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(54) **HEAT EXCHANGER**

(57) A stacked plate type heat exchanger having compactness and providing a heat exchanging rate per unit volume of 10 MWt/m^3 or more is used under conditions of high temperature and high pressure of 4 to 7 MPa of pressure difference between a primary fluid and a secondary fluid, and 500°C to 900°C of maximum operating temperature. A thickness of metal plate is set at 0.3 times or more of an equivalent diameter of a flow path, and a pitch between flow paths along a width direction of the metal plate is set at 0.5 times or more of the equivalent diameter of the flow path.

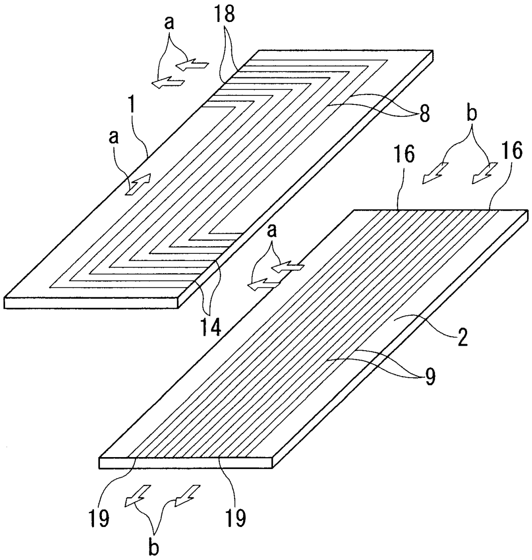

FIG. 2

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Description

Technical Field

[0001] The present invention relates to a heat exchanger of stacked plate type, and more particularly, to a heat exchanger processing a fluid of high temperature and high pressure requiring a large heat exchange rate, having a compact structure, and performing an excellent work in reducing pressure loss.

Background Art

[0002] In recent years, as a compact heat exchanger, there has been utilized in various fields a heat exchanger of stacked plate type, including a flow path member which is formed by metal plates being subjected to groove-forming processing, stacked and bonded to each other, the flow path member including the grooves formed between as a primary flow path and a secondary flow path for heat exchange respectively.

[0003] The stacked plate type heat exchangers proposed in the past include, for example, a heat exchanger having a structure of sandwiching one plate formed with perforations for flowing a secondary fluid therethrough between two plates formed with perforations for flowing a primary fluid therethrough, and causing the two plates to be firmly attached to each other (for example, refer to Japanese Patent No. 2862213, (Patent Document 1)).

[0004] Furthermore, there is also proposed a structure of stacking and bonding a plurality of plates each having a large number of fins attached thereon to form flow paths, thereby improving heat exchange efficiency (for example, refer to Japanese Unexamined Patent Application Publication No. 2000-506966 (Patent Document 2)).

[0005] However, although the heat exchangers proposed in the past technology aim at compactness of the structure, they do not necessarily assume a fluid at high temperature and high pressure requiring a large heat exchange rate as a target fluid, and thus, they are not applicable to, for example, a power generation facility and a hydrogen production facility using a high temperature gas furnace as a heat source.

[0006] Regarding the power generation facility, the hydrogen production facility, and the like using a high temperature gas furnace as the heat source, a common technology installing a high temperature and high pressure heat exchanger is disclosed (refer to INL/EXT-05-00453, 2005, Thermal-Hydraulic Analyses of Heat Transfer Fluid Requirements and Characteristics for Coupling a Hydrogen Product Plant to a High-Temperature Nuclear Reactor, Idaho National Laboratory, (for example, Figures 1 and 2 of page 5), (Non-Patent Document 1)).

[0007] For the above-described stacked plate type heat exchanger, there was not given investigation or consideration as to stress generated in a material of a heat exchanger caused by a pressure difference between the primary fluid and the secondary fluid and a pressure difference from external atmosphere of the heat exchanger, and as to thermal stress generated in the material of the heat exchanger caused by a temperature difference between the primary fluid and the secondary fluid.

[0008] As a result, it has been difficult or impossible to use stacked plate type heat exchangers of the prior art under a condition of high temperature and high pressure.

[0009] In particular, there is not known in the prior art a heat exchanger which is applicable to a plant operating under high temperature and high pressure conditions of 4 to 7 MPa of pressure difference between the primary fluid and the secondary fluid and 800°C to 900°C of maximum operating temperature, such as a power generation facility or a hydrogen production facility using a high temperature gas furnace as the heat source.

Disclosure of the Invention

[0010] The present invention has been made to solve the above-described deficiencies, and an object of the present invention is to provide a stacked plate type heat exchanger having compactness providing a heat exchange rate per unit volume of 10 MWt/m^3 or more, wherein it is possible to provide a heat exchanger applicable under high temperature and high pressure conditions of 4 to 7 MPa of pressure difference between the primary fluid and the secondary fluid and 500°C to 900°C of the maximum operating temperature, providing the compactness and providing high performance and structural integrity under the conditions.

[0011] Inventors of the present invention investigated the following subjects for a stacked plate type heat exchanger having compactness and performing an excellent work in reducing pressure loss for a target fluid at high temperature and high pressure requiring a large heat exchange rate. That is, with reference to the above reference literature (Non-Patent Document 1), (1) investigation of strength evaluation formula, (2) investigation of allowable stress, (3) determination of flow path dimensions and limit thereof, (4) equivalent diameter, (5) grounds for set values in claims, (6) parameter survey, and the like, are investigated.

(1) Strength Evaluation Formula

[0012] As for the flow path dimensions refer to Fig. 6 and Fig. 15 relating to following embodiments. As typical examples of the flow path shape, Fig. 6 shows a semicircular flow path, and Fig. 15 shows a tetragonal flow path. The strength evaluation formula for determining a size of a heat exchanger having a such type of flow path is expressed as follows based on the above reference literature (Non-Patent Document 1), from which formula the respective flow path dimensions, tf, Pf, and tp, are determined.

[0013] In Fig. 6 and Fig. 15, Pf is a pitch of flow paths in a horizontal direction, d is a width of flow path in a horizontal direction, tp is a pitch between flow paths, and tf is a distance between flow paths in a horizontal direction.

[0014] With an allowable stress of So, a pressure difference of ΔP (= P_i - P_o), and a flow path width of d, a necessary pitch Pf of flow paths in a horizontal direction, is limited to

[Equation 1]

$$P_f \geq d\left(1+\frac{\Delta P}{S_0}\right)$$

[0015] A necessary distance tf between the flow paths in the horizontal direction, is limited to

[Equation 2]

$$t_f \geq \frac{P_f}{\frac{S_0}{\Delta P}+1}$$

[0016] A thickness of plate tp, which is the pitch of flow paths in a vertical direction is limited by a following formula.

[Equation 3]

$$t_p \geq \frac{d}{2}\sqrt{\frac{S_0+P_i}{S_0+2P_o-P_i}}$$

(2) Allowable Stress

[0017] From a known comparative diagram of 10^3 h creep fracture stress intensity, the 10^3 h creep fracture stress intensity of an iron-based oxide dispersion strengthened alloy containing chromium and aluminum, such as INCOLOY alloy956 (trade name), is 80 MPa at 900°C. Considering, however, necessity of 10^5 h creep fracture stress intensity for calculating the allowable stress, a value multiplied by 0.5 is adopted as a safety factor.

[0018] When a primary stress is evaluated in a creep region, the maximum allowable stress intensity So is used as the allowable stress. However, generally when temperature becomes 500°C or above, the 10^5 h creep fracture strength becomes predominant, so that the 10^5 h creep fracture strength is used for calculating So. The value of So is determined, referring to the JSME design and construction standards or the ASME Code, by multiplying the average value of 10^5 h creep fracture strength with a factor 0.67. As a result, the allowable stress is calculated as below, and the value is set at 25 MPa on a safety side.

[Equation 4]

$$S0 = 80 \times 0.5 \times 0.67 = 26.8 \text{ MPa} \rightarrow 25 \text{ MPa}$$

(3) Determination of Flow Path Dimensions and Limit thereof

[0019] Referring to the conventional heat exchangers, the flow path width being set at d = 1.5 mm, the pressure difference being set at ΔP = 7 MPa from the specification of high temperature gas furnace set as a target of the present invention, then, from the paragraph 1, the limit value of the pitch Pf is calculated as:

[Equation 5]

$$Pf \geq d(1 + \Delta P/S_0) = 1.5 \times (1 + 7/25) = 1.92\ mm$$

and consequently, Pf = 2.0 mm.

[0020] In this case, the limit value of the necessary distance tf in the horizontal direction is calculated as:

[Equation 6]

$$tf \geq Pf/(S_0/\Delta P + 1) = 2.0/(25/7 + 1) = 0.44\ mm$$

$$tfmin \geq Pfmin/(S_0/\Delta P + 1) = 1.92/(25/7 + 1) = 0.42\ mm$$

accordingly, tf = 0.5mm.

[0021] The limit value of plate thickness tp is calculated as:

[Equation 7]

$$tp \geq d/2\sqrt{(S_0 + P_i)/(S_0 + 2P_o - P_i)} = 1.5/2 \times \sqrt{(25 + 7)/(25 + 2 \times 0 - 7)} = 1.0\ mm, \text{ and}$$

and thus, tp = 1.2 mm. The plate thickness is determined based on the dimensions of a base material.

(4) Equivalent Diameter

[0022] The equivalent diameter de of the flow path is expressed by a following formula, where A is a cross sectional area of the flow path, and S is a wet perimeter length of the flow path.

[Equation 8]

$$d_e = \frac{4A}{S}$$

(4-1) Semicircular flow path (Fig. 6)

[0023] The equivalent diameter d_{e1} of a semicircular flow path is calculated as follows based on the dimensions of paragraph (3).

[Equation 9]

$$A_1 = (\pi \times 1.5^2/4)/2 = 0.884\ mm^2$$

$$S_1 = \pi \times 1.5/2 + 1.5 = 3.86\ mm$$

$$d_{e1} = 4 \times 0.884/3.86 = 0.92\ mm$$

(4-2) Tetragonal flow path (Fig. 15)

[0024] The equivalent diameter d_{e2} of tetragonal flow path is calculated as follows based on the dimensions of paragraph (3).

[Equation 10]

$$A_2 = 1.5 \times 1.5/2 = 1.13\ mm^2$$

$$S_2 = 1.5 \times 2 + 1.5/2 \times 2 = 4.50\ mm$$

$$d_{e2} = 4 \times 1.13/4.50 = 1.00\ mm$$

(5) Grounds for Set values in Present Invention

[0025] Using the equivalent diameter d_e, the dimensions to be important for evaluating the strength of the heat exchanger are investigated.

