes is "4".

[0114] As shown in FIG. 12, the evaporator 201 includes a plurality of the nozzles 224. The plurality of the nozzles 224 are disposed at predetermined intervals in the longitudinal direction (X-axis direction) of the heat transfer tube 222p. Furthermore, the plurality of the nozzles 224 are disposed in the longitudinal direction of the heat transfer tube 222p alternately on a pair of straight lines parallel to the Y-axis direction. Each nozzle 224 is, for example, disposed to spray the liquid phase refrigerant toward between the heat transfer tubes 222p adjacent to each other in the Y-axis direction.

[0115] FIG. 13A and FIG. 13B each illustrate a spray pattern of the liquid phase refrigerant sprayed from the nozzle 224. As shown in FIG. 13A and FIG. 13B, the nozzle 224 sprays the liquid phase refrigerant to form a flat spray pattern having a spray axis Am. The spray axis Am can be regarded as the central axis of the nozzle 224. The spray axis Am can be an axis that passes through the center of the opening of the nozzle 224. As shown in FIG. 13A, the liquid phase refrigerant sprayed from the nozzle 224 forms a sector-shaped spray area M. A spray region S appearing when the spray pattern is projected on a plane H perpendicular to the spray axis

Am has a flat shape. The liquid phase refrigerant sprayed with such a spray pattern passes between the heat transfer tubes 222p.

[0116] FIG. 14 is a longitudinal cross-sectional view of the evaporator 201 as taken at a line IV-IV in FIG. 11 as a cutting plane line. In the heat transfer tube group 222, the number of the heat transfer tubes 222p arranged in the Z-axis direction is not limited to a specific value. In the heat transfer tube group 222, for example, twelve heat transfer tubes 222p are arranged in the Z-axis direction. The nozzle 224 sprays the liquid phase refrigerant such that the spray axis Am passes between a pair of the heat transfer tubes 222p closest to the nozzle 224 in the direction (Z-axis direction) perpendicular to the longitudinal direction of the heat transfer tube 222p, and the spray region S passes between the pair of the heat transfer tubes 222p. For example, the spray axis Am extends horizontally.

[0117] As shown in FIG. 14, the nozzle 224 is, for example, disposed only at one end portion of the heat transfer tube group 222 in the Z-axis direction, and is not disposed at the other end portion of the heat transfer tube group 222 in the Z-axis direction. Therefore, the nozzle 224 sprays the liquid phase refrigerant in, for example, the Z-axis positive direction at a plane (YZ plane) perpendicular to the longitudinal direction of the heat transfer tube 222p.

[0118] FIG. 15 illustrates a region over which the liquid phase refrigerant is sprayed from the nozzle 224. In FIG. 15, the heat transfer tube group 222 and the spray area M of the liquid phase refrigerant sprayed from the nozzle 224 are seen along the Y-axis direction. The nozzle 224 is, for example, disposed to be distant over a distance L from the closest heat transfer tube 222p in the heat transfer tube group 222 in the Z-axis direction. The spray area M has a first contour line W1 and a second contour line W2 that form a central angle α. The central angle α is not limited to a specific angle. The central angle α is, for example, greater than or equal to 90° and less than or equal to 120°.

[0119] FIG. 16 is a diagram illustrating a state where a liquid phase refrigerant is sprayed and flows from the nozzle 224 toward the heat transfer tube group 222. As shown in FIG. 16, the heat transfer tube group 222 includes a first tier 222a and a second tier 222b. The first tier 222a has a plurality of the heat transfer tubes 222p arranged along a first plane. The second tier 222b has a plurality of the heat transfer tubes 222p arranged along a second plane parallel to the first plane, and is adjacent to the first tier 222a in the direction (Y-axis direction) perpendicular to the first plane. The first plane and the second plane are planes parallel to the ZX plane.

[0120] As shown in FIG. 16, for example, an imaginary plane, which does not intersect a tangible object in a space from one end to the other end of the first tier 222a in a direction in which the heat transfer tubes 222p of the first tier 222a are arranged, is between the first tier 222a and the second tier 222b.

[0121] As shown in FIG. 16, for example, the heat transfer tubes 222p in the first tier 222a and the plurality of heat transfer tubes 222p in the second tier 222b form a rectangular grid, a square grid, or a parallelogram grid on a third plane perpendicular to the longitudinal direction (X-axis direction) of the heat transfer tube 222p. The third plane is a plane parallel to the YZ plane.

[0122] As shown in FIG. 16, the spray axis Am of the spray pattern of the liquid phase refrigerant sprayed from the nozzle 224 passes between a first end portion 222j of each of the heat transfer tubes 222p in the first tier 222a and a second end portion 222k of each of the heat transfer tubes 222p in the second tier 222b. The first end portion 222j is an end portion close to the second tier 222b in the direction (Y-axis direction) perpendicular to the first plane. The second end portion 222k is an end portion close to the first tier 222a in the direction (Y-axis direction) perpendicular to the first plane. The spray pattern of the liquid phase refrigerant sprayed from the nozzle 224 passes between the first tier 222a and the second tier 222b.

[0123] The second tier 222b is, for example, disposed below the first tier 222a in the gravitational direction. The heat transfer tube group 222 includes, for example, a lower heat transfer tube group 222c. The lower heat transfer tube group 222c has a plurality of the heat transfer tubes 222p, and is disposed below the second tier 222b in the gravitational direction. Each of the heat transfer tubes 222p of the lower heat transfer tube group 222c is disposed, for example, directly below any of the plurality of heat transfer tubes 222p in the second tier 222b.

[0124] As shown in FIG. 16, for example, the plurality of heat transfer tubes 222p of the lower heat transfer tube group 222c and the plurality of heat transfer tubes 222p in the second tier 222b form a rectangular grid or a square grid on the third plane.

[3-2. Operation]

[0125] An operation and an effect of the evaporator 201 configured as a shell-and-tube heat exchanger as described above, will be described below.

[0126] In a steady operation of the refrigeration cycle device 200, in the evaporator 201, the pump 226 operates, and the liquid phase refrigerant is supplied through the circulation circuit 225 and the header 223 to the nozzle 224. Thus, the liquid phase refrigerant is sprayed from the nozzle 224 toward the heat transfer tube group 222. Meanwhile, the heat medium is introduced from the outside of the evaporator 201 through the secondary-side inflow port 228a into the first cover 229a. Subsequently, the heat medium passes in the heat transfer tube 222p in the X-axis positive direction, and is introduced to a space below the partition 229d inside the second cover 229b. Inside the second cover 229b, the flow direction of the heat medium is inverted, and the heat medium passes in the heat transfer tube 222p in the X-axis negative direction, and is introduced to a space between the two partitions 229c inside the first cover 229a. Subsequently, inside the first cover 229a, the flow direction of the heat medium is inverted, and the heat medium passes in the heat transfer tube 222p in the X-axis positive direction, and is introduced to a space above the partition 229d inside the second cover 229b. Inside the second cover 229b, the flow direction of the heat medium is inverted, and the heat medium passes in the heat transfer tube 222p in the X-axis negative direction, and is introduced into the first cover 229a. Thereafter, the heat medium is introduced to the outside of the evaporator 201 through the secondary-side outflow port 228b.

[0127] As shown in FIG. 14, the nozzle 224 sprays the liquid phase refrigerant toward a space between two tiers of the heat transfer tubes adjacent to each other in the Y-axis direction. The liquid phase refrigerant is sprayed to form a spray pattern in which the spray axis Am extends between the two tiers. The liquid phase refrigerant generated in the form of mist by spraying the liquid phase refrigerant is adhered to the outer surfaces of the heat transfer tubes 222p. Through heat exchange between the heat medium inside the heat transfer tube 222p and the liquid phase refrigerant adhered to the outer surface of the heat transfer tube 222p, the liquid phase refrigerant evaporates and a gas phase refrigerant is generated. The liquid phase refrigerant that has not been evaporated flows along the outer surfaces of the heat transfer tubes 222p, and drops toward the heat transfer tubes 222p disposed on the lower side.

[0128] As shown in FIG. 15, for example, when the first tier 222a is seen in the direction (Y-axis direction) perpendicular to the first plane, a spray pattern of the liquid phase refrigerant is formed such that the spray axis Am extends perpendicular to the central axis Ax of the heat transfer tube 222p in the first tier 222a. The distance L between the nozzle 224 and the heat transfer tube 222p closest to the nozzle 224 in the Z-axis direction in the heat transfer tube group 222, has a predetermined value. Therefore, the spray area M of the liquid phase refrigerant is gradually increased from the heat transfer tube 222p at the forefront line in the first tier 222a toward the heat transfer tube 222p at the rearmost line therein, and a sufficient range of the outer surface of the heat transfer tube 222p at the rearmost line in the first tier 222a is wet with the liquid phase refrigerant.

[0129] As shown in FIG. 16, the liquid phase refrigerant sprayed from the nozzle 224 passes between the heat transfer tubes 222p in the first tier 222a and the heat transfer tubes 222p in the second tier 222b, which are disposed to form a rectangular grid, a square grid, or a parallelogram grid on the third plane. A member such as a heat transfer tube that directly hinders advance of the liquid phase refrigerant sprayed from the nozzle 224 is not present between the first tier 222a and the second tier 222b. Therefore, the liquid phase refrigerant sprayed from the nozzle 224 easily flows straight between the first tier 222a and the second tier 222b. Meanwhile, a part of the liquid phase refrigerant sprayed from the nozzle 224 comes into contact with the first end portion 222j of the heat transfer tube 222p in the first tier 222a and the second end portion 222k of the heat transfer tube 222p in the second tier 222b. A part of the liquid phase refrigerant in contact with the heat transfer tube 222p in the first tier 222a flows in the Y-axis positive direction along the front edge of the heat transfer tube 222p with respect to flow of the liquid phase refrigerant. Meanwhile, a part of the liquid phase refrigerant in contact with the heat transfer tube 222p in the second tier 222b flows in the Y-axis negative direction along the front edge of the heat transfer tube 222p. In addition, another part of the liquid phase refrigerant flows in the Y-axis negative direction along the rear edge of the heat transfer tube 222p in the second tier 222b. Such flow of the liquid phase refrigerant is generated around the heat transfer tubes 222p in each line in the first tier 222a and the second tier 222b.

[0130] As shown in FIG. 16, in an upper heat transfer tube group 222m formed by the first tier 222a and the second tier 222b, the liquid phase refrigerant comes into direct contact with the outer surfaces of the heat transfer tubes 222p, heat transfer involving forced convection is generated, and heat exchange between the liquid phase refrigerant and the heat medium is promoted.

[0131] On the outer surfaces of the heat transfer tubes 222p in the second tier 222b, the liquid phase refrigerant forms a liquid film while flowing in the Y-axis negative direction, and a part of the liquid phase refrigerant forming the liquid film evaporates. An unevaporated liquid phase refrigerant which has not been able to evaporate in the upper heat transfer tube group 222m is dropped from the lowermost portion of the heat transfer tubes 222p in the second tier 222b toward the heat transfer tubes 222p of the lower heat transfer tube group 222c. The dropped liquid phase refrigerant flows downward while forming a liquid film on the outer surfaces of the heat transfer tubes 222p, a part of the liquid phase refrigerant evaporates, and another part of the liquid phase refrigerant is dropped further toward the heat transfer tubes 222p disposed on the lower side. Such flow and drop of the liquid phase refrigerant is generated around the heat transfer tubes 22p in each line of the lower heat transfer tube group 222c. Thus, the liquid phase refrigerant sprayed from the nozzle 224 is dropped and indirectly supplied, from the heat transfer tubes 222p of the upper heat transfer tube group 222m, around the heat transfer tubes 222p of the lower heat transfer tube group 222c. The liquid phase refrigerant that has remained after the dropping is stored at the bottom of the shell 221.

[0132] The liquid phase refrigerant sprayed from the nozzle 224 is directly supplied around the heat transfer tubes 222p of the upper heat transfer tube group 222m, and forced convection is generated. The nozzle 224 sprays the liquid phase refrigerant to form a flat spray pattern having the spray axis Am, so that the liquid phase refrigerant is likely to flow straight between the first tier 222a and the second tier 222b. Thus, in the upper heat transfer tube group 222m, forced convection of the liquid phase refrigerant is likely to be generated also around the heat transfer tubes 222p far from the nozzle 224. Therefore, the outer surfaces of the heat transfer tubes 222p far from the nozzle 224 are likely to be wet with the liquid phase refrigerant, and dryout is unlikely to occur on the outer surfaces of the far heat transfer tubes 222p.

[0133] In addition, the liquid phase refrigerant is dropped from the heat transfer tubes 222p of the upper heat transfer tube group 222m toward the lower heat transfer tube group 22c. Therefore, in the lower heat transfer tube group 222c, a liquid film of the liquid phase refrigerant is likely to be formed also on the outer surfaces of the heat transfer tubes 222p far from the nozzle 224. Therefore, the outer surfaces of the heat transfer tubes 22p disposed far from the nozzle 224 are likely to be wet with the liquid phase refrigerant, and dryout is unlikely to occur on the outer surfaces of the far heat transfer tubes 222p.

[3-3. Effect and the like]

[0134] As described above, in the present embodiment, the evaporator 201 configured as a shell-and-tube heat exchanger includes the shell 221, the heat transfer tube group 222, and the nozzle 224. The heat transfer tube group 222 is disposed inside the shell 221. The nozzle 224 sprays a liquid phase refrigerant toward the heat transfer tube group 222. The heat transfer tube group 222 includes the first tier 222a and the second tier 222b. The first tier 222a has the plurality of heat transfer tubes 222p arranged along the first plane. The second tier 222b has the plurality of heat transfer tubes 222p arranged along the second plane parallel to the first plane, and is adjacent to the first tier 222a in the direction perpendicular to the first plane. The nozzle 224 sprays a liquid phase refrigerant to form a flat spray pattern that has the spray axis Am and that passes between the first tier 222a and the second tier 222b. The spray axis Am passes between the first end portion 222j of each of the heat transfer tubes 222p in the first tier 222a, and the second end portion 222k of each of the heat transfer tubes 222p in the second tier 222b. The first end portion 222j is an end portion, which is close to the second tier 222b in the direction perpendicular to the first plane, of each of the heat transfer tubes 222p in the first tier 222a. The second end portion 222k is an end portion, which is close to the first tier 222a in the direction perpendicular to the first plane, of each of the heat transfer tubes 222p in the second tier 222b.

[0135] Thus, since the nozzle 224 sprays a liquid phase refrigerant to form a flat spray pattern having the spray axis Am, the liquid phase refrigerant is likely to flow straight between the first tier 222a and the second tier 222b. Therefore, in the first tier 222a and the second tier 222b, forced convection of the liquid phase refrigerant is likely to be generated also around the heat transfer tubes 222p far from the nozzle 224. As a result, the outer surfaces of the heat transfer tubes 222p far from the nozzle 224 are likely to be wet with the liquid phase refrigerant, and dryout is unlikely to occur on the outer surfaces of the far heat transfer tubes 222p.

[0136] As in the present embodiment, an imaginary plane that does not intersect a tangible object in a space from one end to the other end of the first tier 222a in the direction in which the heat transfer tubes 222p in the first tier 222a are arranged may be between the first tier 222a and the second tier 222b. Thus, the liquid phase refrigerant is likely to flow straight from one end to the other end of the first tier 222a between the first tier 222a and the second tier 222b, and dryout is more assuredly inhibited from occurring on the outer surfaces of the far heat transfer tubes 222p.

