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(54) Heat exchange plate

(57) A heat exchange plate (10) includes main protrusions (11), intermediate protrusions (12) and non-protruded portions. The main protrusions (11) having a truncated cone or pyramid shape are placed in positions based on a pattern on the plate (10). The intermediate protrusion (12) is placed between two main protrusions (11) that are adjacent to each other at a shortest distance so that the main protrusion (11) is connected to two other main protrusions (11) through two intermediate protrusions (12). The intermediate protrusion (12) is defined by a flat portion extending to opposing surfaces of the two main protrusions (11). The intermediate protrusion (12) has a peak portion placed in a lower position than a top (11a) of the main protrusion (11). The non-protruded portion is placed between adjacent intermediate protrusions (12). The non-protruded portion is placed in a lowest position relative to a protruding direction of the main and intermediate protrusions (11,12) so as to provide a recess (13) surrounded by the main and intermediate protrusions (11,12).

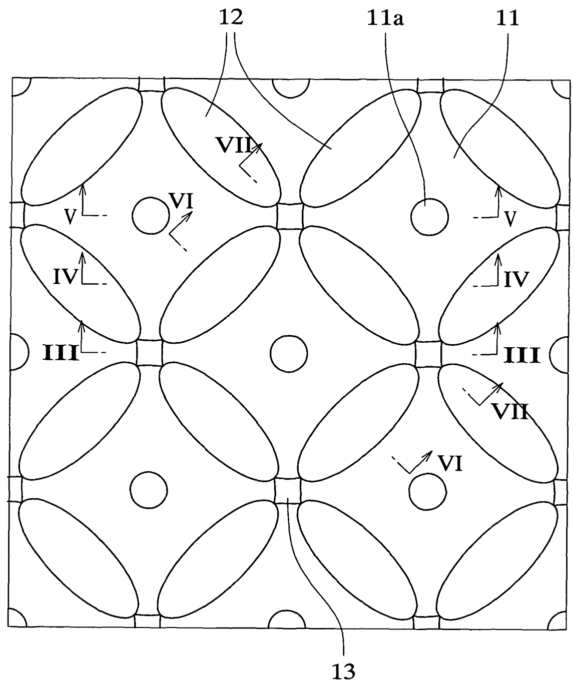

FIG.2

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Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates a heat exchange plate, which is formed of a metallic plate and to be used in combination with the other heat exchange plates having the same structure so that they are combined in parallel and integrally with each other to form a heat exchanger, and especially to such a heat exchange plate that permits to provide an integrally combined state for the heat exchanger in which an appropriate heat exchange can be made between heat exchange fluids in correspondence with differences in characteristic property therebetween, while causing the heat exchange fluids to flow along the opposite surfaces of the heat exchange plate, respectively, thus enhancing heat exchange efficiency.

Description of the Related Art

[0002] If there is a demand that heat transfer coefficient is increased to enhance heat exchange efficiency, utilizing a heat exchanger by which transfer of heat (i.e., heat exchange) is made between a high temperature fluid and a low temperature fluid, a plate-type heat exchanger has conventionally been used widely. The plate-type heat exchanger has a structure in which a plurality of heat transfer plates are placed parallelly one upon another at prescribed intervals so as to form passages, which are separated by means of the respective heat transfer plates. A high temperature fluid and a low temperature fluid flow alternately in the above-mentioned passages to make heat exchange through the respective heat transfer plates. Japanese Patent Provisional Publication No. H3-91695 describes an example of such a conventional plate-type heat exchanger.

[0003] In the conventional plate-type heat exchanger, gasket members formed of elastic material are placed between the adjacent two plates to make the distance between them constant and define passages for fluid. However, a high pressure of the heat exchange fluid flowing between the plates may cause deformation of the gasket member, thus disabling an appropriate separation of the fluids from being ensured or leading to an unfavorable variation in distance between the plates. In such a case, an effective heat exchange may not be carried out, thus causing a problem. In view of these facts, the conventional heat exchanger involves a problem that the heat exchange fluids can be utilized only in a pressure range in which the gasket member withstands.

[0004] There has recently been proposed a heat exchanger having a structure in which metallic thin plates, which are placed at predetermined intervals, are joined together, without using any gasket members, at their ends by welding to assemble the plates into a single unit so as to form passages for heat exchange fluids, on the opposite sides of the respective plates. Japanese Patent Provisional Publication No. 2003-194490 describes, as an example of an invention made by the present inventor, a heat exchange unit in which heat transfer plates formed of metallic thin plates are aligned in parallel with each other so as to be apart from each other, these plates are welded at their periphery excepting one side into a united body having an opening, and the opening is closed by an end plate.