[0026] The dimensions to be important for evaluating the strength of the heat exchanger are the minimum thickness t_{min} of thin metal sheet-shaped plate (= tp_{min} -d/2), and the pitch distance of flow paths in the plate width direction or the distance tf between the flow paths in the horizontal direction. According to the dimensions of paragraph (3), these values become:

[Equation 11]

$$tmin = tpmin - d/2 = 1.0 - 1.5/2 = 0.25\ mm$$

$$tfmin = 0.42\ mm$$

(5-1) Semicircular flow path (Fig. 6)

[0027] From d_{e1} = 0.92 mm,

[Equation 12]

$$\text{The minimum plate thickness} = 0.30 \times d_{e1} = 0.30 \times 0.92 = 0.28 \geq t_{min}$$

$$\text{The distance in the horizontal direction} = 0.5 \times d_{e1} = 0.5 \times 0.92 = 0.46 \geq tf_{min}$$

The dimensions given in the present invention satisfy the limit values.

(5-2) Tetragonal flow path (Fig. 15)

[0028]

[Equation 13]

From d_{e2} = 1.00 mm, the minimum plate thickness becomes $0.30 \times d_{e2} = 0.30 \times 1.00 = 0.30 \geq t_{min}$

[0029] The distance in the horizontal direction = $0.5 \times d_{e2} = 0.5 \times 1.00 = 0.50 \geq tf_{min}$

[0030] For the result, the dimensions given in the present invention satisfy the limit values.

(6) Parameter Survey

[0031] Under the following two conditions, the calculations are conducted to confirm that the minimum thickness of the thin metal sheet-shaped plate is 0.3 times or more of the equivalent diameter of the flow path, and that the pitch distance of flow paths in the plate width direction is 0.5 times or more of the equivalent diameter of flow path.

(6-1-1) The minimum plate thickness is 0.25 times of the equivalent diameter of flow path.

[0032]

(i) Semicircular flow path (Fig. 6)

[Equation 14]

$$tmin_1 = 0.25 \times d_{e1} = 0.25 \times 0.92 = 0.23 \text{ mm}$$

$$tp_1 = tmin_1 + d/2 = 0.23 + 1.5/2 = 0.98 \text{ mm} < tpmin$$

The result is dissatisfactory in the necessary dimensions of paragraph (3).

(ii) Tetragonal flow path (Fig. 15)

[Equation 15]

$$tmin_2 = 0.25 \times d_{e2} = 0.25 \times 1.00 = 0.25 \text{ mm}$$

$$tp_2 = tmin_2 + d/2 = 0.25 + 1.5/2 = 1.00 \text{ mm} < tpmin$$

[0033] The result satisfies the necessary dimensions of paragraph (3).

[0034] Therefore, the case of 0.25 times is dissatisfactory in the dimensional limits in some cases.

(6-1-2) The minimum plate thickness is 0.50 times of the equivalent diameter of flow path.

[0035]

(i) Semicircular flow path (Fig. 6)

[Equation 16]

$$tmin_1 = 0.50 \times d_{e1} = 0.50 \times 0.92 = 0.46 \text{ mm}$$

$$tp_1 = tmin_1 + d/2 = 0.46 + 1.5/2 = 1.21 \text{ mm} > tpmin$$

The result satisfies the necessary dimensions of paragraph (3).
(ii) Tetragonal flow path (Fig. 15)

[Equation 17]

$$tmin_2 = 0.50 \times d_{e2} = 0.50 \times 1.00 = 0.50 \text{ mm}$$

$$tp_2 = tmin_2 + d/2 = 0.50 + 1.5/2 = 1.25 \text{ mm} > tpmin$$

[0036] The result satisfies the necessary dimensions of paragraph (3).

(6-2-1) The pitch distance in the plate width direction is 0.45 times of the equivalent diameter of flow path.

[0037]

(i) Semicircular flow path (Fig. 6)

[Equation 18]

$$tf_1 = 0.45 \times d_{e1} = 0.45 \times 0.92 = 0.41 \text{ mm} < tfmin$$

The result is dissatisfactory in the necessary dimensions of paragraph (3).
(ii) Tetragonal flow path (Fig. 15)

[Equation 19]

$$tf_2 = 0.45 \times d_{e2} = 0.45 \times 1.00 = 0.45 \text{ mm} > tfmin$$

The result satisfies the necessary dimensions of paragraph (3).

[0038] Therefore, the case of 0.45 times is dissatisfactory in the dimensional limits in some cases.

(6-2-2) The pitch distance in the plate width direction is 0.80 times of the equivalent diameter of flow path.

[0039]

(i) Semicircular flow path (Fig. 6)

[Equation 20]

$$tf_1 = 0.80 \times d_{e1} = 0.80 \times 0.92 = 0.74 \text{ mm} > tfmin$$

The result satisfies the necessary dimensions of paragraph (3).

(2) Tetragonal flow path (Fig. 15)

[0040]

[Equation 21]

$$tf_2 = 0.80 \times d_{e2} = 0.80 \times 1.00 = 0.80 \text{ mm} > tfmin$$

[0041] The result satisfies the necessary dimensions of paragraph (3).

[0042] As described above, the evaluation of the dimensional limit values was given, and the evaluation of the reasonability of constants of 0.3 times or more and of 0.5 times or more to the equivalent diameter of flow path was given for the metal plate thickness, and thus proved that no problem arises.

[0043] Therefore, based on the above findings, the present invention provides, in one aspect, a heat exchanger comprising a flow path member which is formed by stacking and bonding metal plates which is subjected to a groove-forming processing, the grooves being formed as a primary flow path and a secondary flow path for heat exchange between the metal plates of the flow path member, wherein a heat exchanging rate per unit volume between both fluids flowing through the respective flow paths is set at 10 MWt/m^3 or more, a thickness of the metal plate is set at 0.3 times or more of an equivalent diameter of the flow path, and a pitch between the flow paths along a width direction of the metal plate is set at 0.5 times or more of the equivalent diameter of the flow path.

[0044] In another aspect, there is also provided, a heat exchanger comprising a flow path member which is formed by stacking and bonding metal plates which is subjected to a groove-forming processing, the grooves being formed as a primary flow path and a secondary flow path for heat exchange between the metal plates of the flow path member, wherein the metal plate is composed of an iron-based oxide dispersion strengthened alloy containing chromium and aluminum.

[0045] In preferred examples of the above aspect, the primary flow path and the secondary flow path may be provided, respectively, with fluid inlet ports and fluid outlet ports at surfaces of a main heat exchange portion of the flow path member along flow directions of the fluids.

[0046] The flow path member may be provided with plenum portions for branching or combining the primary flow path and the secondary flow path, and the fluid inlet ports and the fluid outlet ports of the primary flow path and the secondary flow path, respectively, communicating with the plenum portions are provided at surfaces of the main heat exchange portion of the flow path member along flow directions of the fluids or at surfaces thereof along directions perpendicular to the flow directions of the fluids.

[0047] The primary flow path and the secondary flow path may be wave-shaped flow paths.

[0048] The respective flow paths may be provided with bent portions in which a guide vane or a reinforcement material for guiding each of the fluids along the bent portion.

[0049] The primary flow path and the secondary flow path may have cross sectional shapes formed in semicircle, tetragon, hexagon, or other polygon shape.

[0050] The primary flow path and the secondary flow path may have cross sectional areas which are set to be equal with each other, or are set such that a cross sectional area of the secondary flow path is larger than a cross sectional area of the primary flow path.

[0051] At least one of the primary flow path and the secondary flow path may be formed as a reciprocating flow path in a U-shape, and both front end portions of the reciprocating flow path communicate with the fluid inlet port or the fluid outlet port or with the plenums provided on a same surface of the flow path member.

[0052] The grooves formed as the primary flow path or the secondary flow path may be formed in a manner arranged adjacent to each other on the same metal plate.

[0053] According to the present invention, it is possible to provide a heat exchanger having compactness providing a heat exchange rate per unit volume of 10 MWt/m^3 or more, thus providing high performance and structural integrity.

Brief Description of Drawings

[0054]

Fig. 1 is a perspective view showing a heat exchanger according to the first embodiment of the present invention.

Fig. 2 is an explanatory diagram illustrating a structure of flow paths of the heat exchanger of the first embodiment of the present invention (section II-II of Fig. 1).

Fig. 3 is an explanatory diagram illustrating a plate structure configuring the heat exchanger of the first embodiment of the present invention (cross section of structural components).

Fig. 4 is an explanatory diagram illustrating the flow paths of the heat exchanger of the first embodiment of the present invention (section IV-IV of Fig. 3).

Fig. 5 is an explanatory diagram illustrating the structure of flow paths of the heat exchanger of the first embodiment of the present invention (vertical cross section).

Fig. 6 is an explanatory diagram relating to setting of the heat exchanger of the first embodiment of the present invention.

Fig. 7 is a perspective view illustrating a heat exchanger of the second embodiment of the present invention.

Fig. 8 is an explanatory diagram illustrating a primary flow path of the heat exchanger of the second embodiment of the present invention (section VIII-VIII of Fig. 7).

Fig. 9 is an explanatory diagram illustrating a secondary flow path of the heat exchanger of the second embodiment of the present invention (corresponding to the section VIII-VIII of Fig. 7).

Fig. 10 is an explanatory diagram illustrating the primary flow path of the heat exchanger of the second embodiment of the present invention (horizontal cross section).

Fig. 11 is an explanatory diagram illustrating a secondary flow path of a heat exchanger of the third embodiment of the present invention (vertical cross section).

Fig. 12 is an explanatory diagram illustrating a structure of flow path of a heat exchanger of the fourth embodiment of the present invention (cross section).

Fig. 13 is an explanatory diagram illustrating a structure of flow path of a heat exchanger of the fifth embodiment of the present invention (vertical cross section).

Fig. 14 is an explanatory diagram illustrating a structure of flow path of a heat exchanger of the sixth embodiment of the present invention (vertical cross section).

Fig. 15 is an explanatory diagram relating to setting of the heat exchanger of the sixth embodiment of the present invention.

Fig. 16 is an explanatory diagram illustrating another structure of flow path of the heat exchanger of the sixth embodiment of the present invention (vertical cross section).

Fig. 17 is a perspective view illustrating a heat exchanger of the seventh embodiment of the present invention.

Fig. 18 is an explanatory diagram illustrating a primary flow path of a heat exchanger of the seventh embodiment of the present invention (section XVIII-XVIII of Fig. 17).

Fig. 19 is an explanatory diagram illustrating a secondary flow path of the heat exchanger of the seventh embodiment of the present invention (corresponding to the section XVIII-XVIII of Fig. 17).

Fig. 20 is a perspective view illustrating a heat exchanger of the eighth embodiment of the present invention.

Fig. 21 is an explanatory diagram illustrating a primary flow path of the heat exchanger of the eighth embodiment of the present invention (section XXI-XXI of Fig. 20).

Fig. 22 is an explanatory diagram illustrating a secondary flow path of the heat exchanger of the eighth embodiment of the present invention (corresponding to the section XXI-XXI of Fig. 20).

Fig. 23 is a perspective view illustrating a heat exchanger of the ninth embodiment of the present invention.

Fig. 24 is an explanatory diagram illustrating the heat exchanger of the ninth embodiment of the present invention (section XXIV-XXIV of Fig. 23).

Fig. 25 is a perspective view illustrating a heat exchanger of the tenth embodiment of the present invention.