[0137] As in the present embodiment, the plurality of heat transfer tubes 222p in the first tier 222a and the plurality of heat transfer tubes 222p in the second tier 222b may form a rectangular grid, a square grid, or a parallelogram grid on the third plane perpendicular to the longitudinal direction of the heat transfer tube 222p. Thus, the liquid phase refrigerant between the first tier 222a and the second tier 222b is likely to flow stably and flow straight. As a result, dryout is more assuredly inhibited from occurring on the outer surfaces of the far heat transfer tubes 222p.

[0138] As in the present embodiment, the second tier 222b may be disposed below the first tier 222a in the gravitational direction. In addition, the heat transfer tube group 222 may include the lower heat transfer tube group 222c which has the plurality of heat transfer tubes 222p, and is disposed below the second tier 222b in the gravitational direction. Thus, the liquid phase refrigerant is dropped from the second tier 222b toward the lower heat transfer tube group 222c, and the outer surfaces of the heat transfer tubes 222p far from the nozzle 224 are likely to be also wet with the liquid phase refrigerant in the lower heat transfer tube group 222c. As a result, dryout is unlikely to occur on the outer surfaces of the far heat transfer tubes 222p in the lower heat transfer tube group 222c. In this case, the plurality of heat transfer tubes 222p in the first tier 222a and the plurality of heat transfer tubes 222p in the second tier 222b may form a rectangular grid or a square grid on the third plane perpendicular to the longitudinal direction of the heat transfer tube 222p. Thus, the liquid phase refrigerant is likely to be more assuredly dropped toward the lower heat transfer tube group 222c.

[0139] As in the present embodiment, the plurality of heat transfer tubes 222p of the lower heat transfer tube group 222c and the plurality of heat transfer tubes 222p in the second tier 222b form a rectangular grid or a square grid on the third plane. Thus, the liquid phase refrigerant dropped from the plurality of heat transfer tubes 222p in the second tier 222b more assuredly form a liquid film on the outer surface of each heat transfer tube 222p of the lower heat transfer tube group 222c, and the outer surface thereof is likely to be made wet. As a result, dryout is more assuredly inhibited from occurring on the outer surfaces of the far heat transfer tubes 222p in the lower heat transfer tube group 222c.

[0140] As in the present embodiment, the refrigeration cycle device 200 that includes the evaporator 201 configured as a shell-and-tube heat exchange can be provided. Dryout is unlikely to occur on the outer surfaces of the heat transfer tubes 222p far from the nozzle 224. Therefore, the refrigeration cycle device 200 is likely to have high coefficient of performance (COP).

[0141] The present embodiment can provide a heat exchange method including the following matters (I) and (II).

(I) The heat medium is caused to pass in the heat transfer tube group 222 that includes the first tier 222a and the second tier 222b. The first tier 222a has the plurality of heat transfer tubes arranged along the first plane. The second tier 222b has the plurality of heat transfer tubes 222p arranged along the second plane parallel to the first plane, and is adjacent to the first tier 222a in the direction perpendicular to the first plane.

(II) A liquid phase refrigerant is sprayed toward the heat transfer tube group 222 to form a flat spray pattern that has the spray axis Am and that passes between the first tier 222a and the second tier 222b, to cause heat exchange between the heat medium and the liquid phase refrigerant. The spray axis Am passes between the first end portion 222j, which is close to the second tier 222b, of each of the heat transfer tubes 222p in the first tier 222a and the second end portion 222k, which is close to the first tier 222a, of each of the heat transfer tubes 222p in the second tier 222b.

(Embodiment 4)

[0142] Embodiment 4 will be described below with reference to FIG. 17. The configuration of Embodiment 4 is the same as the configuration of Embodiment 3 except for the particularly described matter. The components of Embodiment 4 which are the same as or correspond to the components of Embodiment 3 are denoted by the same reference signs, and the detailed description thereof is omitted. The description for Embodiment 3 also applies to Embodiment 4 as long as there is no technical contradiction.

[4-1. Configuration]

[0143] FIG. 17 illustrates a region over which a liquid phase refrigerant is sprayed from the nozzle 224 in Embodiment 4. In FIG. 17, the heat transfer tube group 222 and the spray area M of a liquid phase refrigerant sprayed from the nozzle 224 are seen along the Y-axis direction. As shown in FIG. 17, when the first tier 222a is seen along the direction (Y-axis direction) perpendicular to the first plane, the spray axis Am of the spray pattern of the liquid phase refrigerant sprayed from the nozzle 224 forms an acute angle θ having a predetermined value relative to a straight line P. The straight line P extends perpendicular to the longitudinal direction (X-axis direction) of the heat transfer tube 222p in the first tier 222a.

[0144] The acute angle θ is not limited to an angle having a specific value. The acute angle θ is, for example, $\alpha/2$. α represents the central angle of the spray area M. For example, the central angle α is 80°, and the acute angle θ is 40°.

[4-2. Operation]

[0145] An operation and an effect of Embodiment 2 having the above-described configuration will be described below.

[0146] As shown in FIG. 17, a liquid phase refrigerant is sprayed from the nozzle 224 such that the spray axis Am forms the acute angle θ relative to the straight line P. Also in a case where the nozzle 224 is disposed near the heat transfer tube group 222, a range of the heat transfer tube group 222 overlapping the spray area M is likely to be large on the XZ plane. For example, a first contour line W1 of the spray area M is likely to extend along the straight line P, and a second contour line W2 of the spray area M is likely to extend along the central axis Ax of the heat transfer tube 22p.

[0147] A case where the nozzle 224 is disposed such that the spray axis Am is parallel to the straight line P, in other words, a case where the nozzle 224 is disposed such that the spray axis Am is perpendicular to the central axis Ax of the heat transfer tube 222p, will be considered. In this case, in a case where a distance L is short, and the nozzle 224 is disposed near the heat transfer tube group 222, a range over which the spray area M and the heat transfer tubes 222p close to the nozzle 224 in the heat transfer tube group 222 overlap each other becomes small on the XZ plane. Particularly, a portion distant from the nozzle 224 in the longitudinal direction of the heat transfer tube 222p is unlikely to overlap the spray area M. Thus, on the outer surfaces of the heat transfer tubes 222p of the heat transfer tube group 222, a portion which is unlikely to be reached by the liquid phase refrigerant sprayed from the nozzle 224 is likely to be generated. Meanwhile, according to the present embodiment, occurrence of such a state can be inhibited. Therefore, a wide range of the outer surfaces of the heat transfer tubes 222p of the heat transfer tube group 222 can be made wet with the liquid phase refrigerant, and dryout is unlikely to occur on the outer surfaces of the heat transfer tubes 222p.

[0148] As shown in FIG. 17, in a case where the liquid phase refrigerant is sprayed such that the spray axis Am forms the acute angle θ relative to the straight line P, the liquid phase refrigerant sprayed from the nozzle 224 forms a flow C1 and a flow C2. The flow C1 is a flow of the liquid phase refrigerant which passes between the heat transfer tube 222p in the first tier 222a and the heat transfer tube 222p in the second tier 222b. The flow C2 is a flow of the liquid phase refrigerant which collides with the front edge of the outer surface of the heat transfer tube 222p and moves along the longitudinal direction (X-axis direction) of the heat transfer tube 222p. A part of the liquid phase refrigerant sprayed from the nozzle 224 collides with the front edge of the outer surface of the heat transfer tube 222p in a state where the part of the liquid phase refrigerant has a velocity component in the X-axis direction. Therefore, such a flow of the liquid phase refrigerant is generated.

[0149] The flow C1 is a flow of the liquid phase refrigerant which is sprayed from the nozzle 224 and spreads to form the spray area M having the central angle α. The liquid phase refrigerant in the flow C1 passes between the first tier 222a and the second tier 222b while coming into contact with the first end portions 222j of the plurality of heat transfer tubes 222p in the first tier 222a or the second end portions 222k of the plurality of heat transfer tubes 222p in the second tier 222b.

[0150] Generation of the flow C1 and the flow C2 causes not only movement of the liquid phase refrigerant in the direction (Z-axis direction) in which the heat transfer tubes 222p are arranged in the first tier 222a, but also movement of the liquid phase refrigerant in the longitudinal direction (X-axis direction) of the heat transfer tube 22p. Therefore, heat transfer involving forced convection is promoted. In addition, as described above, a wide range of the outer surfaces of the heat transfer tubes 222p of the heat transfer tube group 222, which include the heat transfer tubes 222p close to the nozzle 224, is wet with the liquid phase refrigerant.

[4-3. Effect and the like]

[0151] As described above, in the present embodiment, when the first tier 222a is seen along the direction (Y-axis direction) perpendicular to the first plane, the spray axis Am forms the acute angle θ having a predetermined value relative to the straight line P.

[0152] Thus, even in a case where the nozzle 224 is disposed near the heat transfer tube group 222, a wide range of the outer surfaces of the heat transfer tubes 222p of the heat transfer tube group 222 can be made wet with the liquid phase refrigerant, and dryout is unlikely to occur on the outer surfaces of the heat transfer tubes 222p.

[0153] For example, a pressure at which the liquid phase refrigerant is supplied to the nozzle 224 is considered to be reduced to cope with an operation of the refrigeration cycle device 200 under a low load condition. In this case, the central angle of the spray pattern of the liquid phase refrigerant sprayed from the nozzle 224 becomes small, and the spray area M may become narrow. Furthermore, a flow rate of the liquid phase refrigerant sprayed from the nozzle 224 may become low. However, according to the present embodiment, also in such a case, a desired range of the outer surfaces of the heat transfer tubes 222p of the heat transfer tube group 222 can be made wet with the liquid phase refrigerant, and dryout is unlikely to occur on the outer surfaces of the heat transfer tubes 222p.

(Embodiment 5)

[0154] Embodiment 5 will be described below with reference to FIG. 18. The configuration of Embodiment 5 is the same as the configuration of Embodiment 3 except for the particularly described matter. The components of Embodiment 5 which are the same as or correspond to the components of Embodiment 3 are denoted by the same reference signs, and the detailed description thereof is omitted. The description for Embodiment 3 also applies to Embodiment 5 as long as there is no technical contradiction.

[5-1. Configuration]

[0155] FIG. 18 illustrates a state where a liquid phase refrigerant is sprayed and flows in the evaporator 201 according to Embodiment 5. As shown in FIG. 18, the heat transfer tube group 222 has a distal heat transfer tube 222d. The distal heat transfer tube 222d is positioned to intersect the spray axis Am. For example, the distal heat transfer tube 222d intersects the central axis of the nozzle 224. The first tier 222a is disposed between the nozzle 224 and the distal heat transfer tube 222d in the direction (Z-axis direction) in which the plurality of heat transfer tubes 222p in the first tier 222a are arranged.

[0156] As shown in FIG. 18, the heat transfer tube group 222 has, for example, lower heat transfer tubes 222e. The lower heat transfer tube 222e is disposed directly blow the distal heat transfer tube 222d in the gravitational direction.

[0157] The distal heat transfer tube 222d and the lower heat transfer tube 222e have, for example, the same shape and size as those of the heat transfer tube 222p in the first tier 222a, the second tier 222b, or the lower heat transfer tube group 222c.

[5-2. Operation]

[0158] An operation and an effect of Embodiment 5 having the above-described configuration will be described below.

[0159] A liquid phase refrigerant that has passed between the first tier 222a and the second tier 222b collides with and is captured by the distal heat transfer tube 222d. Therefore, heat transfer involved by forced convection around the distal heat transfer tube 222d is promoted more greatly than heat transfer involved by forced convection around the heat transfer tubes 222p in the first tier 222a and the second tier 222b. In addition, the outer surface of the distal heat transfer tube 222d disposed far from the nozzle 224 can be made wet with the liquid phase refrigerant, and dryout on the outer surface of the heat transfer tube far from the nozzle 224 can be inhibited.

[0160] The liquid phase refrigerant that has collided with the distal heat transfer tube 222d flows along the outer surface of the distal heat transfer tube 222d, and is dropped toward the lower heat transfer tubes 222e. Thus, the outer surfaces of the lower heat transfer tubes 222e disposed far from the nozzle 224 can be made wet with the liquid phase refrigerant, and dryout on the outer surface of the heat transfer tube far from the nozzle 224 can be inhibited.

[5-3. Effect and the like]

[0161] As described above, in the present embodiment, the heat transfer tube group 222 has the distal heat transfer tube 222d, and the distal heat transfer tube 222d is positioned to intersect the spray axis Am. In addition, the first tier 222a is disposed between the nozzle 224 and the distal heat transfer tube 222d in the direction in which the plurality of heat transfer tubes 222p in the first tier 222a are arranged.

[0162] Thus, heat transfer involved by forced convection around the distal heat transfer tube 222d is greatly promoted, and dryout on the outer surface of the distal heat transfer tube 222d disposed far from the nozzle 224 can be inhibited.

[0163] For example, also in a case where a load abruptly changes in the refrigeration cycle device 200, and a pressure at which the liquid phase refrigerant is supplied to the nozzle 224 is changed, the outer surfaces of the heat transfer tubes 222p of the heat transfer tube group 222 can be stably made wet regardless of a pressure at which the liquid phase refrigerant is supplied to the nozzle 224. Therefore, in a wide range of operation conditions including a low load condition and an overload condition, the outer surfaces of the heat transfer tubes 222p of the heat transfer tube group 222 can be made wet with liquid phase refrigerant in a desired state.

[0164] For example, in a case where the refrigeration cycle device 200 is an absorption refrigerator, a gas phase refrigerant generated in the evaporator 201 can be supplied toward an absorber. At this time, a liquid phase refrigerant is desirably inhibited from being introduced to the absorber on the flow of the gas phase refrigerant supplied from the evaporator 201, from the viewpoint of enhancing the COP of the absorption refrigerator. According to the present embodiment, the liquid phase refrigerant that has passed between the first tier 222a and the second tier 222b collides with and is captured by the distal heat transfer tube 222d. Therefore, the liquid phase refrigerant is easily inhibited from being introduced from the evaporator 201 toward the absorber.

[0165] As in the present embodiment, the heat transfer tube group 222 may have the lower heat transfer tube 222e disposed directly below the distal heat transfer tube 222d in the gravitational direction. Thus, the outer surface of the lower heat transfer tube 222e can be made wet with the liquid phase refrigerant dropped from the distal heat transfer tube 222d.

(Other embodiments)

[0166] Embodiments 3, 4, and 5 have been described above as examples of the technique disclosed in the present application. However, the technique of the present disclosure is not limited thereto, and can also be applied to embodiments obtained by modification, replacement, addition, omission, or the like. Furthermore, the components described above in Embodiments 3, 4, and 5 can be combined to obtain a new embodiment. Other embodiments will be illustrated below.

[0167] In Embodiment 3, the evaporator 201 that includes the nozzle 224 for spraying a liquid phase refrigerant is described as an example of the shell-and-tube heat exchanger. In the shell-and-tube heat exchanger, the nozzle 224 may be any nozzle which sprays liquid. Therefore, a liquid sprayed from the nozzle 224 is not limited to a liquid phase refrigerant. Accordingly, the liquid sprayed from the nozzle 224 may be a coolant used by a condenser of a refrigeration cycle device for condensing a gas phase refrigerant, or another liquid. However, in a case where the liquid sprayed from the nozzle 224 is a liquid phase refrigerant, the shell-and-tube heat exchanger can be used as an evaporator of the refrigeration cycle device.