[0005] A pattern of irregularity of herringbone type has conventionally and widely applied to the heat transfer plates of the plate-type heat exchanger. However, such a pattern of irregularity could not achieve a balance of decrease in pressure loss and assured resistance to pressure. Accordingly, various kinds of different pattern of irregularities have been proposed. Japanese Patent Provisional Publication No. 2000-257488 describes an example of such different pattern of irregularities.

[0006] The plates for the above-mentioned conventional heat exchanger has a structure in which the plate includes a plurality of heat transfer sections each of which has a mound configuration provided at its top with a flat portion in a thickness direction of the plate (i.e., a cross section thereof) and a rectangular shape in a plan view of the plate. These plates are combined to each other so as to be placed one upon another to form a single heat exchanger.

[0007] The conventional heat exchangers (i.e., heat exchange units) have structures as described in Japanese Patent Provisional Publication Nos. H3-91695, 2003-194490 and 2000-257488. With respect to the conventional plates described in Japanese Patent Provisional Publication No. 2000-257488, which have a pattern of irregularity that is applicable also to the plates described in Japanese Patent Provisional Publication Nos. H3-91695 and 2003-194490, the plates are placed one upon another to form a heat exchanger so that alternating plates are turned upside down and upper end portions of heat transfer sections of the plate faces flowing passage-intersections of the adjacent plate. The plates are combined to each other so that the heat transfer sections protrude the same direction, with the result that the flowing passages formed between the adjacent two plates have the same pattern.

[0008] Two kinds of liquids used usually in a heat exchanger are different from each other in chemical composition, resulting not only in difference in characteristic property, but also in quite difference in conditions in use such as pressure and flow rate during a heat exchange process. It is therefore theoretically preferable to make heat exchange, with consideration given to heat transfer in accordance with the respective fluids. However, the same pattern of flowing passages formed on the opposite surfaces of the plate leads to substantially the same heat transfer conditions for the plate. Consequently, there is no choice but to make heat exchange under the same heat transfer conditions for the two kinds of liquids flowing the passages. It is therefore difficult to apply optimized heat transfer conditions in accordance with difference in temperature and characteristic properties of the two kinds of heat exchange liquids between which heat exchange is to be made through the plate, thus causing a problem of no achievement of effective heat exchange.

SUMMARY OF THE INVENTION

[0009] An object of the present invention, which was made to solve the above-mentioned problems, is therefore to provide a heat exchange plate, which permits to optimize a pattern of irregularity of heat transfer sections to cope with a problem of difference in characteristic properties of fluids that flow on the opposite surfaces of the plate, respectively, and ensure sufficient heat transfer performance, thus obtaining a high heat exchange efficiency.

[0010] In order to attain the aforementioned object, a heat exchange plate of the first aspect of the present invention, which is formed of a metallic plate and has a predetermined pattern of irregularity, the heat exchange plate being placed on another heat exchange plate having a same structure so as to come into contact with each other on a same side of the heat exchange plate to provide a pair of heat exchange plates, the pair of heat exchange plates being combined to one or more other pair of heat exchange plates integrally with each other to form a heat exchanger in which heat exchange is to be made between first and second heat exchange fluids that come into contact with opposite surfaces of the heat exchange plate, respectively, the heat exchange plate comprises: a plurality of main protrusions that protrude outward from one surface of the heat exchange plate in a form of a truncated cone or a truncated pyramid, the protrusions being placed in predetermined positions based on a predetermined pattern on the heat exchange plate; a plurality of intermediate protrusions each of which is placed between two main protrusions that are adjacent to each other at a shortest distance so that each of the main protrusions is connected to two or more other main protrusions through two or more intermediate protrusions, each of the intermediate protrusions being defined by one or more flat or curved portions that extend to opposing surfaces of the two main protrusions, and each of the intermediate protrusions having one or more peak portions that are placed in a lower position than a top of the main protrusion; and a plurality of non-protruded portions each of which is placed between adjacent intermediate protrusions of the plurality of intermediate protrusions, each of the plurality of non-protruded portions being placed in a lowest position relative to a protruding direction of the main and intermediate protrusions, the plurality of non-protruded portions providing recesses surrounded by the main and intermediate protrusions.