Fig. 26 is an explanatory diagram illustrating the heat exchanger of the tenth embodiment of the present invention (section XXVI-XXVI of Fig. 25).

Fig. 27 is an enlarged cross section (horizontal cross section) illustrating a heat exchanger of the eleventh embodiment of the present invention.

Fig. 28 is a perspective view illustrating a heat exchanger of the twelfth embodiment of the present invention.

Fig. 29 is an explanatory diagram illustrating a primary flow path of the heat exchanger of the twelfth embodiment of the present invention (section XXIX-XXIX of Fig. 28).

Fig. 30 is an explanatory diagram illustrating a secondary flow path of the heat exchanger of the twelfth embodiment of the present invention (corresponding to the section XXIX-XXIX of Fig. 28).

Best Mode for Carrying Out the Invention

[0055] Embodiments of a heat exchanger according to the present invention will be described hereunder with reference to the accompanying drawings.

[First Embodiment (Figs. 1 to 6)]

[0056] The first embodiment of the present invention will be described hereunder with reference to Figs. 1 to 6.
[0057] Fig. 1 is a perspective view of the heat exchanger of the first embodiment of the present invention. As illustrated in Fig. 2 and Fig. 3, a heat exchanger 3 of the first embodiment is constituted by stacking the thin metal plates 1 and 2, which are one pair of opposing metal plates, as one set (hereinafter referred to as "the plates"). The metal plate 1 is a plate for the flow of primary fluid, having a number of semicircular grooves 8a functioning as a flow path 8 of the primary fluid "a" on one side surface thereof. The other metal plate 2 is a plate for the flow of secondary fluid having a number of semicircular grooves 8b functioning as a flow path 9 of the secondary fluid "b" on one side surface thereof.
[0058] The plate 1 for the flow of primary fluid is, for example, in a rectangular shape. As shown in Fig. 2, for example, a plurality of grooves 8 opens at one side-edge portion at an end side in the longitudinal direction of the plate 1 so as to form a primary fluid inlet port 14, and extends in parallel to each other in the width direction as a shorter side of the plate, and then opens at the other side-edge portion at an end side in the longitudinal direction of the plate 1 to thereby form a primary fluid outlet port 18. That is, the primary fluid forms a main heat exchange portion to flow the primary fluid "a" upward from the lower side of Fig. 2.
[0059] The plate 2 for the flow of secondary fluid has the rectangular shape identical to that of the plate 1 for the flow of the primary fluid. A plurality of grooves 9 opens, for example, at a side-edge part at one end side edge portion in the longitudinal direction of the plate 2 to form the primary fluid inlet port 14, and extends linearly to and opens at the other side edge portion at the other end side in the longitudinal direction, thus forming a secondary fluid outlet port 19. The plate 2 for the flow of the secondary fluid forms the main heat exchange portion to let the secondary fluid "b" flow downward from upper side of Fig. 2.
[0060] As illustrated in Fig. 3, the plates 1 for the flow of the primary fluid and the plates 2 for the flow of the secondary fluid are integrated by bonding them together with surfaces having no grooves 8a and 9a which form the flow paths 8 and 9, respectively, facing the same direction each other, by stacking the bonded plates, for example, in a state that the surface having grooves of a plate face the surface without grooves of the other plate, and by, for example, diffusion bonding the plates.
[0061] Figs. 4 and 5 illustrate a structure in which the above-described plates 1 and 2 are bonded together to form flow paths 5 (primary flow path 8 and secondary flow path 9) separately by wall portions 1a and 1b, and are integrated with each other, while forming the primary flow path 8 and the secondary flow path 9 into semicircular cross section. The primary flow path 8 and the secondary flow path 9 are in a wave-shaped flow path, and the cross sectional areas of the primary flow path 8 and the secondary flow path 9 are designed to be the same with each other.
[0062] As described above, Fig. 6 shows the dimensions and the like of the respective flow paths 8 and 9, that is, Pf: as the flow path pitch in the horizontal direction; d: as the flow path width in the horizontal direction; tp: as the pitch of flow paths; and tf: as the distance between flow paths in the horizontal direction.
[0063] Regarding the dimensional relationship and the material composition of above structure, the setting is determined so as to keep the strength to endure the conditions of temperature range of the primary fluid "a" supplied to the primary flow path 8 in a range from 800°C to 900°C, the pressure difference between the primary fluid "a" and the secondary fluid "b" in a range from 4 to 7 MPa, and the heat exchange rate per unit volume between fluids of 10 MWt/m^3 or more.
[0064] That is, each of the plates 1 and 2 has a thickness of 0.3 times or more of the equivalent diameter of flow path, and the pitch tp of flow paths in the width direction of the plates 1 and 2 is 0.5 times or more of the equivalent diameter of flow path.
[0065] The plates 1 and 2 are made of an iron-based oxide dispersion strengthened alloy containing chromium and aluminum, such as INCOLOY alloy 956 (Fe: 75%, Cr: 20%, Al: 4.5%, Ti: 0.5%, C: 0.05%, and Y_2O_3: 0.5%).
[0066] As described above, in the first embodiment the plate 1 having a number of flow paths of the primary fluid with the plate 2 having a number of flow paths of the secondary fluid are stacked and integrated by means of, for example, diffusion joining, thus forming the heat exchanger 3.
[0067] Further, Fig. 2 illustrates a case of the opposing flows of a flow 15 of the primary fluid entering through the primary fluid inlet port 14 and a flow 17 of the secondary fluid flow entering through a secondary fluid inlet port 16. Although this case may give the best heat exchanging performance, depending on the use, flows parallel to each other may be adopted.
[0068] In the first embodiment, as described above, as the structural material 10, there may be used an iron-based oxide dispersion strengthened (ODS) alloy having high temperature strength of about 25 MPa of allowable stress at 900°C, for example INCOLOY alloy MA 956, and there may be adopted dimensions that the distance P_f 11 between flow paths in the vertical direction is set at 0.7 times or more of the diameter dl_2 of the semicircular flow path and that the distance 13 of flow paths in the horizontal direction is set at 1.3 times or more of the diameter dl_2 of the semicircular flow path. The structural material 10 may be a high nickel-based alloy, such as Alloy 617.
[0069] According to the first embodiment of the structure mentioned above, there can be provided a heat exchanger

realizing compactness having a heat exchanging rate per unit volume of 10 MWt/m^3 or more, thus providing high performance and excellent structural integrity.

[Second Embodiment (Figs. 7 to 9)]

[0070] The second embodiment of the present invention will be described below with reference to Figs. 7 to 9.
[0071] The second embodiment provides a structure in which the fluid inlet port and the fluid outlet port of the respective primary flow path and secondary flow path are provided on the surface of a flow path member along the fluid flow direction at the main heat exchange portion of the flow path member.
[0072] As illustrated in these figures, similar to the first embodiment, the second embodiment is also composed of the plate 1 having the flow path of the primary fluid and the plate 2 having the flow path of the secondary fluid. The primary fluid inlet port 14 and the secondary fluid outlet port 19 are positioned on the same surface, and the primary fluid outlet port 18 and the secondary fluid inlet port 16 are also arranged on the same surface, so that the inlet ports 14 and 16 and the outlet ports 18 and 19 of the primary fluid and the secondary fluid are arranged, respectively, along the fluid flow direction.
[0073] That is, as illustrated in Fig. 8, both the primary flow path 8 and the secondary flow path 9 are formed along the longitudinal direction of the plate 1. Further the other structure is the same to that of the first embodiment.
[0074] Although according to the first embodiment, the primary fluid outlet/inlet port 14 is provided at the position in a direction perpendicular to the secondary fluid outlet/inlet port 16, or at the side surface of the heat exchanger, according to the second embodiment, the primary fluid outlet/inlet port 14 and the secondary fluid outlet/inlet port 16 are positioned on the same surface, so that it is not necessary to install a header or piping on the side surface, thereby decreasing the outer configuration of the heat exchanger 3.
[0075] Furthermore, the flow direction does not turn in right angle as in the case of the first embodiment, and accordingly, in the second embodiment, the pressure loss can be kept at a low level.
[0076] As described above, according to the second embodiment, a heat exchanger having compact structure providing a heat exchange rate per unit volume of 10 MWt/m^3 or more can be provided, thus achieving excellent performance to reduce the pressure loss.

[Third Embodiment (Figs. 10 and 11)]

[0077] The third embodiment of the present invention will be described below with reference to Figs. 10 and 11.
[0078] Similar to the first embodiment, this third embodiment also relates to a heat exchanger having the plate 1 provided with the flow path of the primary fluid and the plate 2 provided with the flow path of the secondary fluid.
[0079] The primary flow path 8 is branched and then combined, and connected to plenums 20 functioning as an inlet port and an outlet port of the flow path, respectively, at side surfaces of the heat exchanger. Compared with the first embodiment in which the inlet port and the outlet port are provided at the side surfaces using the flow paths 21 turning toward the respective side surfaces, this third embodiment can decrease a region 22 in which fluid does not flow countercurrently.
[0080] As described above, this third embodiment provides a heat exchanger having compact structure providing a heat exchanging rate per unit volume of 10 MWt/m^3 or more, thus providing excellent performance to reduce the pressure loss.

[Fourth Embodiment (Fig. 12)]

[0081] The fourth embodiment of the present invention will be described below referring to Fig. 12.
[0082] The fourth embodiment describes a heat exchanger equipped with guide vanes or reinforcement materials in the bent portion of each flow path for guiding each fluid along the bent portion.
[0083] Further, the fourth embodiment constitutes the heat exchanger 3 by the plate walls 1a forming the flow path and guide vanes 24.
[0084] As shown in Fig. 12 of an enlarged view of flow path, a flow 25 of fluid flowing through the flow path 5 is suppressed from generating vortex and separation at curved portions owing to the guide vanes 24 provided at the curved portions of the flow path 5 to thereby reduce the pressure loss. Other structure is almost the same to that of previous embodiments.
[0085] As described above, this fourth embodiment can provide a heat exchanger having compact structure providing a heat transfer rate per unit volume of 10 MWt/m^3 or more, thus providing excellent performance to reduce the pressure loss.

[Fifth Embodiment (Fig. 13)]

[0086] The fifth embodiment of the present invention will be described below referring to Fig. 13.
[0087] The fifth embodiment describes a heat exchanger in which the cross sectional area of the secondary flow path is set to be larger than that of the primary flow path.
[0088] As illustrated in Fig. 13, the fifth embodiment forms the secondary flow path 9 having larger flow path cross sectional area than that of the primary flow path 8. Other structure is almost the same to that of the previous embodiments.
[0089] When the flow rate of the secondary fluid is relatively large compared with that of the primary fluid, a secondary flow path 26 which has larger flow path cross sectional area suppresses the increase in the velocity of the secondary fluid, which can reduce the pressure loss of the secondary fluid.
[0090] As described above, this fifth embodiment can provide a heat exchanger having compact structure providing a heat exchanging rate per unit volume of 10 MWt/m^3 or more, thus providing excellent performance to reduce the pressure loss.