[0168] In Embodiment 3, the evaporator 201 in which the spray axis Am extends horizontally is described as an example of the shell-and-tube heat exchanger. The spray axis Am may be any spray axis that passes between the first end portions 222j, which are close to the second tier 222b, of the heat transfer tubes 222p in the first tier 222a and the second end portions 222k, which are close to the first tier 222a, of the plurality of heat transfer tubes 222p in the second tier 222b. Therefore, the spray axis Am may be inclined relative to the horizontal plane. However, in a case where the spray axis Am extends horizontally, the plurality of heat transfer tubes 222p in the first tier 222a and the second tier 222b can be easily disposed.

[0169] In Embodiment 3, it is indicated that an imaginary plane that does not intersect a tangible object in a space from one end to the other end of the first tier 222a in the direction in which the heat transfer tubes 222p in the first tier 222a are arranged may be between the first tier 222a and the second tier 222b. The spray axis Am may be any spray axis that passes between the first end portions 222j of the heat transfer tubes 222p in the first tier 222a and the second end portions 222k of the heat transfer tubes 222p in the second tier 222b, in the shell-and tube heat exchanger. Therefore, a member such as a wire material or a rod material that hardly affects a flow of liquid sprayed from the nozzle 224 and does not affect formation of the spray axis Am may be disposed between the first tier 222a and the second tier 222b.

[0170] In Embodiment 5, an example in which the distal heat transfer tube 222d has the same shape and size as the heat transfer tube 222p has been described. In the shell-and-tube heat exchanger, the distal heat transfer tube 222d may be any one that can be positioned to intersect the spray axis Am. Therefore, the shape and size of the distal heat transfer tube 222d are not limited to the same shape and size as those of the heat transfer tube 222p. However, in a case where the distal heat transfer tube 222d has the same shape and size as the heat transfer tube 222p, the distal heat transfer tube 222d need not be prepared separately from the heat transfer tube 222p, and production management is easily performed. Furthermore, a tube having an outer diameter greater than that of the heat transfer tube 222p may be used as the distal heat transfer tube 222d. In this case, the liquid phase refrigerant can be more assuredly captured by the distal heat transfer tube 222d.

INDUSTRIAL APPLICABILITY

[0171] The shell-and-tube heat exchanger disclosed in the present specification is particularly useful for an air conditioner such as a business-use air conditioner. The shell-and-tube heat exchanger may be used as a condenser as well as an evaporator. The refrigeration cycle device disclosed in the present specification is not limited to an air conditioner, and may be another device such as an absorption refrigerator, a chiller, and a heat storage device.

Claims

1. A shell-and-tube heat exchanger comprising:

a shell;
a plurality of heat transfer tubes disposed inside the shell; and
a nozzle, wherein
the shell-and-tube heat exchanger satisfies the following conditions (Ia), (Ib), (Ic), and (Id) or the following conditions (IIa), (IIb), (IIc), and (IId),
(Ia) the plurality of heat transfer tubes is disposed inside the shell in a manner that the heat transfer tubes are parallel to each other, and a first fluid flows in the plurality of heat transfer tubes,
(Ib) the nozzle includes a plurality of nozzles that is disposed inside the shell and that sprays a second fluid toward the plurality of heat transfer tubes,
(Ic) when a direction parallel to a longitudinal direction of the plurality of heat transfer tubes is defined as an X direction, a direction perpendicular to the X direction is defined as a Y direction, and a direction perpendicular to the X direction and the Y direction is defined as a Z direction,
the plurality of nozzles includes a plurality of first nozzles that sprays the second fluid from a first side toward a second side in the Z direction, and a plurality of second nozzles that sprays the second fluid from the first side toward the second side in the Z direction,
(Id) on a projected image obtained by projecting the plurality of first nozzles and the plurality of second nozzles in the Z direction, the plurality of first nozzles and the plurality of second nozzles form a staggered arrangement pattern,
(IIa) the plurality of heat transfer tubes constitutes a heat transfer tube group,
(IIb) the nozzle sprays liquid toward the heat transfer tube group,
(IIc) the heat transfer tube group includes a first tier having a plurality of heat transfer tubes arranged along a first plane, and a second tier that has a plurality of heat transfer tubes arranged along a second plane parallel to the first plane and that is adjacent to the first tier in a direction perpendicular to the first plane, and
(IId) the nozzle sprays the liquid to form a flat spray pattern that has a spray axis passing between a first end portion, which is close to the second tier in the direction perpendicular to the first plane, of the plurality of heat transfer tubes in the first tier and a second end portion, which is close to the first tier in the direction perpendicular to the first plane, of the plurality of heat transfer tubes in the second tier and that passes between the first tier and the second tier.

2. The shell-and-tube heat exchanger according to claim 1, wherein the shell-and-tube heat exchanger satisfies the conditions (Ia), (Ib), (Ic), and (Id).

3. The shell-and-tube heat exchanger according to claim 2, wherein a spray axis of each of the first nozzles and a spray axis of each of the second nozzles are parallel to a direction inclined relative to both the X direction and the Z direction.

4. The shell-and-tube heat exchanger according to claim 3, wherein

in a planar view in the Y direction, the spray axis of each of the first nozzles is inclined clockwise relative to a first reference line that passes through a center of an opening of the first nozzle and is parallel to the Z direction, and
in a planar view in the Y direction, the spray axis of each of the second nozzles is inclined counterclockwise relative to a second reference line that passes through a center of an opening of the second nozzle and is parallel to the Z direction.

5. The shell-and-tube heat exchanger according to claim 4, wherein, in a planar view in the Y direction, an angle between the spray axis of the first nozzle and the first reference line is equal to an angle between the spray axis of the second nozzle and the second reference line.

6. The shell-and-tube heat exchanger according to any one of claims 2 to 5, wherein

the plurality of nozzles includes a plurality of third nozzles that sprays the second fluid from the second side toward the first side in the Z direction, and a plurality of fourth nozzles that sprays the second fluid from the second side toward the first side in the Z direction, and
on a projected image obtained by projecting the plurality of third nozzles and the plurality of fourth nozzles in the Z direction, the plurality of third nozzles and the plurality of fourth nozzles form a staggered arrangement pattern.

7. The shell-and-tube heat exchanger according to claim 6, wherein a spray axis of each of the third nozzles and a spray axis of each of the fourth nozzles are parallel to a direction inclined relative to both the X direction and the Z direction.

8. The shell-and-tube heat exchanger according to claim 7, wherein

in a planar view in the Y direction, the spray axis of each of the third nozzles is inclined clockwise relative to a third reference line that passes through a center of an opening of the third nozzle and is parallel to the Z direction, and
in a planar view in the Y direction, the spray axis of each of the fourth nozzles is inclined counterclockwise relative to a fourth reference line that passes through a center of an opening of the fourth nozzle and is parallel to the Z direction.

9. The shell-and-tube heat exchanger according to claim 7 or 8, wherein, in a planar view in the Y direction, an angle between the spray axis of the third nozzle and the third reference line is equal to an angle between the spray axis of the fourth nozzle and the fourth reference line.

10. The shell-and-tube heat exchanger according to any one of claims 6 to 9, wherein

in a planar view in the Y direction, a position of the plurality of third nozzles is offset relative to a position of the plurality of first nozzle in the X direction, and
in a planar view in the Y direction, a position of the plurality of fourth nozzles is offset relative to a position of the plurality of second nozzles in the X direction.

11. The shell-and-tube heat exchanger according to any one of claims 2 to 10, wherein

the spray axis of each of the first nozzles passes between the heat transfer tube and the heat transfer tube adjacent to each other in the Y direction, and
the spray axis of each of the second nozzles passes between the heat transfer tube and the heat transfer tube adjacent to each other in the Y direction.

12. The shell-and-tube heat exchanger according to any one of claims 6 to 10, wherein

the spray axis of each of the third nozzles passes between the heat transfer tube and the heat transfer tube adjacent to each other in the Y direction, and
the spray axis of each of the fourth nozzles passes between the heat transfer tube and the heat transfer tube adjacent to each other in the Y direction.

13. The shell-and-tube heat exchanger according to any one of claims 2 to 12, wherein the plurality of heat transfer tubes is located on grid points of a square grid, on a cross-section perpendicular to the X direction and parallel to the Y direction and the Z direction.

14. The shell-and-tube heat exchanger according to any one of claims 2 to 13,
wherein the plurality of heat transfer tubes includes a round tube having a round cross-section.

15. A refrigeration cycle device comprising the shell-and-tube heat exchanger according to any one of claims 2 to 14.

16. The shell-and-tube heat exchanger according to claim 1, wherein the shell-and-tube heat exchanger satisfies the conditions (IIa), (IIb), (IIc), and (IId).

17. The shell-and-tube heat exchanger according to claim 16, wherein an imaginary plane that does not intersect a tangible object in a space from one end of the first tier to the other end thereof in a direction in which the plurality of heat transfer tubes in the first tier are arranged is between the first tier and the second tier.

18. The shell-and-tube heat exchanger according to claim 16 or 17, wherein the plurality of heat transfer tubes in the first tier and the plurality of heat transfer tubes in the second tier form a rectangular grid, a square grid, or a parallelogram grid, on a third plane perpendicular to the longitudinal direction of the heat transfer tubes.

19. The shell-and-tube heat exchanger according to any one of claims 16 to 18, wherein

the second tier is disposed below the first tier in a gravitational direction, and
the heat transfer tube group includes a lower heat transfer tube group that has a plurality of heat transfer tubes and that is disposed below the second tier in the gravitational direction.

20. The shell-and-tube heat exchanger according to claim 19, wherein the plurality of heat transfer tubes of the lower heat transfer tube group and the plurality of heat transfer tubes in the second tier form a rectangular grid or a square grid on the third plane perpendicular to the longitudinal direction of the heat transfer tubes.

21. The shell-and-tube heat exchanger according to any one of claims 16 to 20, wherein, when the first tier is seen along a direction perpendicular to the first plane, the spray axis forms an acute angle having a predetermined value relative to a straight line extending perpendicular to the longitudinal direction of the heat transfer tubes in the first tier.

22. The shell-and-tube heat exchanger according to any one of claims 16 to 21, wherein

the heat transfer tube group has a distal heat transfer tube positioned to intersect the spray axis, and
the first tier is disposed between the nozzle and the distal heat transfer tube in a direction in which the plurality of heat transfer tubes in the first tier are arranged.

23. The shell-and-tube heat exchanger according to claim 22, wherein the heat transfer tube group has a lower heat transfer tube disposed directly below the distal heat transfer tube in the gravitational direction.

24. A refrigeration cycle device comprising the shell-and-tube heat exchanger according to any one of claims 16 to 23.

25. A heat exchange method comprising:

causing a heat medium to pass in a heat transfer tube group that includes a first tier having a plurality of heat transfer tubes arranged along a first plane, and a second tier that has a plurality of heat transfer tubes arranged along a second plane parallel to the first plane and that is adjacent to the first tier in a direction perpendicular to the first plane; and
spraying a liquid toward the heat transfer tube group to form a flat spray pattern that has a spray axis passing between a first end portion, which is close to the second tier in the direction perpendicular to the first plane, of the plurality of heat transfer tubes in the first tier and a second end portion, which is close to the first tier in the direction perpendicular to the first plane, of the plurality of heat transfer tubes in the second tier and that passes between the first tier and the second tier, and causing heat exchange between the heat medium and the liquid.