[0011] According to the first aspect of the present invention, the heat exchange plate has the pattern of irregularity in which the main protrusions and the intermediate protrusions are formed on the metallic plate. When the heat exchange plate is combined to the other heat exchange plate having the same structure so that they face each other on the same side and the tops of the main protrusions of the former plate come into contact with the corresponding tops of the main protrusions of the latter plate, or projections formed on the rear sides of the recesses surrounded by the main and intermediate protrusions of the former plate come into contact with corresponding projections formed on the rear sides of the recesses surrounded by the main and intermediate protrusions of the latter plate, to form a combined unit, and then the thus formed combined unit is combined to the other combined units in the same manner, a gap in which wide and narrow areas repeatedly continue along lines along which the protrusions are aligned on the plate is formed between the respective adjacent two plates. As a result, the gaps having different configuration and size are provided on the opposite surfaces of the plate. Such gaps provide different passages, thus achieving different heat transfer performance. As a result, appropriate selection of the passages in accordance with characteristic property of the heat exchange fluids makes it possible to progress heat transfer between the plate and the respective fluids in a remarkably effective manner, thus providing an effective heat exchange between the heat exchange fluids. In addition, gaps between the protrusions extend linearly on straight lines along which the protrusions are aligned, while expanding and reducing in a repeated manner, to form passage sections so that the passage section intersects the other passage section so as to communicate therewith, thus providing a braided passage structure. Even when a flowing relationship of the heat exchange fluids is based on any one of a parallel flowing system, a counter-flowing system and a cross flowing system, it is therefore possible to cause the heat exchange fluids to behave in flow in substantially the same manner to provide substantially the same heat transfer performance. In addition, even when the heat exchange fluids flow on the basis of any combination of the flowing directions, it is possible to make smoothly heat exchange with low pressure-loss and enhance degree of freedom in design of a heat exchanger, thus providing excellent versatility.

[0012] In the second aspect of the heat exchange plate of the present invention, each of the main protrusions may have a shape of the truncated cone; and each of the intermediate protrusions is defined by the one or more curved portions.

[0013] According to the second aspect of the present invention, the plate is constructed in the combined form of curved bodies by defining each of the main protrusions by the truncated cone and each of the intermediate protrusions by the one or more curved portions. It is therefore possible to reduce pressure loss and achieve smooth flow of the heat exchange fluids and smooth heat transfer, thus improving heat exchange efficiency. In addition, such a curved structure permits dispersion of force applied to the plate, thus enhancing strength to cope with a fluid having a high pressure and improving formability. When seawater is used as one of the heat exchange fluids, which is introduced into the passage between the plates, such a curved structure prevents fouling from attaching thereto, thus avoiding deterioration of performance for a long period of time.

[0014] In the third aspect of the heat exchange plate of the present invention, each of the main protrusions may have a shape of the truncated pyramid; and each of the intermediate protrusions may be constructed by the one or more flat portions.

[0015] According to the third aspect of the present invention, the plate is constructed in the combined form of flat surface bodies by defining each of the main protrusions by the truncated pyramid and each of the intermediate protrusions by the one or more flat portions. It is therefore possible to provide an easier design of the heat transfer sections of the plate and easily impart suitable heat exchange properties for the respective heat exchange fluids to the plate. In addition, it is possible to easily manufacture the plate, thus reducing costs.

[0016] In the fourth aspect of the heat exchange plate of the present invention, each of the intermediate protrusions may have two or more mound portions that are placed on a straight line, which is perpendicular to a reference line along which the adjacent two main protrusions are aligned so that the intermediate protrusion is placed between the surfaces the main protrusions, each of the mound portions having a height that is smaller than one-half of a height of the main protrusion.

[0017] According to the fourth aspect of the present invention, the height of the intermediate protrusion is decreased to create variation in configuration of the passages provided on the opposite surfaces of the plate so that the height of the passage provided above the intermediate protrusion is smaller than the height of the passage provided below the intermediate protrusion. As a result, it is possible to create variation in flow rate and flow velocity of the heat exchange fluids respectively flowing the adjacent passages between which the plate is placed. This can cope with a case where the two kinds of heat exchange fluids with which heat exchange is to be made are remarkably different from each other in amounts of the fluids flowing into and discharging from the heat exchanger, to achieve heat transfer without loss, thus improving the heat exchange efficiency. The passage having the smaller height is provided below the intermediate protrusion so as to increase the flowing velocity of the fluid, thus achieving effective progress of heat transfer and more remarkably improving the heat exchange efficiency.