[Sixth Embodiment (Figs. 14 to 16)]

[0091] The sixth embodiment of the present invention will be described hereunder with reference to Figs. 14 to 16.
[0092] Description is given to a heat exchanger in which the flow path cross section of the primary flow path and of the secondary flow path has a shape of tetragon, hexagon or other polygon.
[0093] As illustrated in Fig. 14, the sixth embodiment forms flow paths 27 in a cross section of almost rectangular shape in the flow path member 4. Fig. 15 shows the dimensions and the like of the respective flow paths 8 and 9, in which character Pf denotes the flow path pitch in the horizontal direction; letter "d" denotes the flow path width in the horizontal direction, tp denotes the pitch of flow paths; and tf denotes the distance between flow paths in the horizontal direction.
[0094] Compared with the cases of flow paths in semicircular shape having the same cross sectional area shown in the previous embodiments, this sixth embodiment having the structure mentioned above provides the flow paths 8 and 9 having almost rectangular cross section. These flow paths 8 and 9 increase the heat transfer area with the structural material of the flow path member 4, thus the heat transfer performance being further improved.
[0095] On corners of the rectangular flow path, stress caused by pressure difference or temperature difference is concentrated. Compared with the case of semicircular flow path, however, a structural analysis and the like confirm that the rectangular flow path gives an equivalent stress value.
[0096] As illustrated in Fig. 16, polygonal cross section such as hexagonal shape, other than tetragonal shape, may be applied. Even with such a structure, the flow paths 8 and 9 increase the heat transfer area with the structural material of the flow path member 4 so that the heat transfer performance can be increased.
[0097] As described above, according to this sixth embodiment, a heat exchanger having compact structure providing a heat transfer rate per unit volume of 10 MWt/m^3 or more can be provided, thus achieving high performance and excellent structural integrity.

[Seventh Embodiment (Figs. 17 to 19)]

[0098] The seventh embodiment of the present invention will be described hereunder with reference to Figs. 17 to 19.
[0099] The seventh embodiment describes a heat exchanger in which the plenum portions are formed in the flow path member each branching and combining the primary flow path and the secondary flow path, respectively. The fluid inlet ports and the fluid outlet ports of the primary flow path and the secondary flow path, respectively, communicating with the respective plenum portions are provided at surfaces of the main heat exchanging portion of the flow path member along the flow directions of the fluids or at surfaces thereof along directions perpendicular to the flow directions of the fluids.
[0100] This seventh embodiment provides the heat exchanger with the plate 1 provided with the primary flow path and the plate 2 provided with the secondary flow path. The primary flow path 8 is branched and then combined to be connected with primary plenums 28 serving as the primary flow path inlet port 14 and the primary flow path outlet port 19 at the front surface and the rear surface of the heat exchanger, respectively.
[0101] Similarly, the secondary flow path 9 also has the secondary flow path inlet port 16 of and the secondary flow path outlet port 18, formed by a secondary plenums 29, at the front surface and the rear surface of the heat exchanger, respectively, thereby making it possible to arrange the inlet/outlet ports of the primary flow path and the secondary flow path in the fluid flow direction.
[0102] According to the structure of the seventh embodiment, since the flow path outlet/inlet ports are positioned only on both end-surfaces, it is not necessary to position the flow path outlet/inlet portions at side surface, and it becomes possible to provide the structure reducing the region of cross flow appeared in the case of the first embodiment, thus reducing the longitudinal size of the heat exchanger.

[0103] As described above, according to the seventh embodiment, it is possible to provide a heat exchanger having compact structure providing a heat exchanging rate per unit volume of 10 MWt/m^3 or more.

[Eighth Embodiment (Figs. 20 to 22)]

[0104] The eighth embodiment of the present invention will be described hereunder with reference to Figs. 20 to 22.
[0105] The eighth embodiment describes a heat exchanger in which at least one of the primary flow path and the secondary flow path is formed as reciprocating flow path in a U-shape.
[0106] This eighth embodiment provides the heat exchanger with the plate 1 provided with the primary flow path and the plate 2 provided with the secondary flow path.
[0107] Since the primary flow path 8 and the secondary flow path 9 are formed in U-shape, the secondary flow path inlet port 16 and the primary flow path outlet port 18 are positioned at front surface and rear surface of the heat exchanger, respectively.
[0108] With such a structure, it is not necessary to position the flow path outlet/inlet ports at side surfaces, and according to this structure, the longitudinal size of the heat exchanger can be reduced.
[0109] In addition, the eighth embodiment can provide a heat exchanger having excellent compact structure providing a heat exchanging rate per unit volume of 10 MWt/m^3 or more.

[Ninth Embodiment (Figs. 23 and 24)]

[0110] The ninth embodiment of the present invention will be described hereunder with reference to Figs. 23 and 24.
[0111] This ninth embodiment describes a heat exchanger in which the grooves functioning as the primary flow path and the secondary flow path, respectively, are formed in such an arrangement that the grooves are arranged adjacent to each other on the same metal plate, and the front end portions of the primary flow path and the secondary flow path communicate with the respective fluid outlet ports and the plenums provided on the same surface of the flow path member.
[0112] According to this ninth embodiment, the heat exchanger is provided with plates 30 in which the primary flow path 8 and the secondary flow path 9 are positioned adjacent to each other. Furthermore, the front end portions of the primary flow path 8 and the secondary flow path 9 communicate with the respective fluid outlet ports 18 and 19 opened on the same surface as upper surface of the flow path member and also communicate with the respective plenums 31 and 32 extending in the vertical direction.
[0113] With such a structure, since the primary flow path 8 and the secondary flow path 9 are positioned on the same plate, the heat transfer between the fluids can be enhanced, and it is possible to arrange primary fluid outlet port 18 and the secondary fluid outlet port 19 in a surface parallel with the plate 30 provided with the primary flow path and the secondary flow path owing to the vertically located plenums 31. In addition, the heat exchanging function is conducted only by countercurrent flow mode, eliminating the cross flow, and thus, the outer size of the heat exchanger can be reduced.
[0114] As described above, according to the ninth embodiment, it is possible to provide a heat exchanger having compact structure exhibiting a heat exchanging rate per unit volume of 10 MWt/m^3 or more, thus achieving excellent heat exchange performance.

[Tenth Embodiment (Figs. 25 and 26)]

[0115] The tenth embodiment of the present invention will be described hereunder with reference to Figs. 25 and 26.
[0116] The tenth embodiment describes a heat exchanger in which at least one of the primary flow path and the secondary flow path is formed as reciprocating flow path so as to provide a U-shape, and the front end portions of the reciprocating flow paths communicate with the fluid inlet port and/or the fluid outlet port of the plenum.
[0117] According to this embodiment, the heat exchanger is formed with plates 30 in which the primary flow path and the secondary flow path are provided, giving a modification of the ninth embodiment, arranging the primary flow path 8 in U-shape and the secondary flow path 9 in U-shape on the same plate. The structure makes the heat exchange portion solely countercurrent flow. With such a structure, the tenth embodiment can reduce the outer size of the heat exchanger, and further the presence of turning portion in U-shape increases heat exchange density.
[0118] As described above, according to the tenth embodiment, a heat exchanger having compact structure providing a heat transfer rate per unit volume of 10 MWt/m^3 or more can be provided, thus achieving excellent heat exchange performance.

[Eleventh Embodiment (Fig. 27)]

[0119] The eleventh embodiment of the present invention will be described hereunder with reference to Fig. 27.
[0120] The eleventh embodiment describes a heat exchanger in which reinforcement materials are provided in the

curved portion of each flow path so as to guide the fluid along the curved portion.

[0121] According to the eleventh embodiment, the heat exchanger is configured with the plate 1 provided with the primary flow path, the plate 2 provided with the secondary flow path, and the flow path reinforcement materials 32 shown in the flow path enlarged view of Fig. 27.

[0122] According to such a structure, the flow path reinforcement materials 32 increase the stiffness of upper and lower surfaces of the flow path of the plate, or increase the geometric moment of inertia, thereby significantly increasing the pressure-resistance performance. Furthermore, since the flow path reinforcement materials 32 also play the role of heat transfer fins or turbulators, thus considerably contributing to the improvement of heat transfer performance.

[0123] As described above, according to the eleventh embodiment, a heat exchanger having compact structure providing a heat transfer rate per unit volume of 10 MWt/m^3 or more can be provided, thus achieving high performance and excellent structural integrity.

[Twelfth Embodiment (Figs. 28 to 30)]

[0124] The twelfth embodiment of the present invention will be described hereunder with reference to Figs. 28 to 30.

[0125] The twelfth embodiment describes a heat exchanger 3 in which the flow path structuring member 4 has near-hexagonal shape in planar view, with both end portions thereof in near-triangular shape.

[0126] As shown in Figs. 28 to 30, the heat exchanger of this twelfth embodiment is provided with the plate 1 provided with the primary flow path and the plate 2 provided with the secondary flow path, and both end portions of each plate are formed into approximately triangular shape. The primary fluid "a" and the secondary fluid "b" enter the primary fluid inlet ports 14 adjacent to each other and the secondary fluid inlet ports 16 at opposite side to the primary fluid inlet ports 14, and the respective fluids are discharged from the primary fluid outlet ports 18 and the secondary fluid outlet ports 19, arranged at substantially parallel with each other.

[0127] With such a structure, the materials of fluid inlet/ outlet portions can be reduced in comparison with the case of the rectangular plate 2, and cost reduction can be achieved. Furthermore, the obtuse angle of the curve of the flow path may reduce the pressure loss.

[0128] As described above, the twelfth embodiment can provide a heat exchanger having compact structure providing a heat exchange rate per unit volume of 10 MWt/m^3 or more, thus reducing cost and pressure loss.

Claims

1. A heat exchanger comprising a flow path member which is formed by stacking and bonding metal plates which is subjected to a groove-forming processing, the grooves being formed as a primary flow path and a secondary flow path for heat exchange between the metal plates of the flow path member, wherein a heat exchanging rate per unit volume between both fluids flowing through the respective flow paths is set at 10 MWt/m^3 or more, a thickness of the metal plate is set at 0.3 times or more of an equivalent diameter of the flow path, and a pitch between the flow paths along a width direction of the metal plate is set at 0.5 times or more of the equivalent diameter of the flow path.

2. The heat exchanger according to claim 1, wherein the primary flow path and the secondary flow path are provided, respectively, with fluid inlet ports and fluid outlet ports at surfaces of a main heat exchange portion of the flow path member along flow directions of the fluids.

3. The heat exchanger according to claim 1, wherein the flow path member is provided with plenum portions for branching or combining the primary flow path and the secondary flow path, and the fluid inlet ports and the fluid outlet ports of the primary flow path and the secondary flow path, respectively, communicating with the plenum portions are provided at surfaces of the main heat exchange portion of the flow path member along flow directions of the fluids or at surfaces thereof along directions perpendicular to the flow directions of the fluids.

4. The heat exchanger according to claim 1, wherein the primary flow path and the secondary flow path are wave-shaped flow paths.

5. The heat exchanger according to claim 1, wherein the respective flow paths are provided with bent portions in which a guide vane or a reinforcement material for guiding each of the fluids along the bent portion.