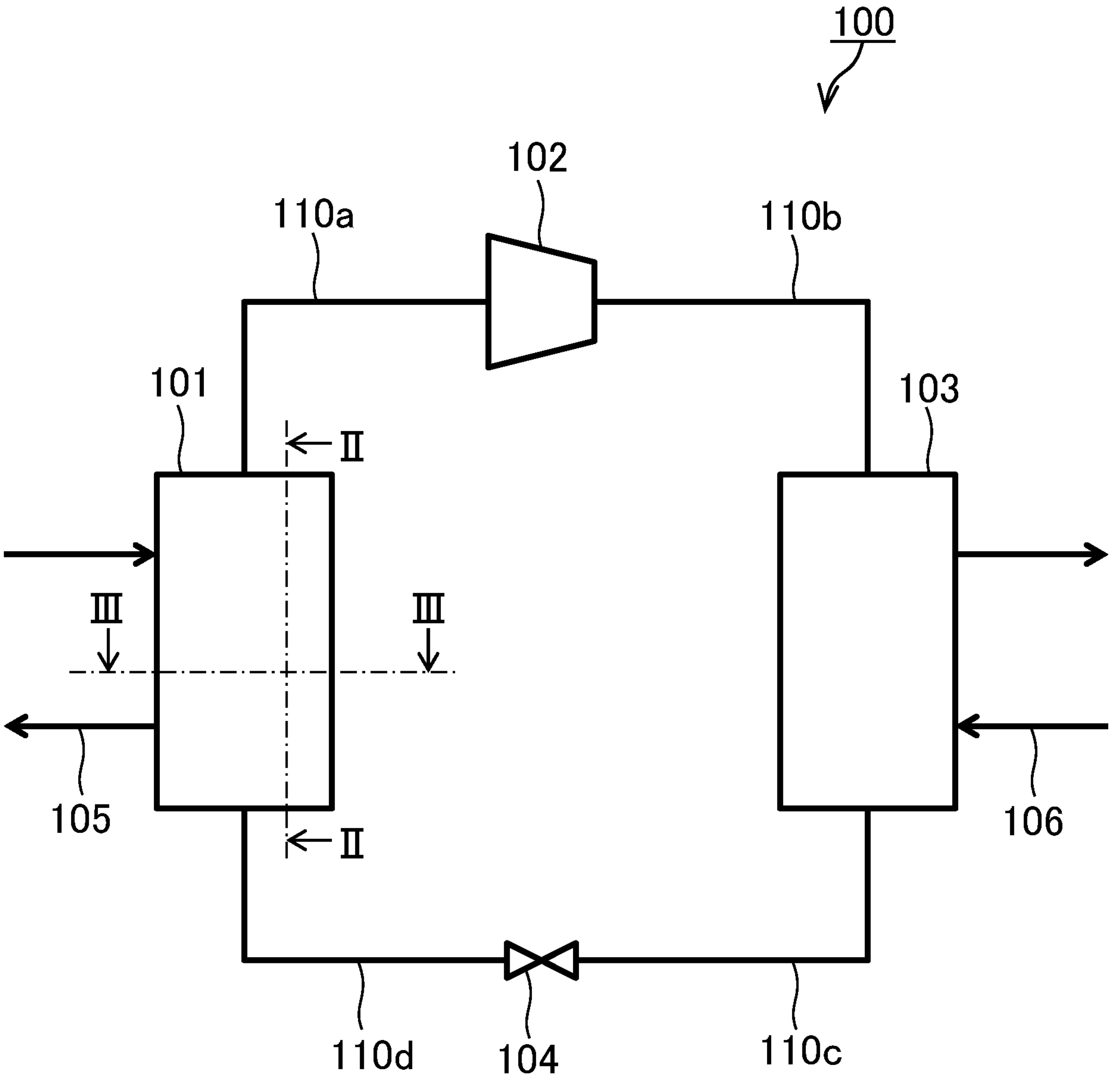

FIG. 1

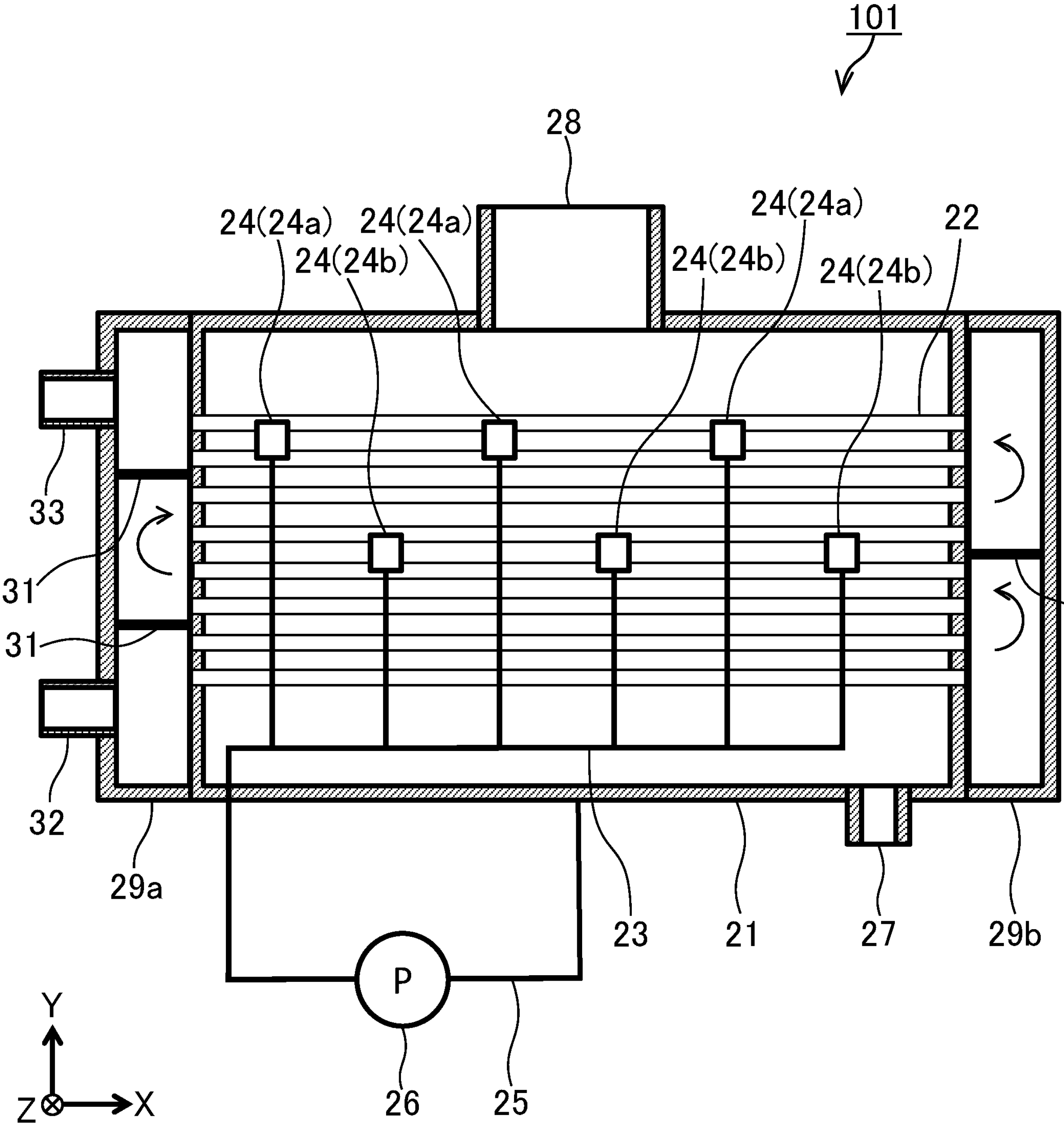
101
28
24(24a)
24(24a)
24(24a)
24(24b)
24(24b)
24(24b)
22
33
31
31
31
32
29a
23
21
27
29b
P
26
25
Y
Z
X

FIG. 2

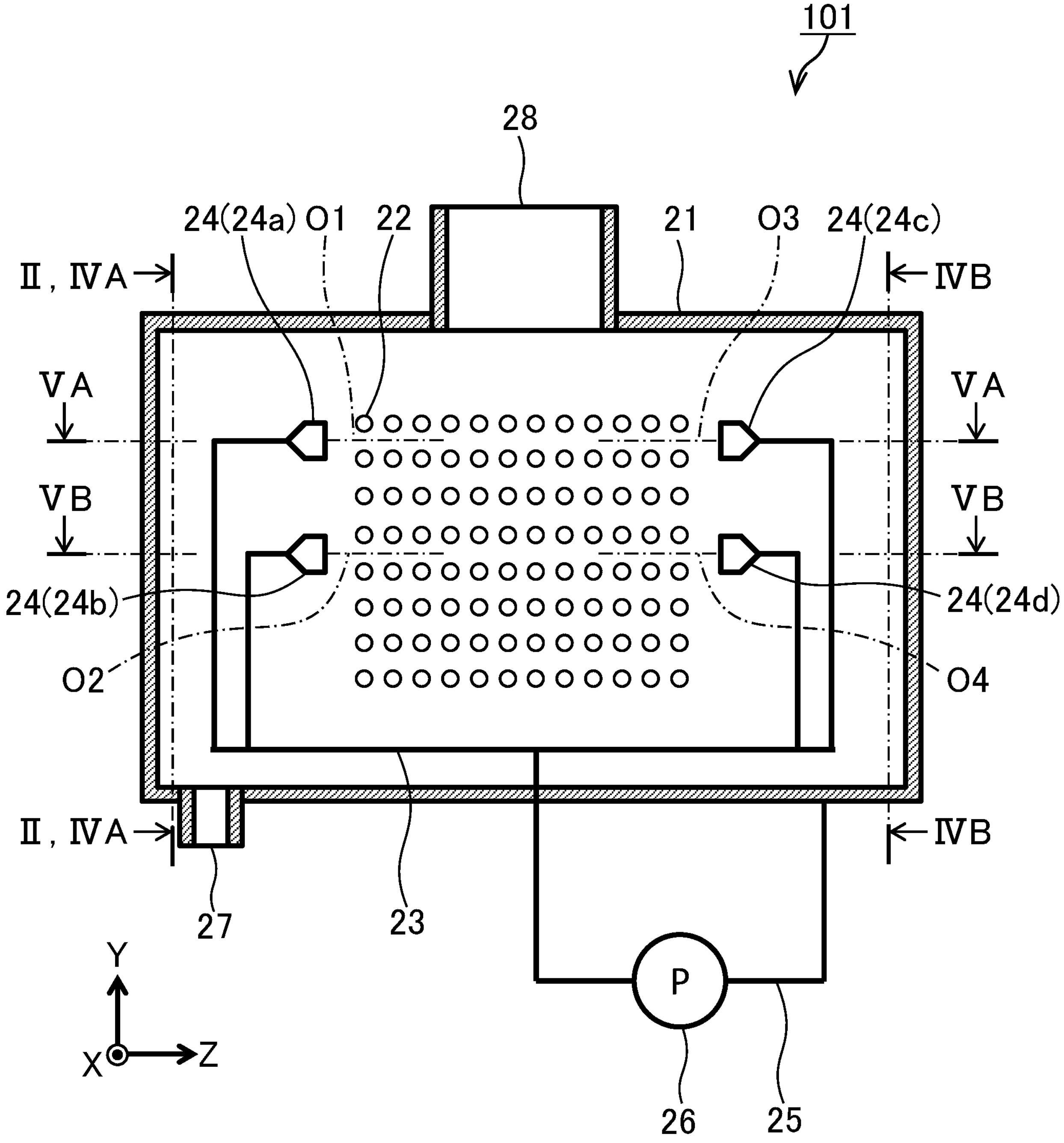
101
28
24(24a) O1
22
21
O3
24(24c)
Ⅱ, ⅣA
ⅣB
ⅤA
ⅤA
ⅤB
ⅤB
24(24b)
24(24d)
O2
O4
Ⅱ, ⅣA
ⅣB
27
23
Y
X
Z
P
26
25

FIG. 3

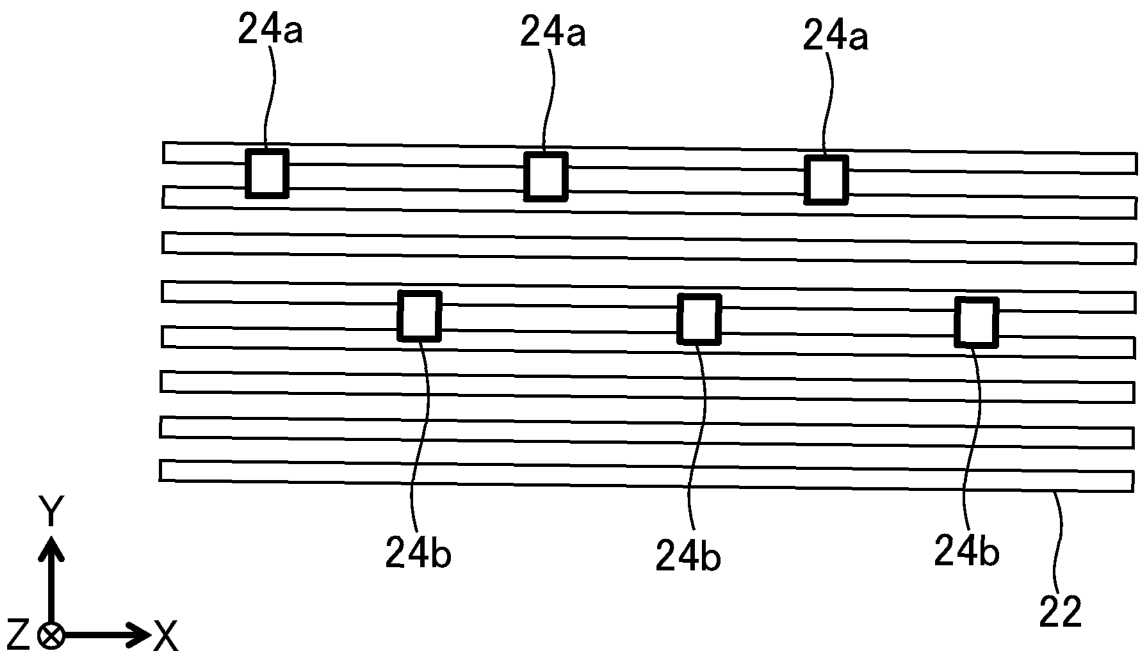

FIG. 4A

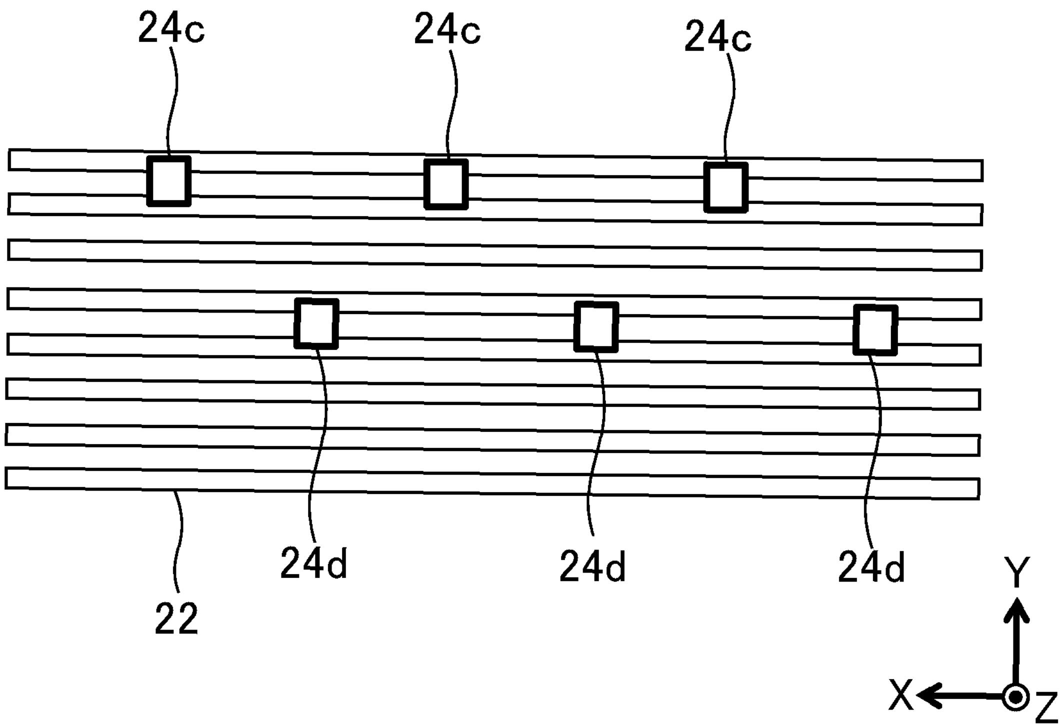

FIG. 4B

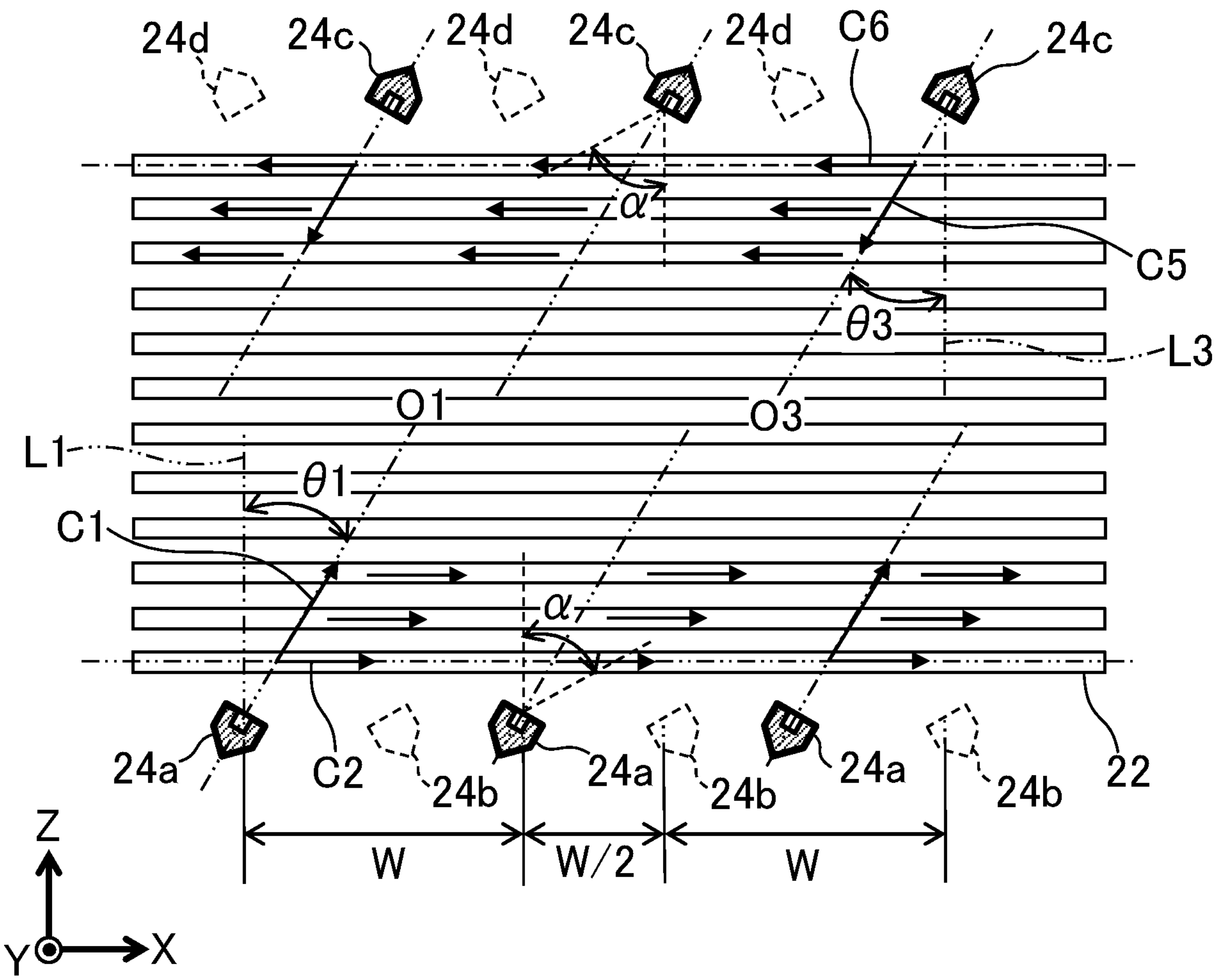
24d
24c
24d
24c
24d
C6
24c
α
C5
θ3
L3
O1
O3
L1
θ1
C1
α
24a
C2
24b
24a
24b
24a
24b
22
W
W/2
W
Z
Y
X

FIG. 5A

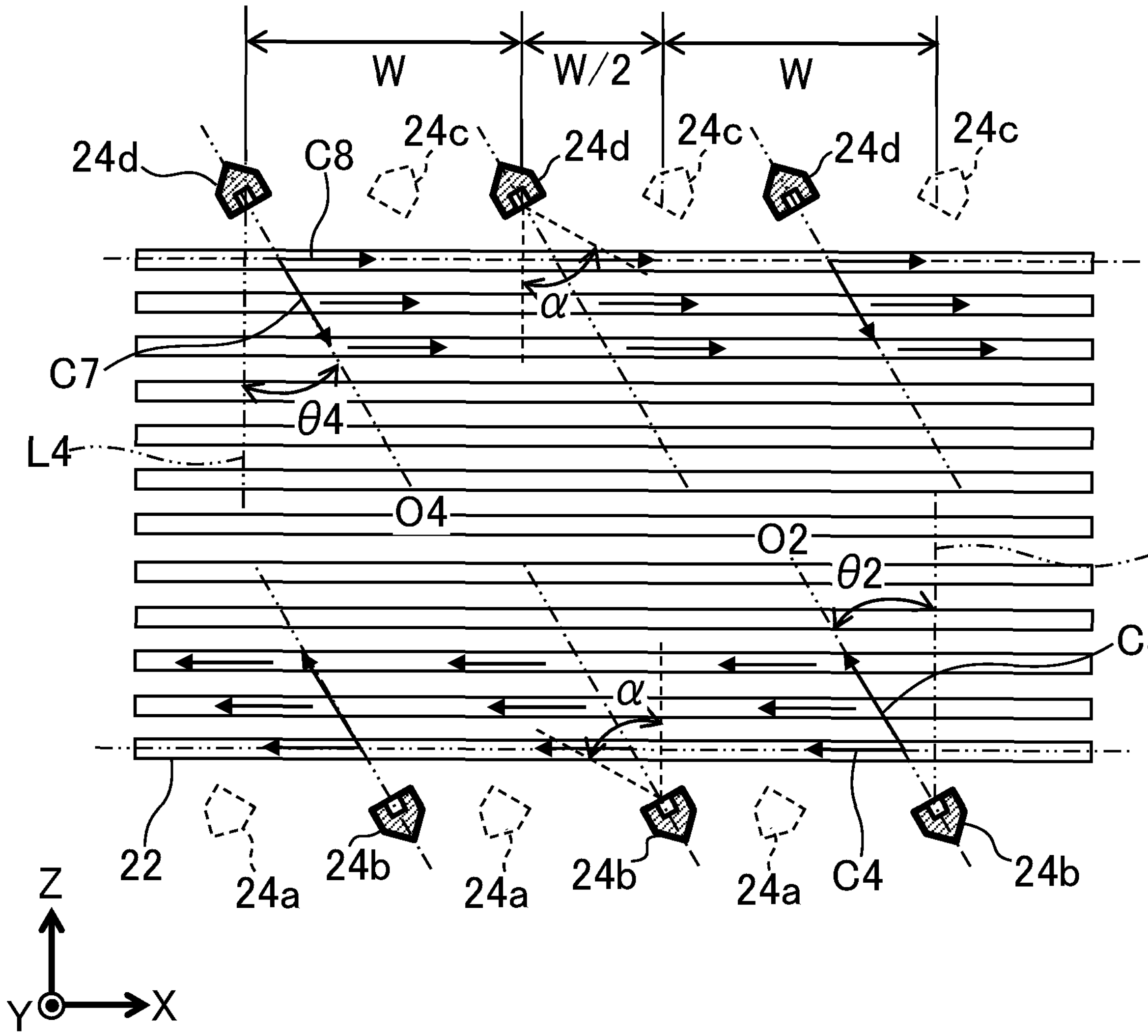
W
W/2
W
24d
C8
24c
24d
24c
24d
24c
α
C7
θ4
L4
O4
O2
L2
θ2
C3
α
22
24b
24a
24b
24a
24a
C4
24b
Z
Y
X

FIG. 5B

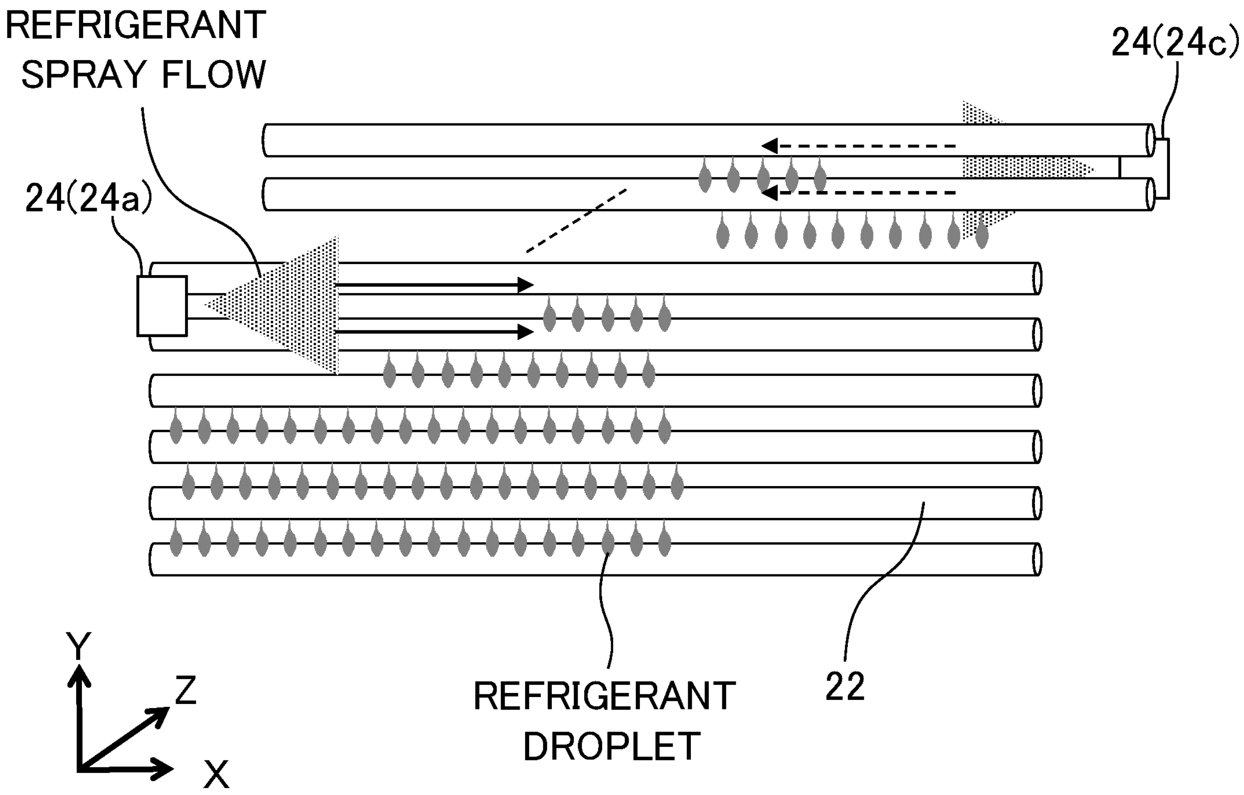
REFRIGERANT
SPRAY FLOW
24(24c)
24(24a)
Y
Z
X
REFRIGERANT
DROPLET
22

FIG. 6

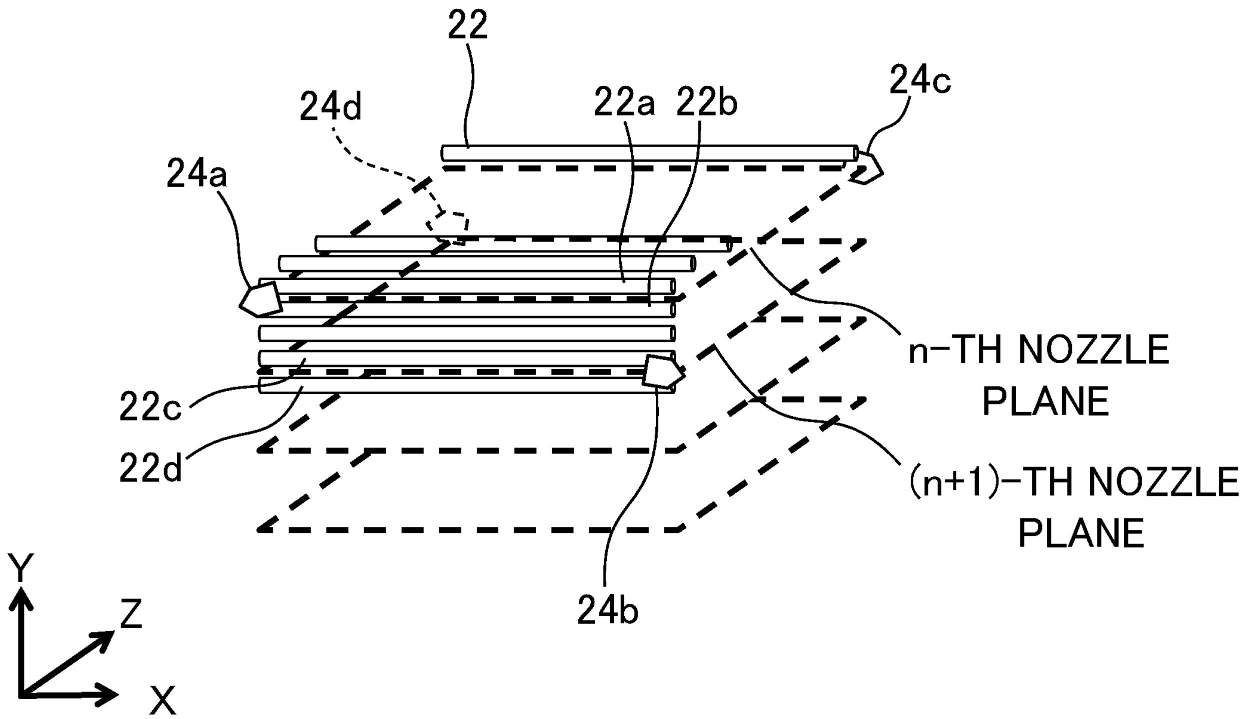
22
24c
24d
22a 22b
24a
n-TH NOZZLE PLANE
22c
22d
(n+1)-TH NOZZLE PLANE
Y
Z
24b
X

FIG. 7A

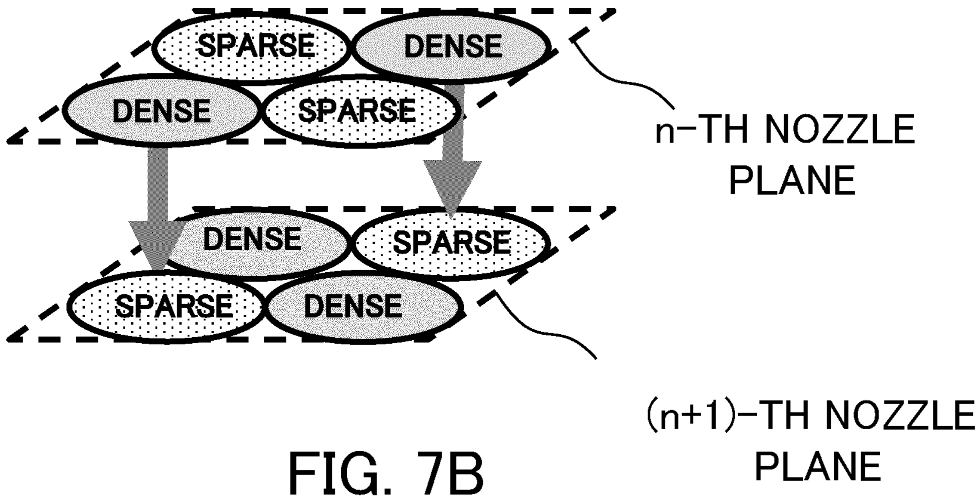
SPARSE
DENSE
DENSE
SPARSE
n-TH NOZZLE PLANE
DENSE
SPARSE
SPARSE
DENSE
(n+1)-TH NOZZLE PLANE