6. The heat exchanger according to claim 1, wherein the primary flow path and the secondary flow path have cross sectional shapes formed in semicircle, tetragon, hexagon, or other polygon shape.

7. The heat exchanger according to claim 1, wherein the primary flow path and the secondary flow path have cross sectional areas which are set to be equal with each other, or are set such that a cross sectional area of the secondary flow path is larger than a cross sectional area of the primary flow path.

8. The heat exchanger according to claim 1, wherein at least one of the primary flow path and the secondary flow path is formed as a reciprocating flow path in a U-shape, and both front end portions of the reciprocating flow path communicate with the fluid inlet port or the fluid outlet port or with the plenums provided on a same surface of the flow path member.

9. The heat exchanger according to claim 1, wherein the grooves formed as the primary flow path or the secondary flow path are formed in a manner arranged adjacent to each other on the same metal plate.

10. A heat exchanger comprising a flow path member which is formed by stacking and bonding metal plates which is subjected to a groove-forming processing, the grooves being formed as a primary flow path and a secondary flow path for heat exchange between the metal plates of the flow path member, wherein the metal plate is composed of an iron-based oxide dispersion strengthened alloy containing chromium and aluminum.

11. The heat exchanger according to claim 10, wherein the primary flow path and the secondary flow path are provided, respectively, with fluid inlet ports and fluid outlet ports at surfaces of a main heat exchange portion of the flow path member along flow directions of the fluids.

12. The heat exchanger according to claim 10, wherein the flow path member is provided with plenum portions for branching or combining the primary flow path and the secondary flow path, and the fluid inlet ports and the fluid outlet ports of the primary flow path and the secondary flow path, respectively, communicating with the plenum portions are provided at surfaces of the main heat exchange portion of the flow path member along flow directions of the fluids or at surfaces thereof along directions perpendicular to the flow directions of the fluids.

13. The heat exchanger according to claim 10, wherein the primary flow path and the secondary flow path are wave-shaped flow paths.

14. The heat exchanger according to claim 10, wherein the respective flow paths are provided with bent portions in which a guide vane or a reinforcement material for guiding each of the fluids along the bent portion.

15. The heat exchanger according to claim 10, wherein the primary flow path and the secondary flow path have cross sectional shapes formed in semicircle, tetragon, hexagon, or other polygon shape.

16. The heat exchanger according to claim 10, wherein the primary flow path and the secondary flow path have cross sectional areas which are set to be equal with each other, or are set such that a cross sectional area of the secondary flow path is larger than a cross sectional area of the primary flow path.

17. The heat exchanger according to claim 10, wherein at least one of the primary flow path and the secondary flow path is formed as a reciprocating flow path in a U-shape, and both front end portions of the reciprocating flow path communicate with the fluid inlet port or the fluid outlet port or with the plenums provided on a same surface of the flow path member.

18. The heat exchanger according to claim 10, wherein the grooves formed as the primary flow path or the secondary flow path are formed in a manner arranged adjacent to each other on the same metal plate.