FIG. 7B

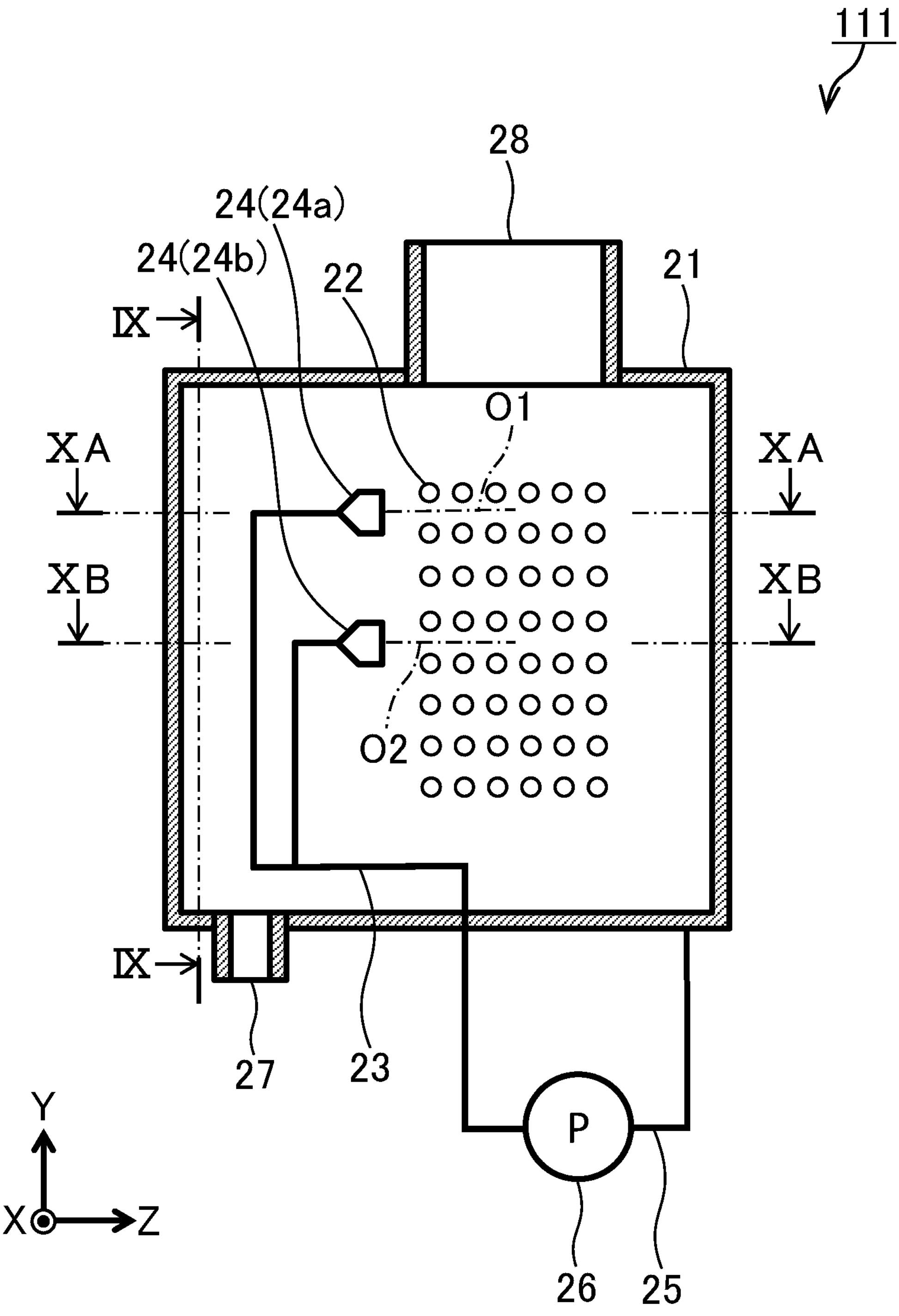

FIG. 8

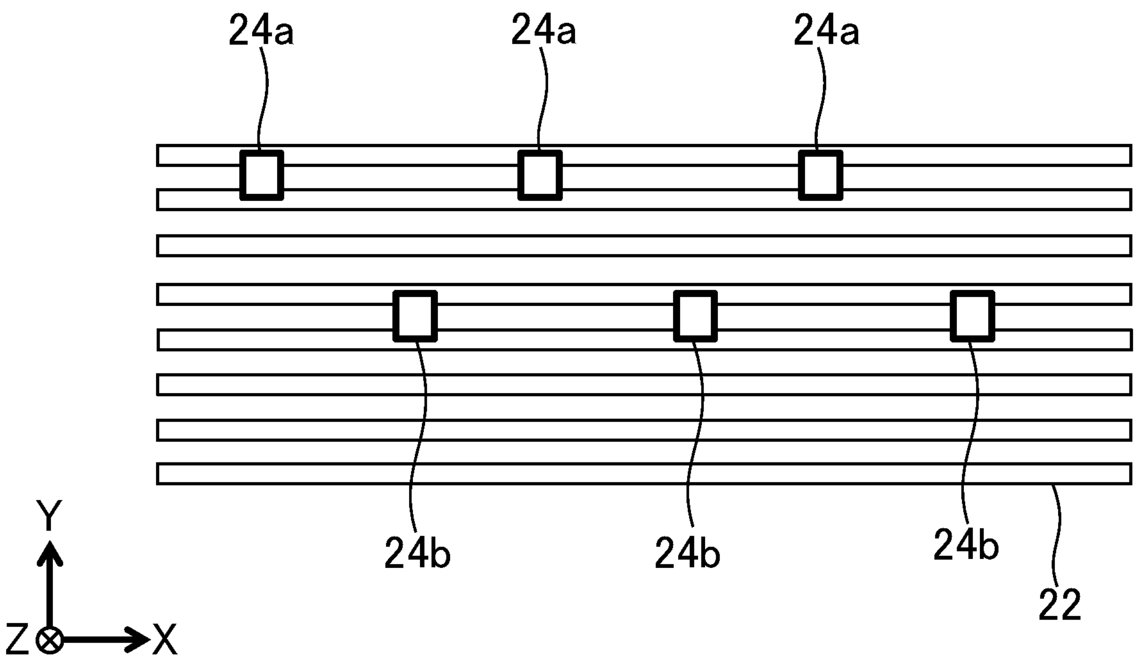

FIG. 9

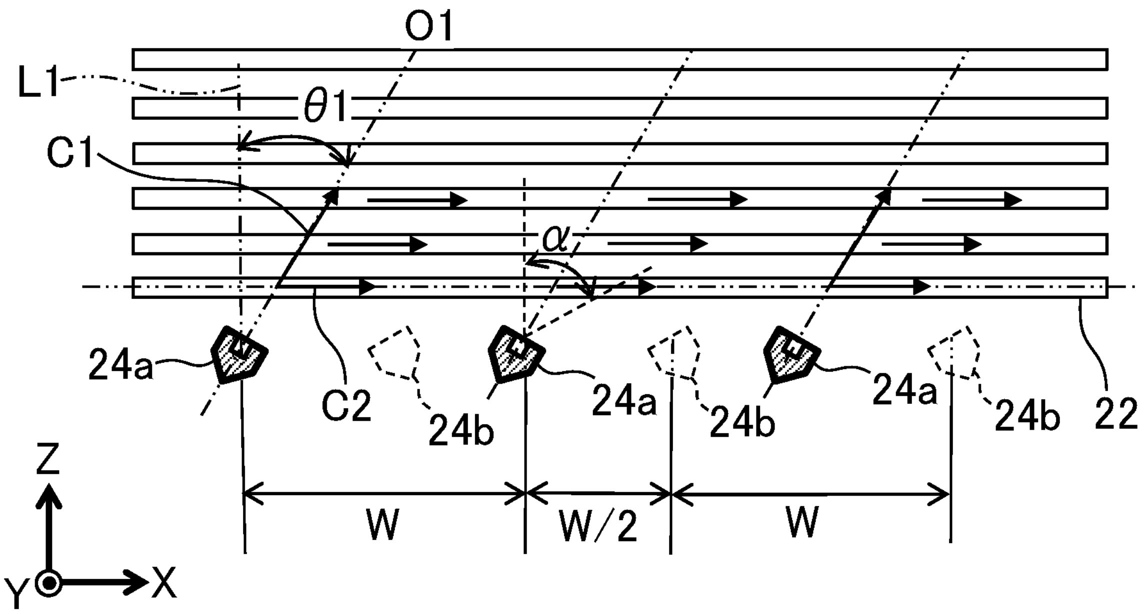

FIG. 10A

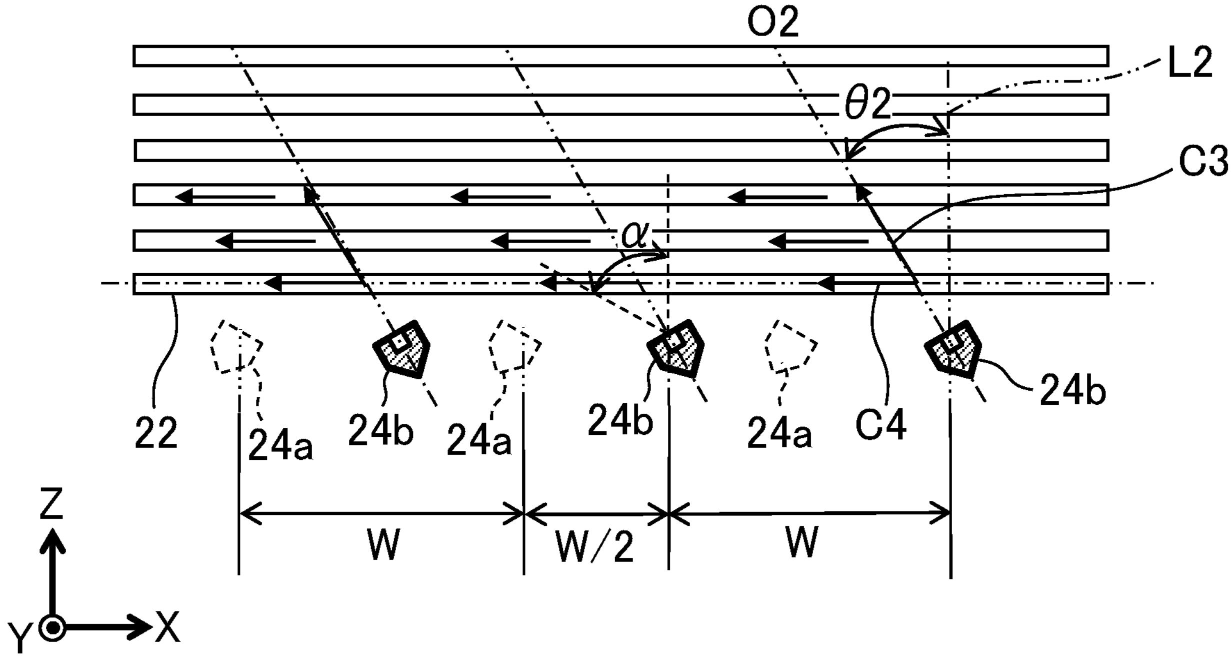

FIG. 10B

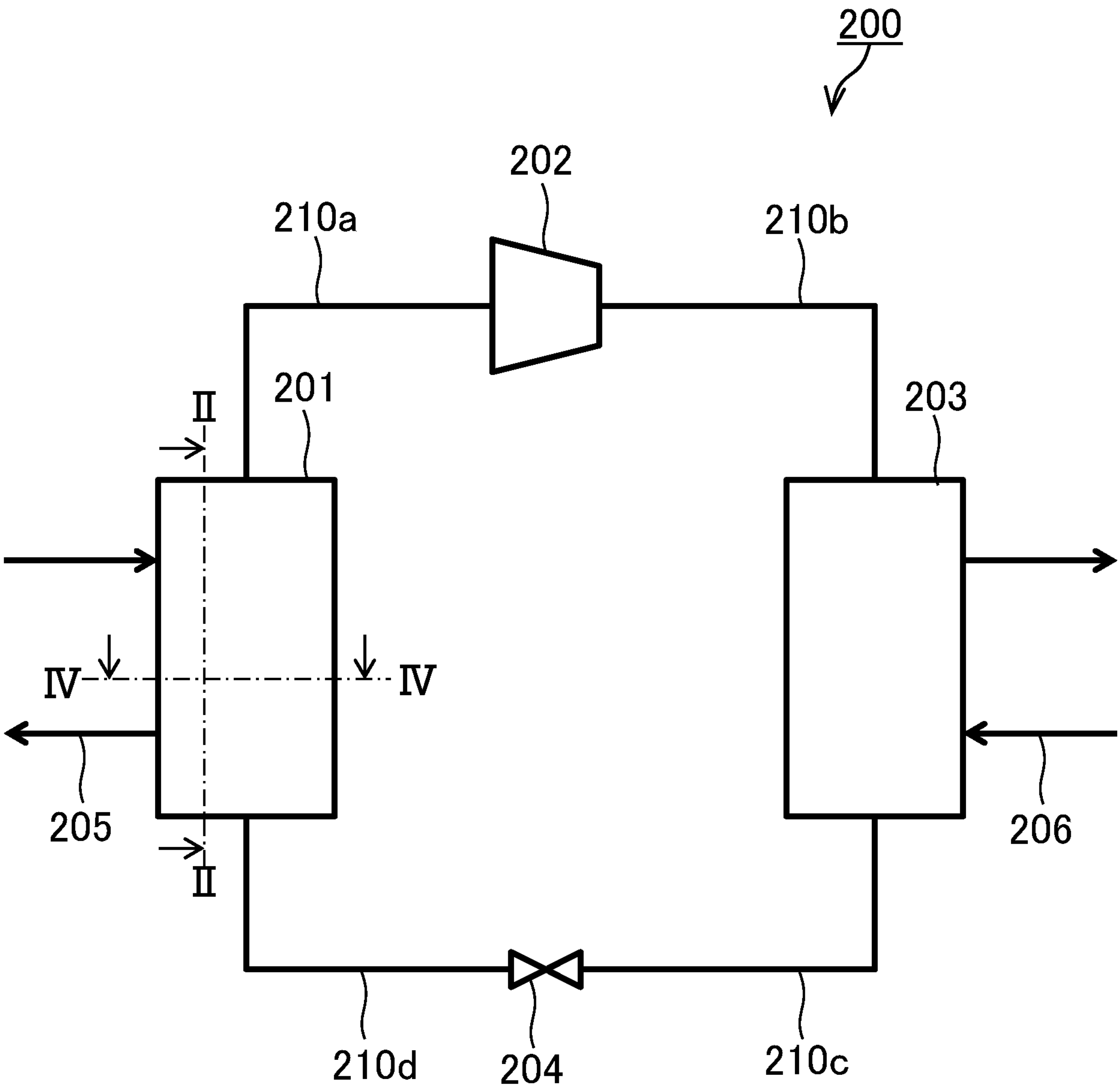

FIG. 11

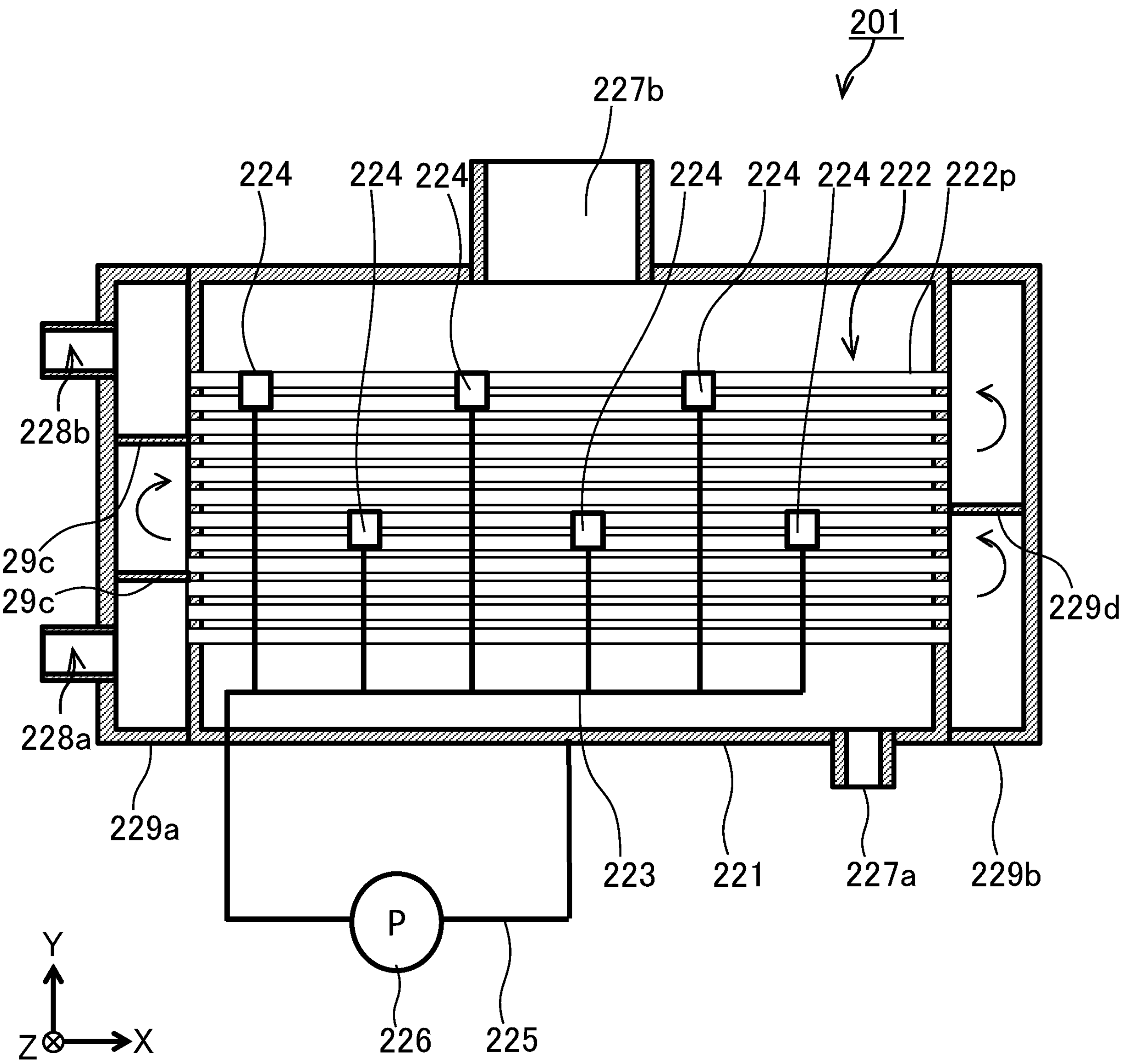
201
227b
224
224
224
224
224
224
222
222p
228b
229c
229c
229d
228a
229a
223
221
227a
229b
P
226
225
Y
Z
X