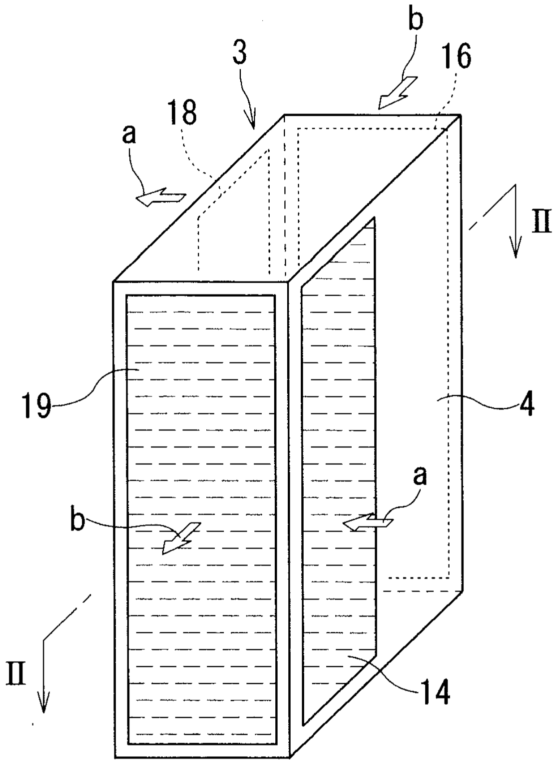

FIG. 1

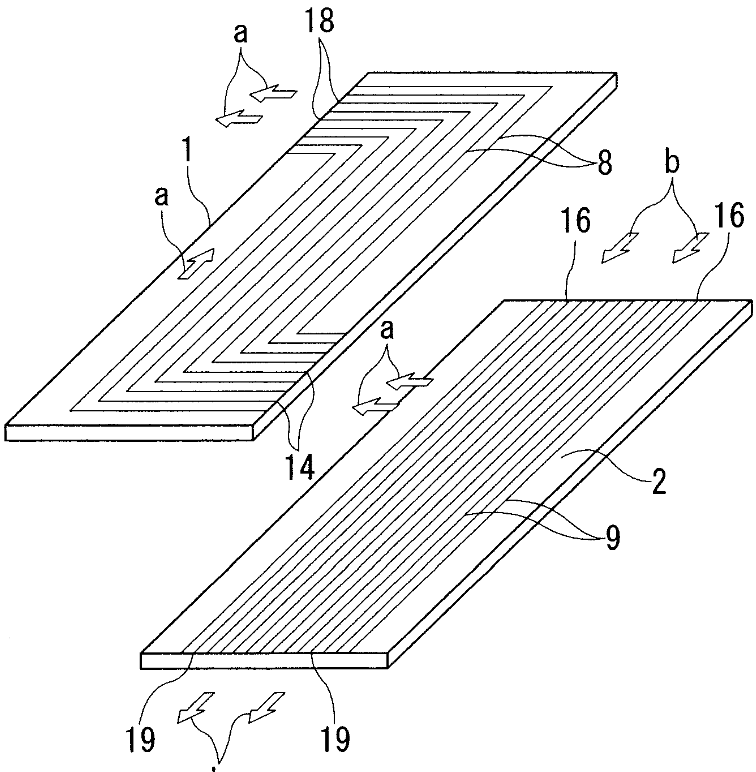

FIG. 2

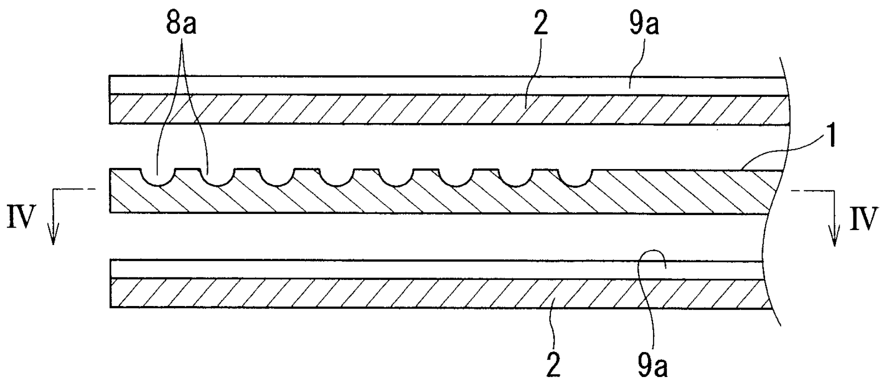

FIG. 3

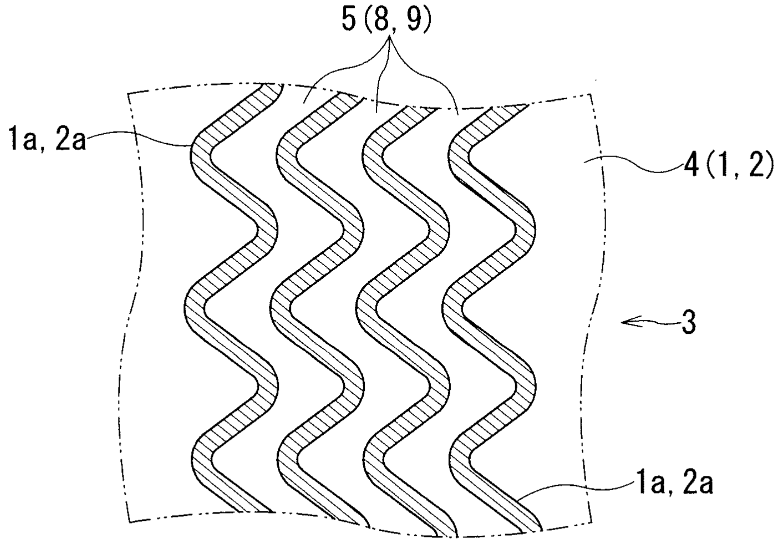

FIG. 4

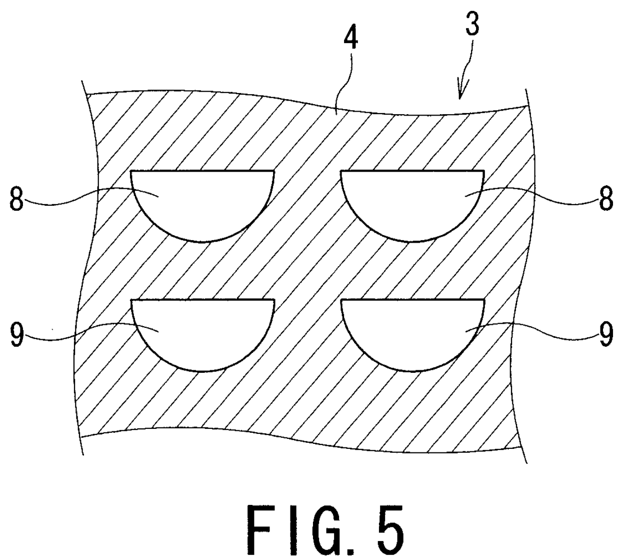

FIG. 5

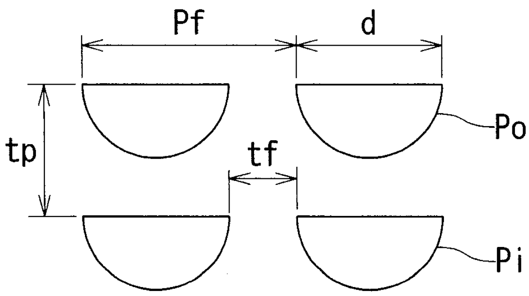

FIG. 6

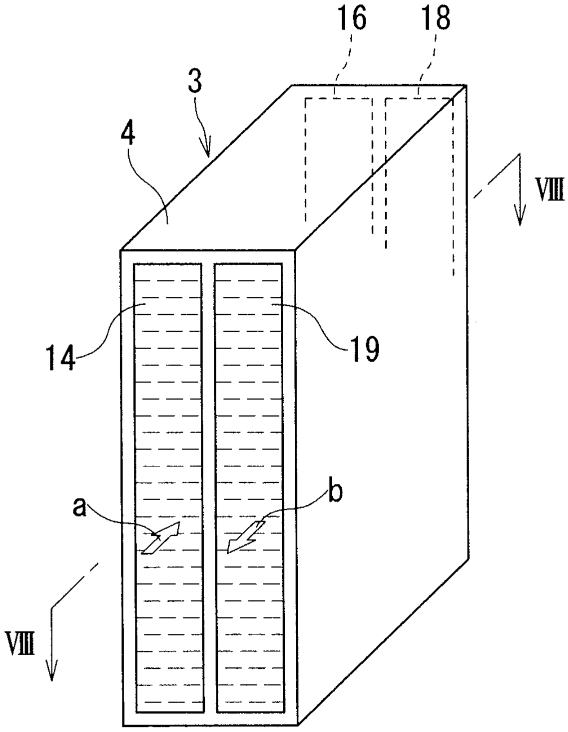

FIG. 7

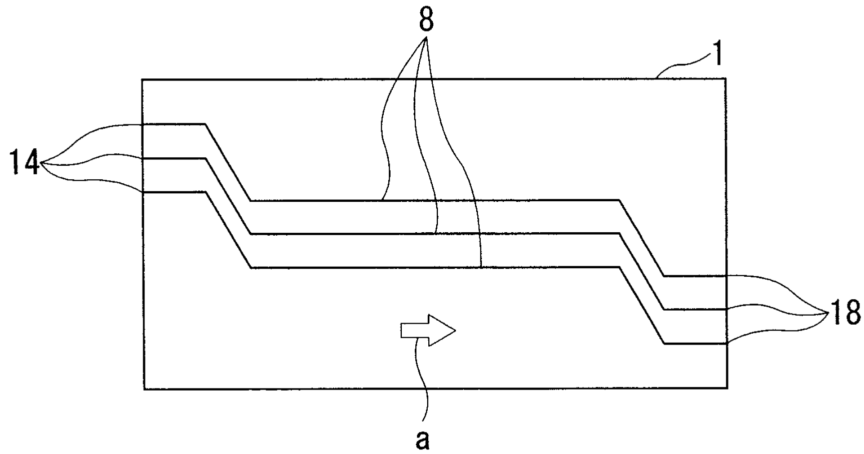

FIG. 8

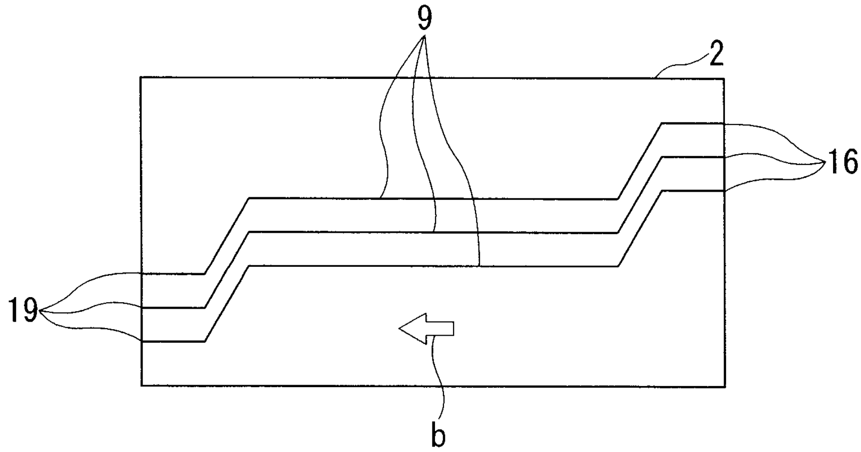

FIG. 9

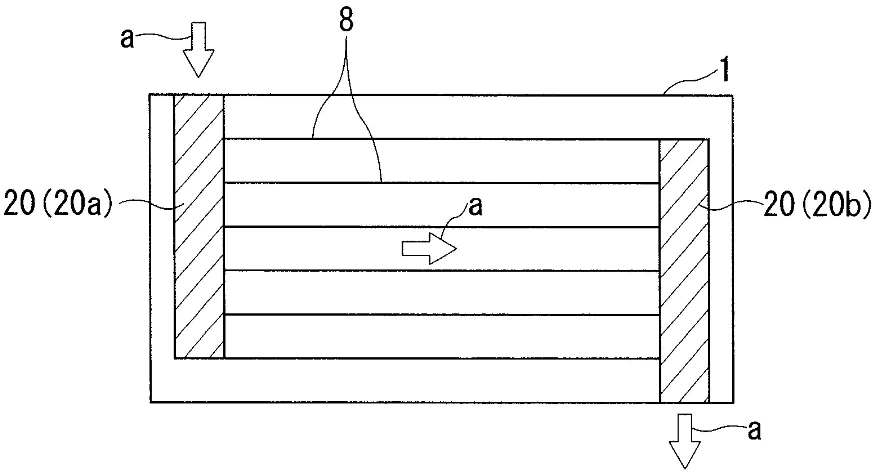

FIG. 10

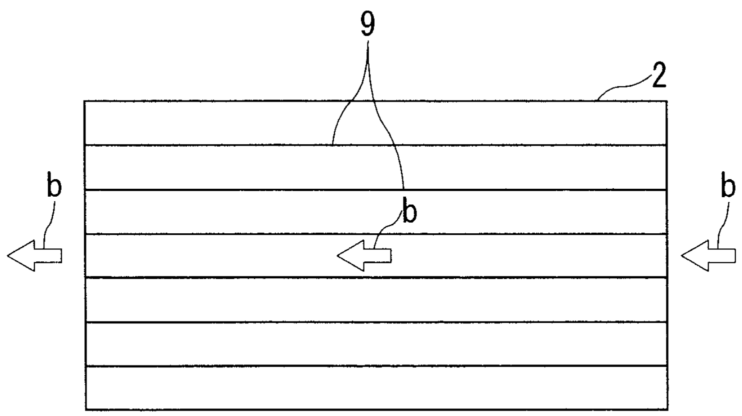

FIG. 11

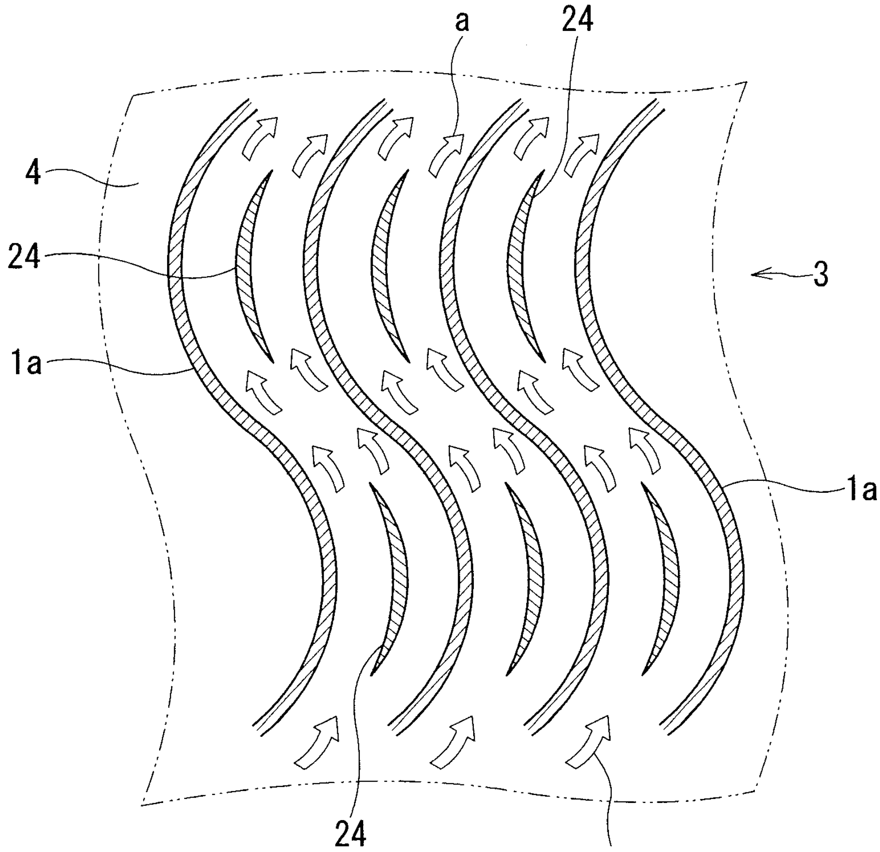

FIG. 12

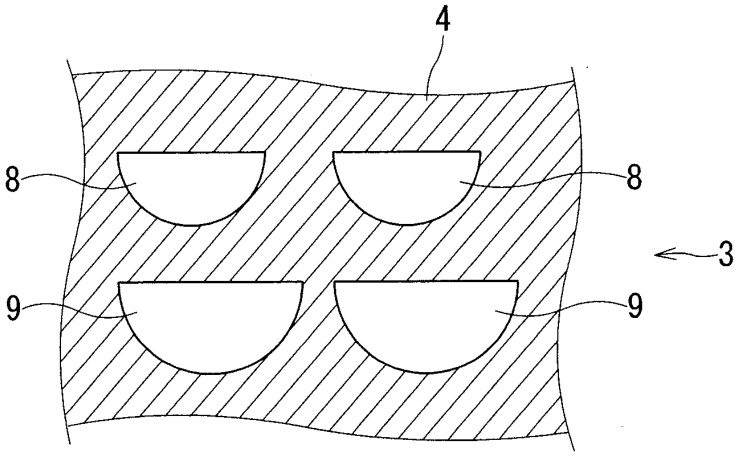

FIG. 13

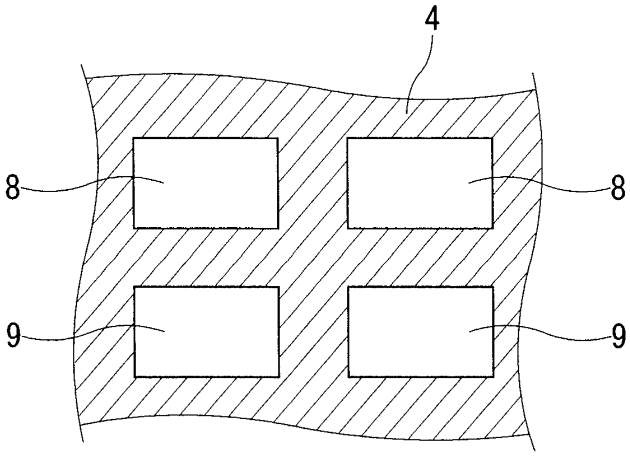

FIG. 14

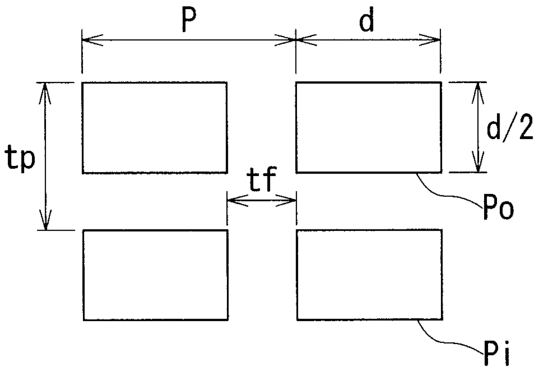

FIG. 15

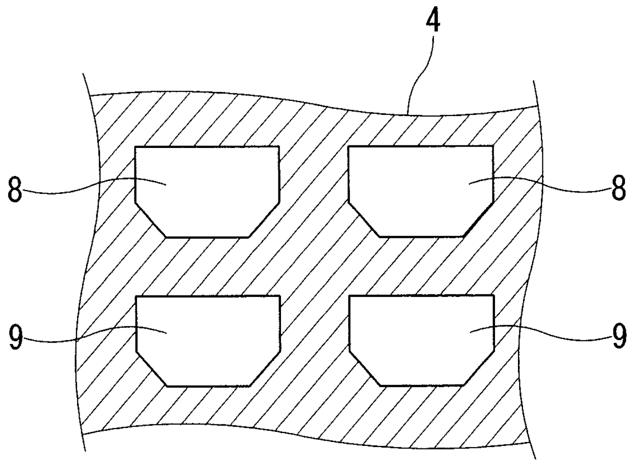

FIG. 16

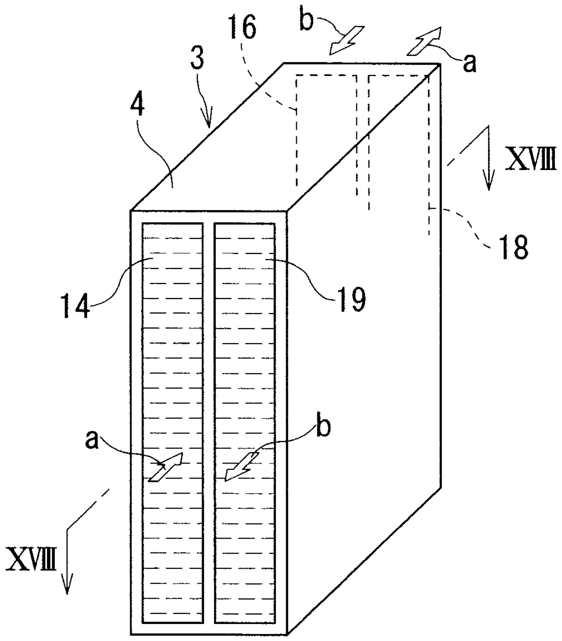

FIG. 17

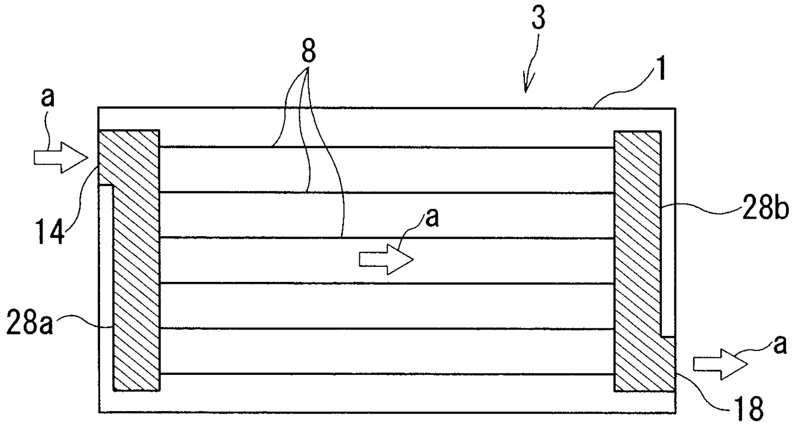

FIG. 18

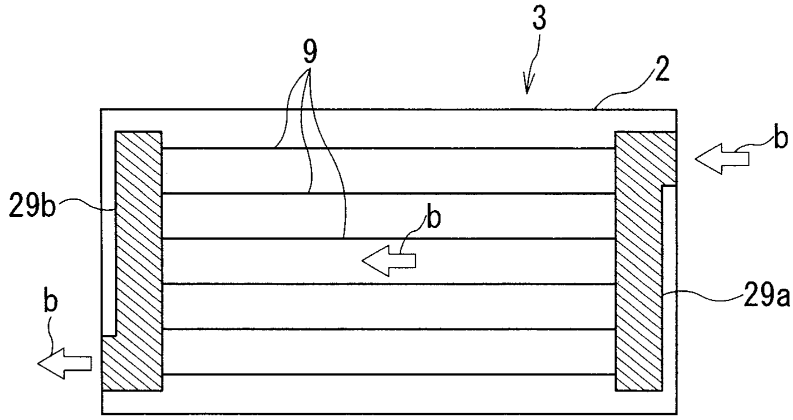

FIG. 19

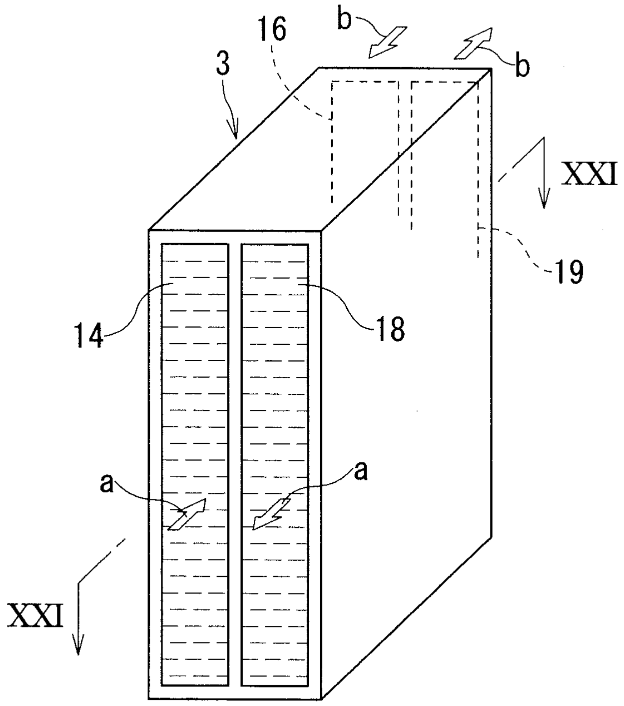

FIG. 20

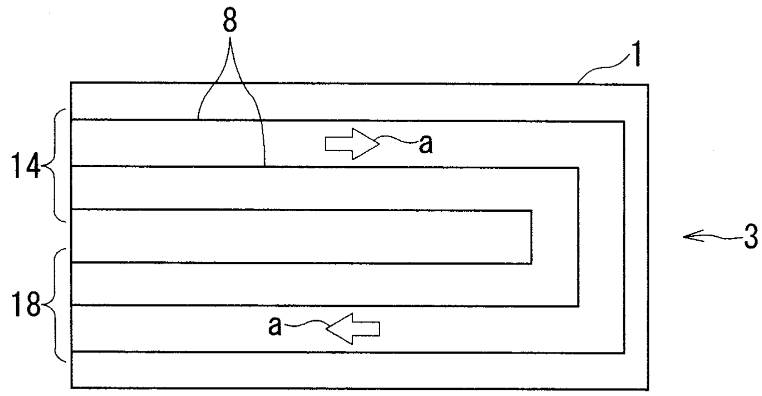

FIG. 21

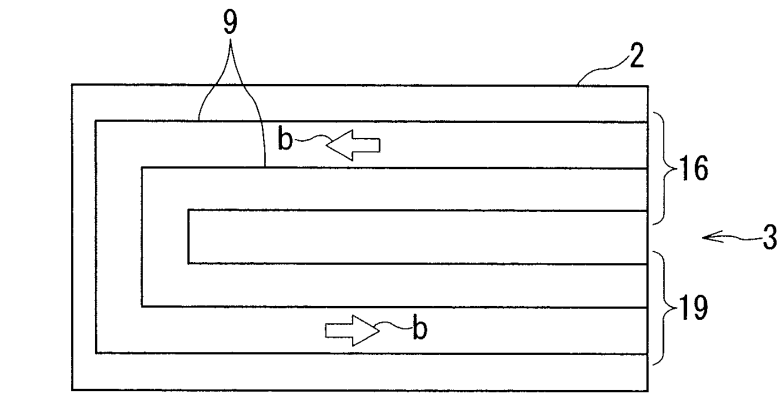

FIG. 22

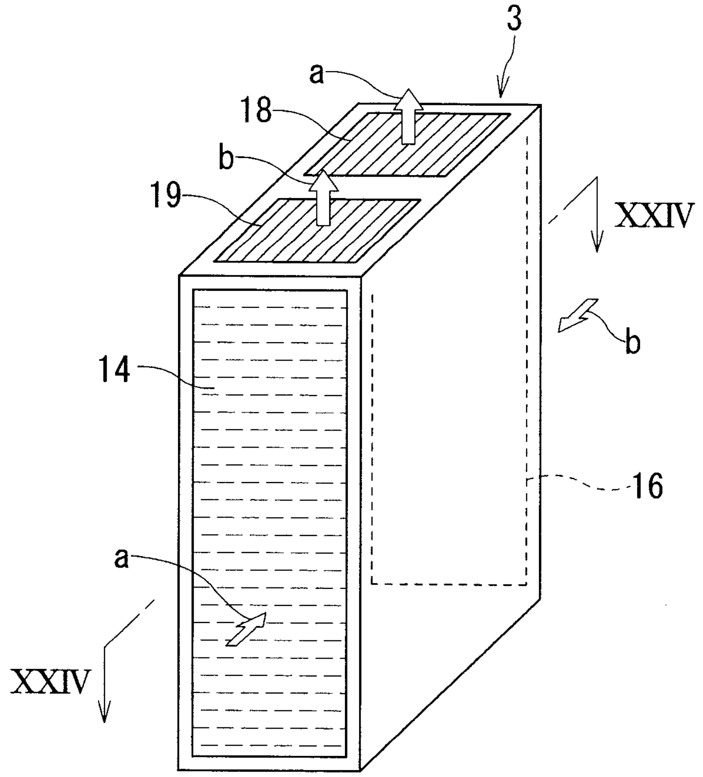
3
a
18
b
19
XXIV
b
14
16
a
XXIV

FIG. 23

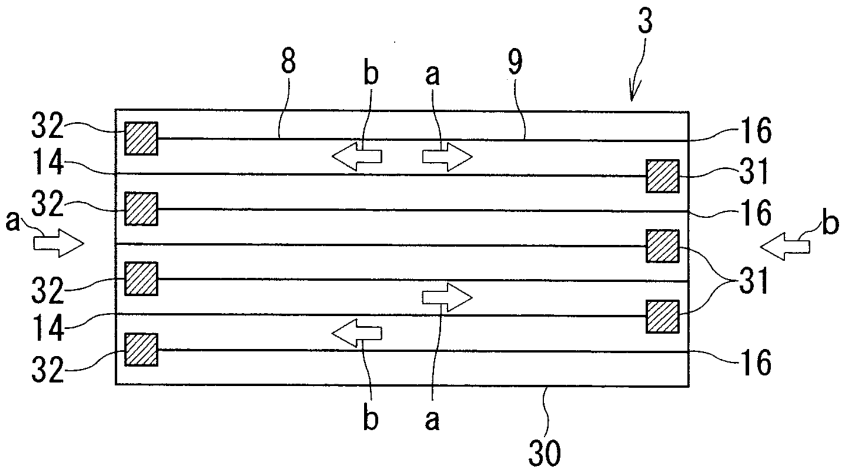
3
8
b
a
9
32
16
14
31
32
16
a
b
32
31
14
32
16
b
a
30