FIG. 12

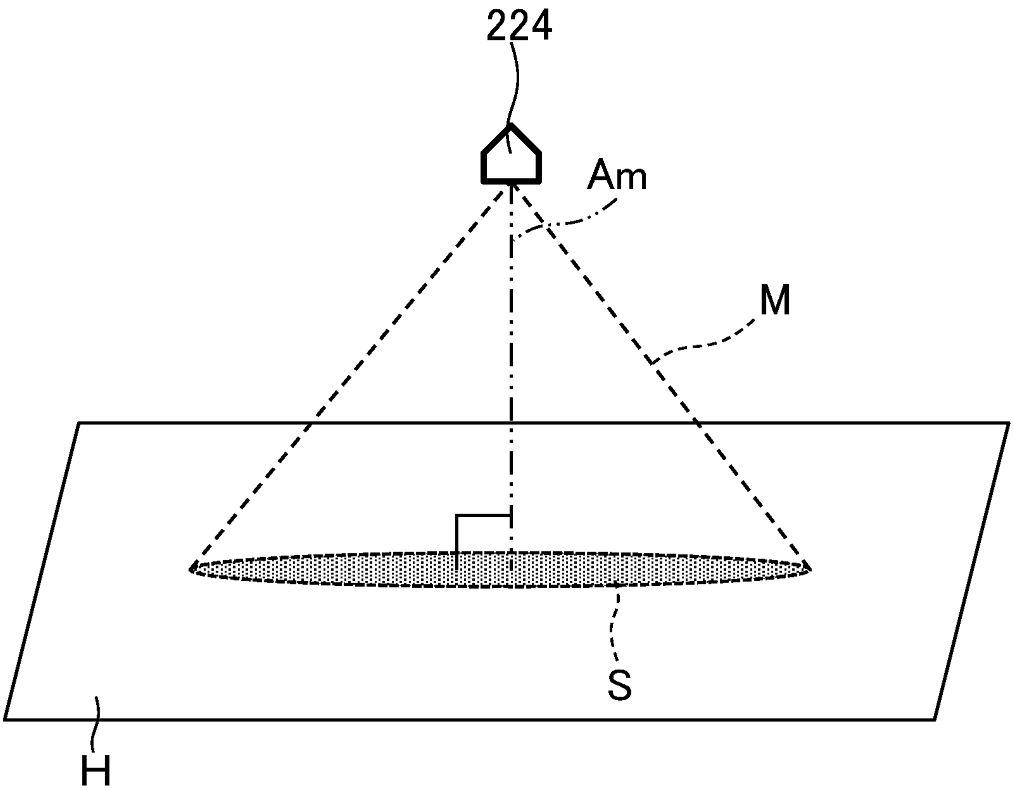

FIG. 13A

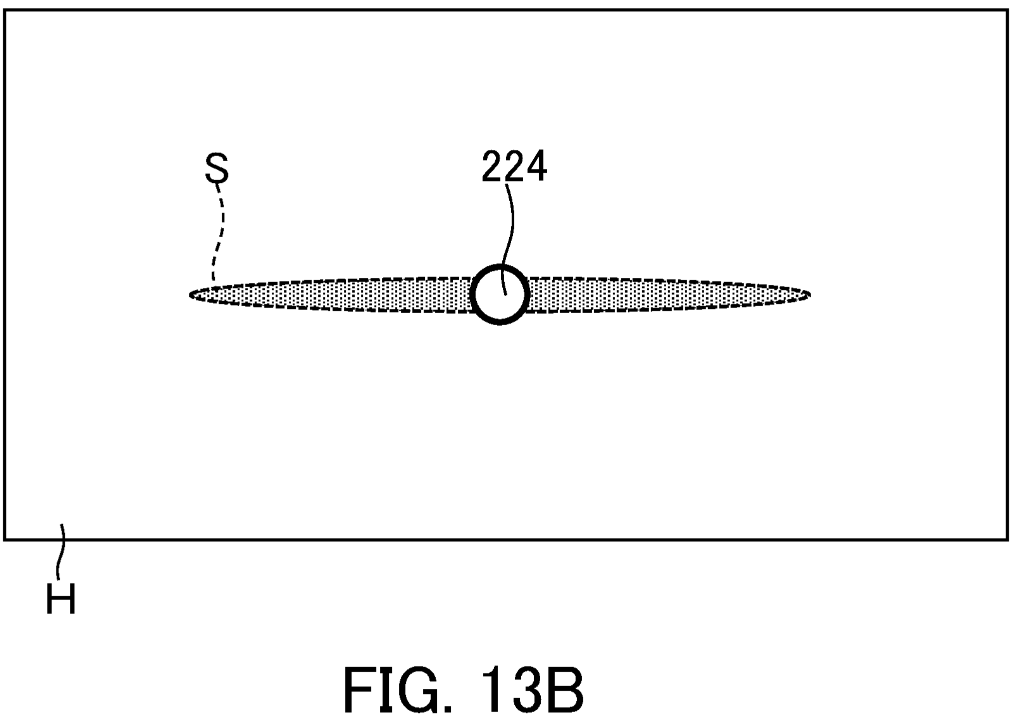

FIG. 13B

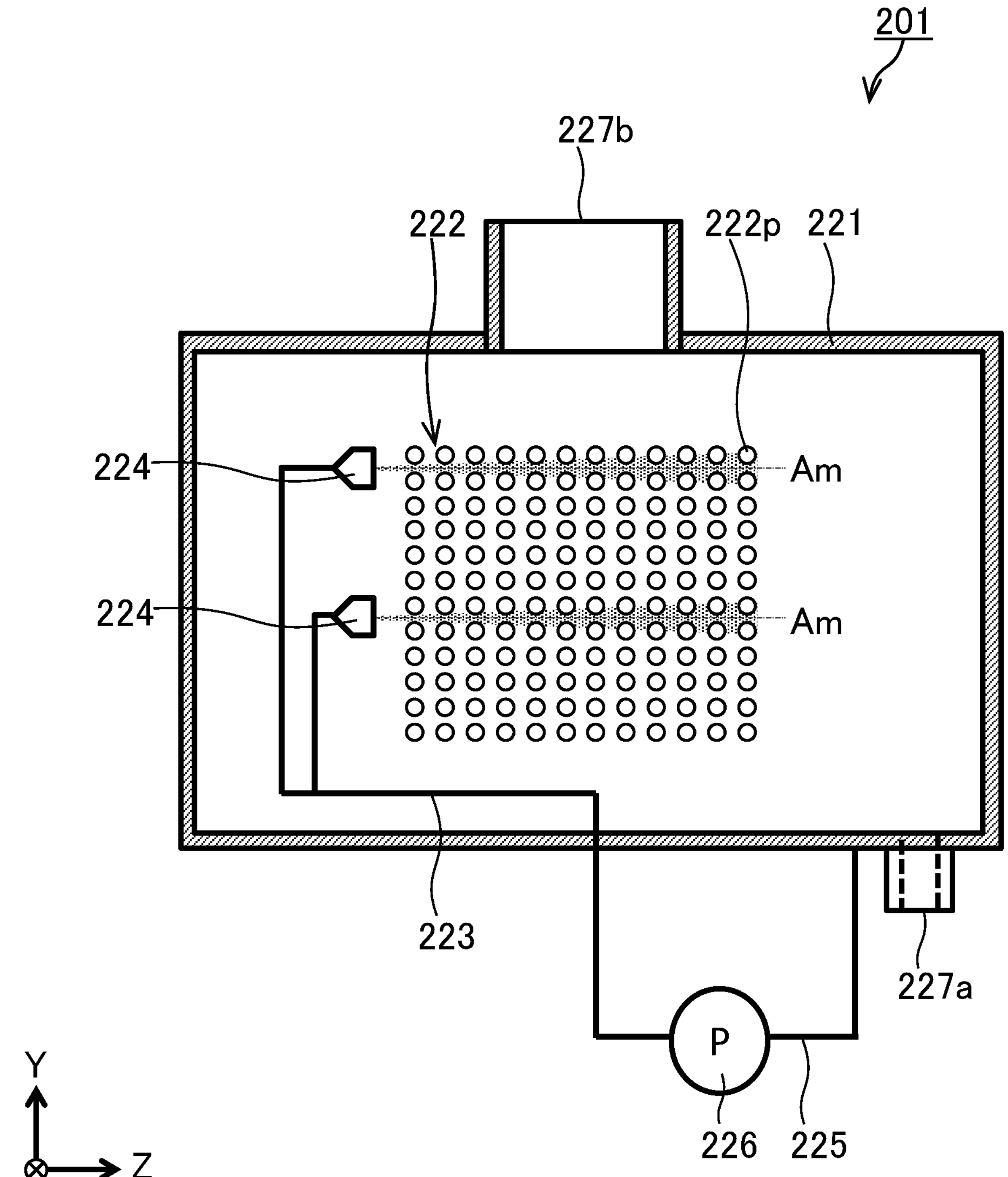

FIG. 14

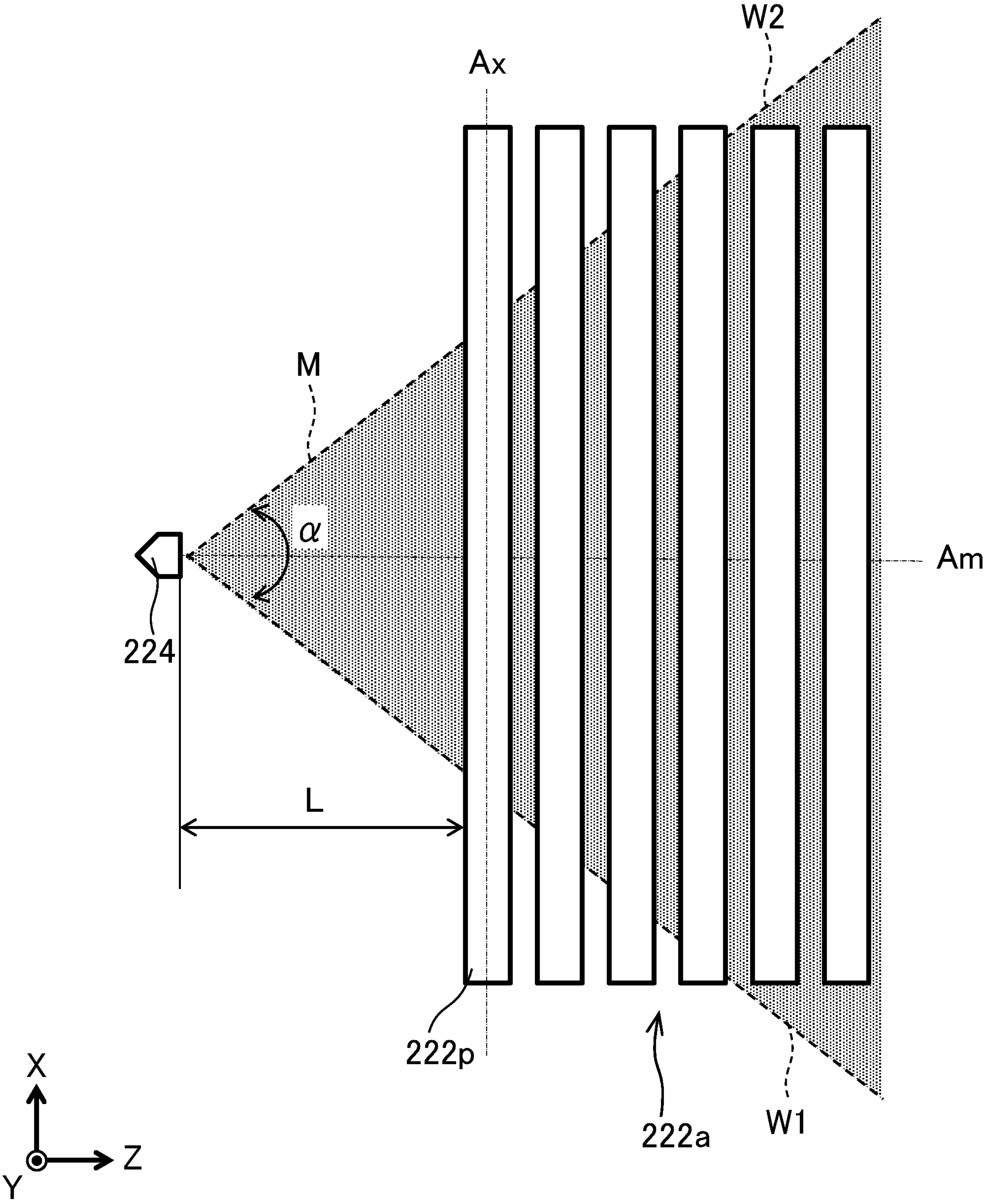

FIG. 15

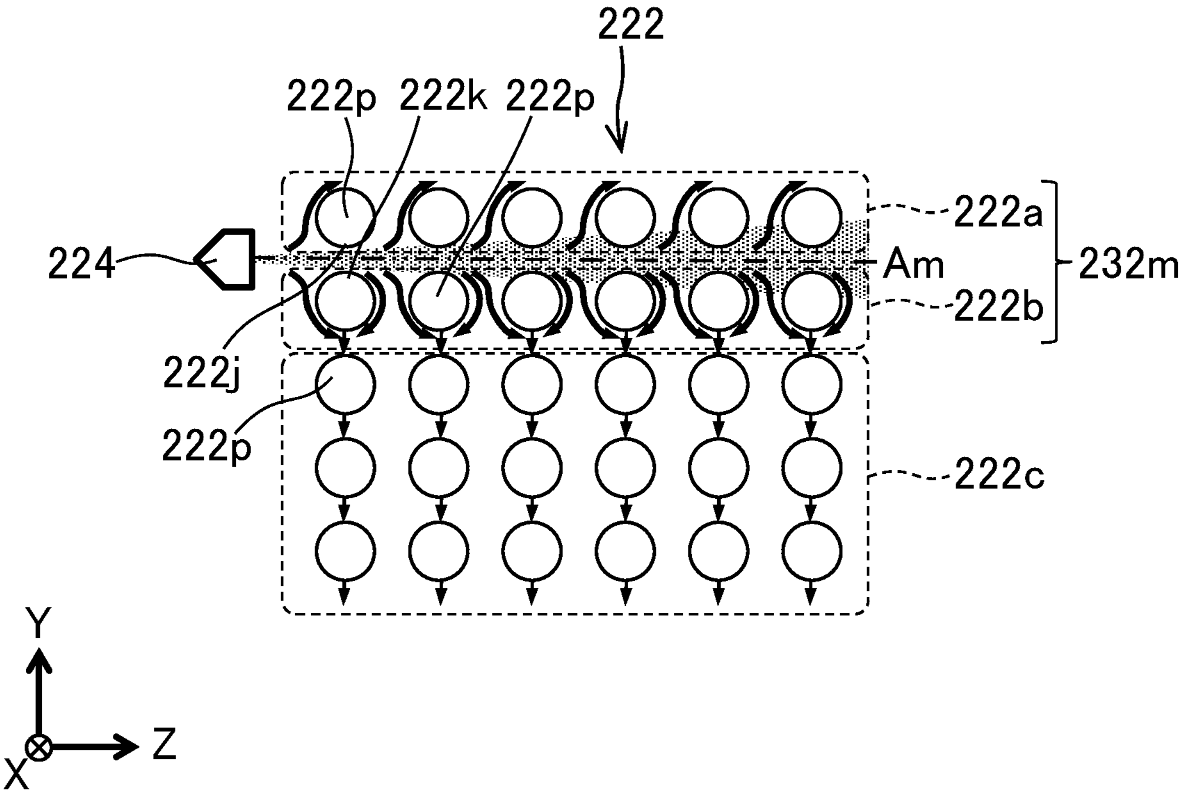

FIG. 16

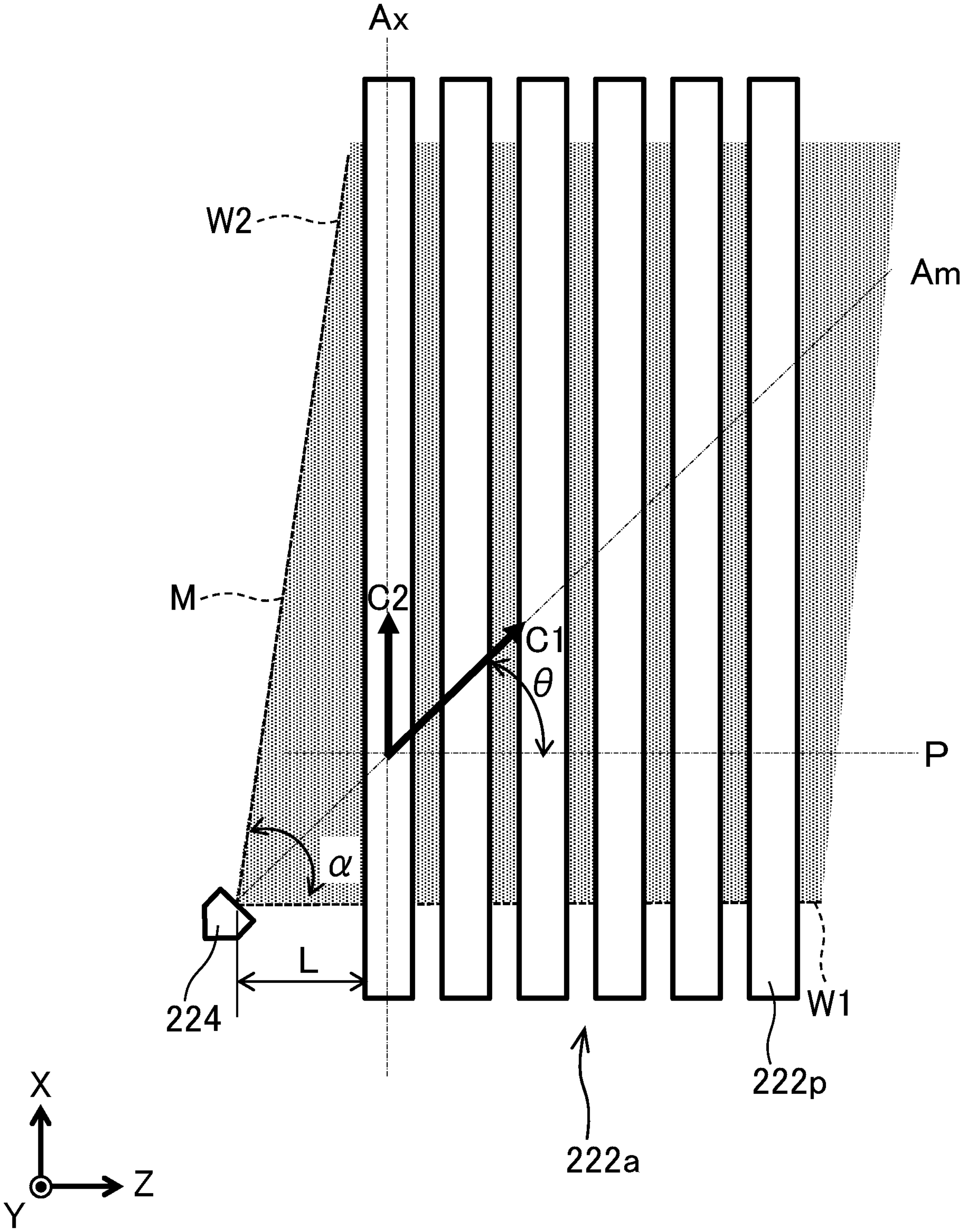

FIG. 17

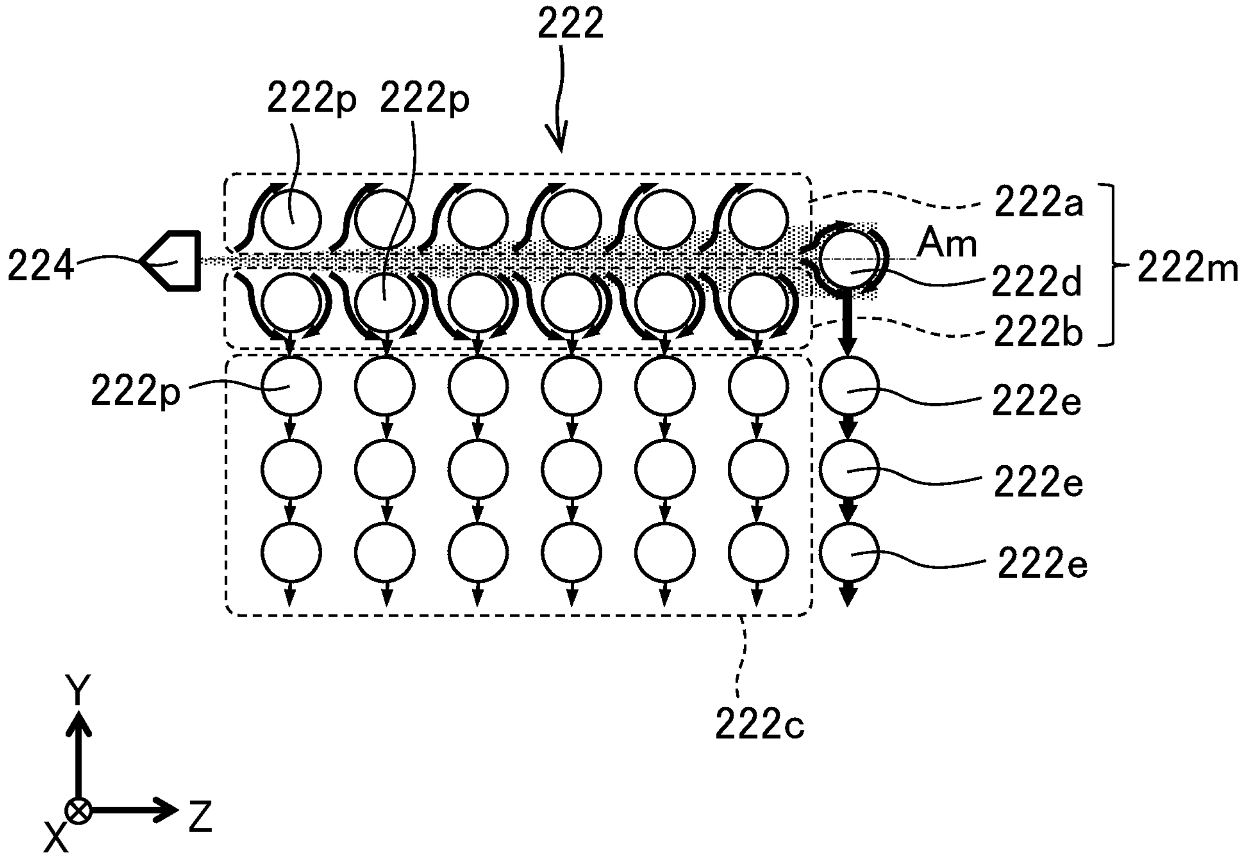
222
222p
222p
224
222a
Am
222d
222m
222b
222p
222e
222e
222e
222c
Y
X
Z

FIG. 18

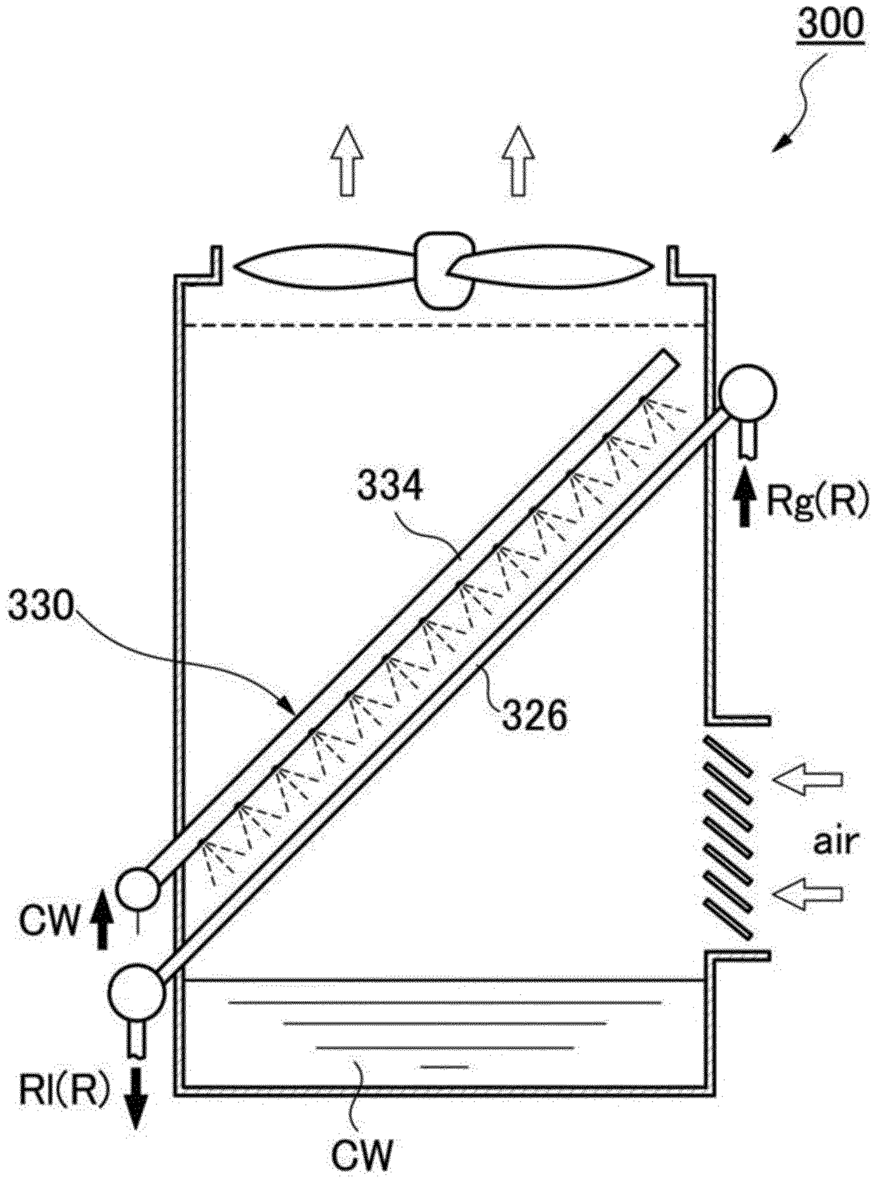

FIG. 19

INTERNATIONAL SEARCH REPORT

International application No. **PCT/JP2021/044142**

A. CLASSIFICATION OF SUBJECT MATTER

F25B 39/02(2006.01)i; ***F28D 3/02***(2006.01)i; ***F28D 7/16***(2006.01)i; ***F28F 13/02***(2006.01)i; ***F25B 1/00***(2006.01)i
FI: F28D7/16 A; F28D3/02; F25B1/00 383; F25B39/02 N; F28F13/02 Z

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)

F25B39/00-39/04; F28D1/00-13/00; F28F1/00-99/00; F25B1/00; F28B1/00-11/00; F28C1/00-3/18; F24F1/42

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 1971-2022
Registered utility model specifications of Japan 1996-2022
Published registered utility model applications of Japan 1994-2022

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.
Y A	JP 2020-56532 A (PANASONIC IP MANAGEMENT CORP.) 09 April 2020 (2020-04-09) particularly, paragraphs [0027]-[0065], fig. 1-5	1-3, 6-7, 10-25 4-5, 8-9
Y	JP 2008-286473 A (MITSUBISHI ELECTRIC CORP.) 27 November 2008 (2008-11-27) particularly, paragraphs [0019], [0021], fig. 1-3	1-3, 6-7, 10-15