FIG. 24

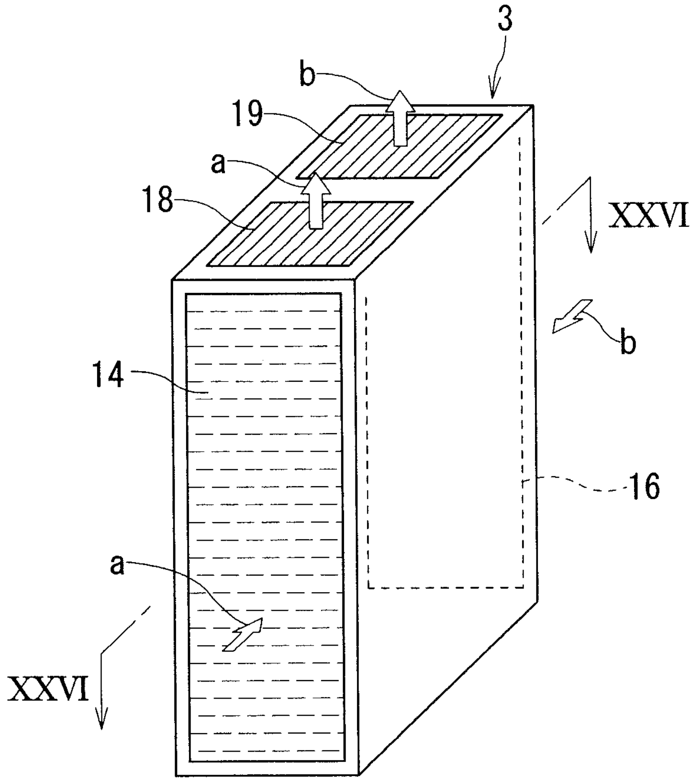

FIG. 25

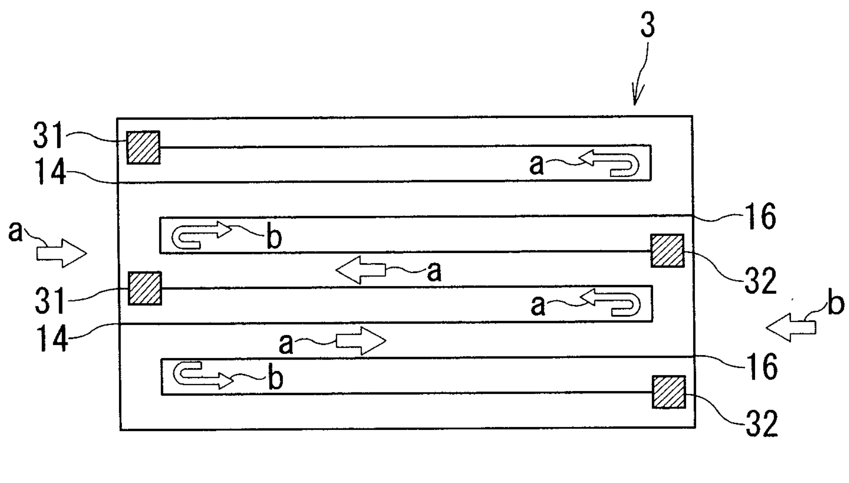

FIG. 26

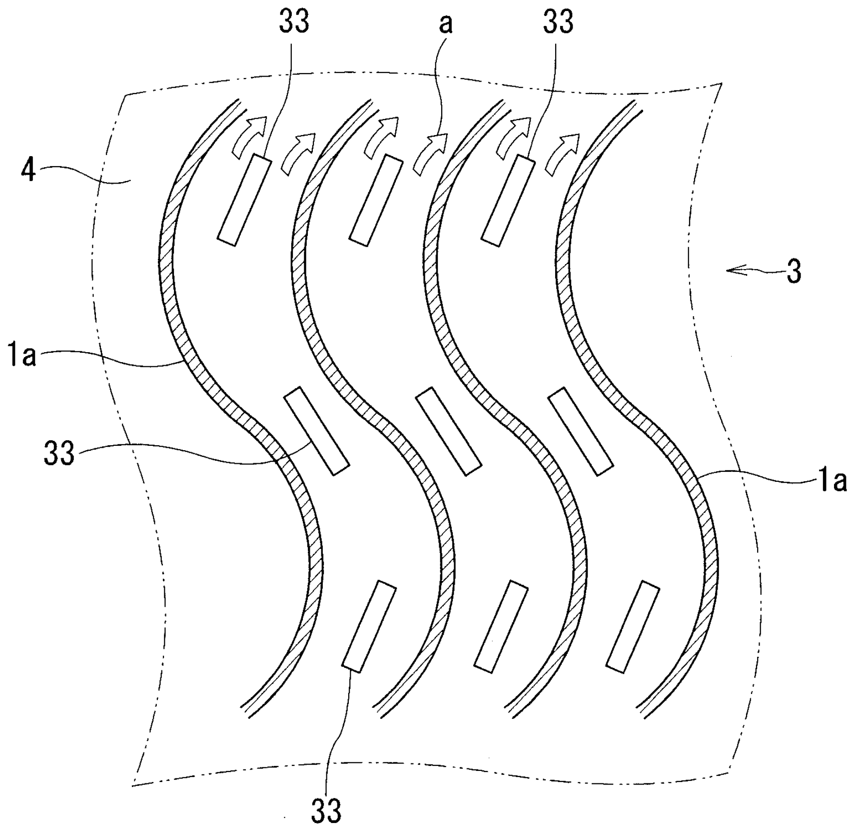

FIG. 27

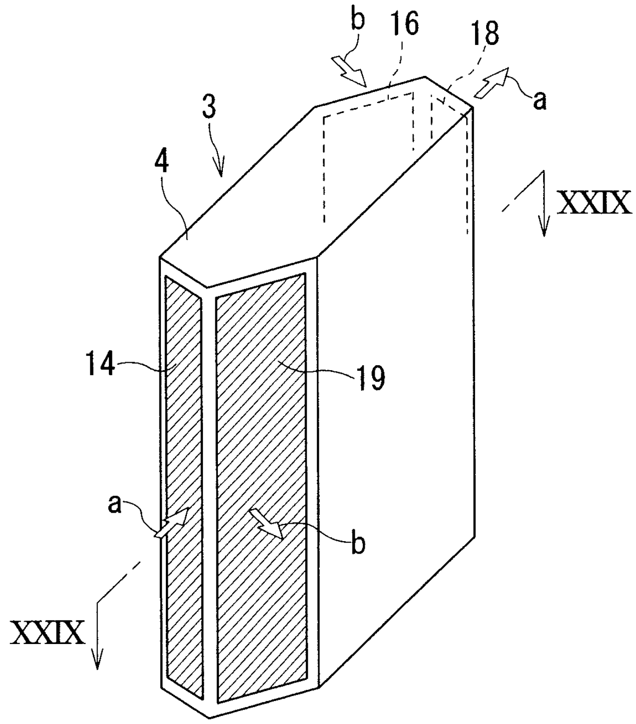

FIG. 28

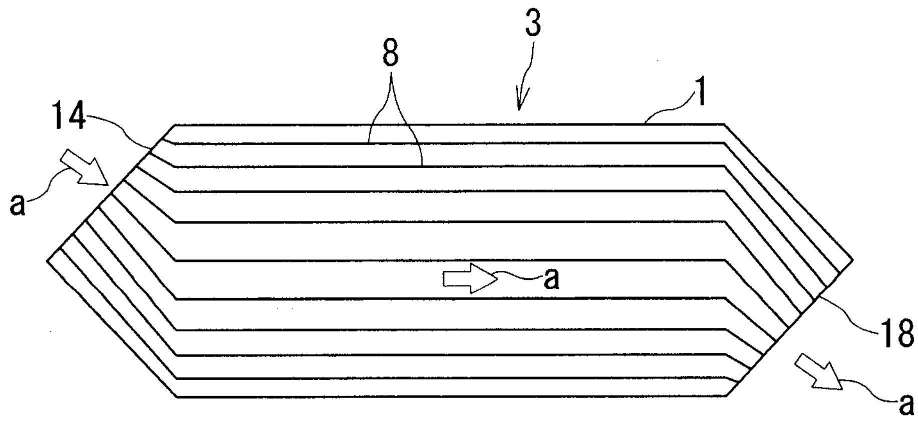

FIG. 29

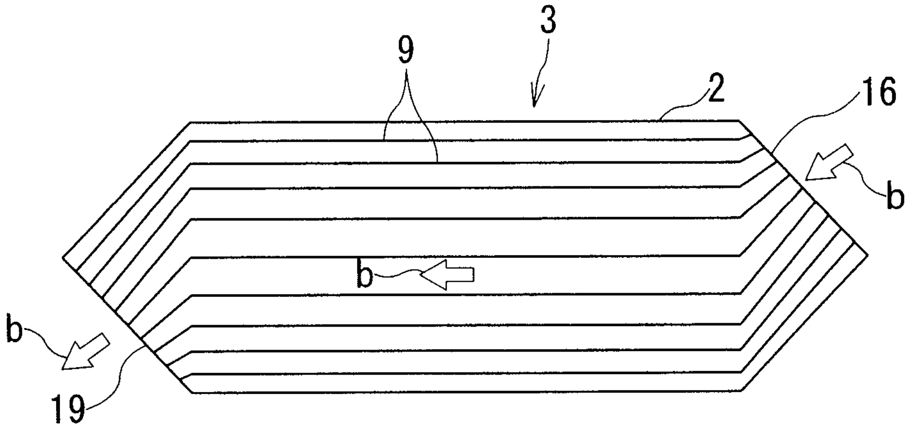

FIG. 30

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2007/072481

A. CLASSIFICATION OF SUBJECT MATTER
F28F3/04(2006.01)i, *F28F3/06*(2006.01)i, *F28F3/08*(2006.01)i, *F28F21/08*(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F28F3/04, F28F3/06, F28F3/08, F28F21/08

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2007
Kokai Jitsuyo Shinan Koho	1971-2007	Toroku Jitsuyo Shinan Koho	1994-2007

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.
X Y	JP 62-37687 A (Heatric Pty. Ltd.), 18 February, 1987 (18.02.87), Page 2, upper right column, line 7 to lower left column, line 2; page 4, lower left column, line 2 to page 5, lower left column, line 16; Figs. 1 to 7 & EP 0212878 A1	1,4,6,7 2,3,5,8-18
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☒ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

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Date of the actual completion of the international search
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Japanese Patent Office

Facsimile No.

Authorized officer

Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2007/072481

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2862213 B **[0003]**
- JP 2000506966 A **[0004]**