Y	CN 210980875 U (CHINA DATANG CORPORATION SCIENCE AND TECH. RESEARCH INSTITUTE CO., LTD. THERMAL POWER TECH. RESEARCH INST.) 10 July 2020 (2020-07-10) particularly, paragraphs [0022]-[0027], fig. 1-3	1-3, 6-7, 10-15
Y	JP 2019-132460 A (PANASONIC CORP.) 08 August 2019 (2019-08-08) particularly, paragraph [0023], fig. 2-3	1, 6-7, 10-25
Y	JP 2020-153592 A (PANASONIC CORP.) 24 September 2020 (2020-09-24) particularly, fig. 2	1, 6-7, 10-25
Y	JP 2013-53620 A (USUI KOKUSAI SANGYO KAISHA, LTD.) 21 March 2013 (2013-03-21) particularly, paragraphs [0029], [0075]-[0076], fig. 40	1, 16-25

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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Date of the actual completion of the international search	Date of mailing of the international search report
09 February 2022	**22 February 2022**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2021/044142

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2019/0107332 A1 (SCHNEIDER ELECTRIC IT CORPORATION) 11 April 2019 (2019-04-11) particularly, paragraph [0038], fig. 6	1, 16-25
Y	JP 7-158805 A (MITSUBISHI HEAVY IND., LTD.) 20 June 1995 (1995-06-20) particularly, paragraph [0014]	1, 16-25

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2021/044142

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US 2019/0107332 A1	11 April 2019	EP 3480527 A2 CN 109654708 A	
JP 7-158805 A	20 June 1995	(Family: none)	

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REFERENCES CITED IN THE DESCRIPTION

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