[0018] In order to attain the aforementioned object, a heat exchange plate of the fifth aspect of the present invention, which is formed of a metallic plate and has a predetermined pattern of irregularity, the heat exchange plate being placed on another heat exchange plate having a same structure so as to come into contact with each other on a same side of the heat exchange plate to provide a pair of heat exchange plates, the pair of heat exchange plates being combined to one or more other pair of heat exchange plates integrally with each other to form a heat exchanger in which heat exchange is to be made between first and second heat exchange fluids that come into contact with opposite surfaces of the heat exchange plate, respectively, the heat exchange plate comprises: a plurality of main protrusions that protrude outward from one surface of the heat exchange plate in a form of a truncated cone, the protrusions being placed in predetermined positions based on a predetermined pattern on the heat exchange plate, each of the main protrusions being provided at a foot portion thereof with alternating first and second conical surface edges, two main protrusions that are adjacent to each other at a shortest distance are connected to each other at the first conical surface edge so that each of the main protrusions are connected to two or more other main protrusions through two or more first conical surface edges; and a plurality of non-protruded portions each of which is placed between the second conical surface edges of other two main protrusions that are adjacent to each other at a longer distance than the shortest distance, each of the plurality of non-protruded portions being placed in a lowest position relative to a protruding direction of the main protrusions, the plurality of non-protruded portions providing recesses surrounded by the main protrusions.

[0019] According to the fifth aspect of the present invention, the heat exchange plate has the pattern of irregularity in which the main protrusions are provided in the form of truncated cone on the metallic plate. When the heat exchange plate is combined to the other heat exchange plate having the same structure so that they face each other on the same side and the tops of the main protrusions of the former plate come into contact with the corresponding tops of the main protrusions of the latter plate, or projections formed on the rear sides of the recesses surrounded by the main protrusions of the former plate come into contact with corresponding projections formed on the rear sides of the recesses surrounded by the main protrusions of the latter plate, to form a combined unit, and then the thus formed combined unit is combined to the other combined units in the same manner, a gap in which wide and narrow areas repeatedly continue along lines along which the main protrusions are aligned on the plate is formed between the respective adjacent two plates. As a result, the gaps having different configuration and size are provided on the opposite surfaces of the plate. Such gaps provide different passages, thus achieving different heat transfer performance. As a result, appropriate selection of the passages in accordance with characteristic property of the heat exchange fluids makes it possible to progress heat transfer between the plate and the respective fluids in a remarkably effective manner, thus providing an effective heat exchange between the heat exchange fluids. In addition, gaps between the protrusions extend linearly on straight lines along which the protrusions are aligned, while expanding and reducing in a repeated manner, to form passage sections so that the passage section intersects the other passage section so as to communicate therewith, thus providing a braided passage structure. Even when a flowing relationship of the heat exchange fluids is based on any one of a parallel flowing system, a counter-flowing system and a cross flowing system, it is therefore possible to cause the heat exchange fluids to behave in flow in substantially the same manner to provide substantially the same heat transfer performance. In addition, even when the heat exchange fluids flow on the basis of any combination of the flowing directions, it is possible to make smoothly heat exchange with low pressure-loss and enhance degree of freedom in design of a heat exchanger, thus providing excellent versatility.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020]

FIG. 1 is a schematic structural view of a heat exchange plate according to the first embodiment of the present invention;
FIG. 2 is an enlarged view of a portion shown by the symbol "A" or "B" in FIG. 1;
FIG. 3 is a cross-sectional view cut along the line III-III in FIG. 2;
FIG. 4 is a cross-sectional view cut along the line IV-IV in FIG. 2;
FIG. 5 is a cross-sectional view cut along the line V-V in FIG. 2;
FIG. 6 is a cross-sectional view cut along the line VI-VI in FIG. 2;
FIG. 7 is a cross-sectional view cut along the line VII-VII in FIG. 2;
FIGS. 8 and 9 are structural views of gaps provided above and below the heat exchange plate, respectively, according to the first embodiment of the present invention in a state in which the heat exchange plates are combined in parallel with each other;
FIG. 10 is an enlarged view of an essential part of the heat exchange plate according to the modified embodiment of the present invention;
FIG. 11 is enlarged view of an essential part of the heat exchange plate according to the second embodiment of the present invention;
FIG. 12 is a cross-sectional view cut along the line XII-XII in FIG. 11;
FIG. 13 is a cross-sectional view cut along the line XIII-XIII in FIG. 11;
FIG. 14 is a cross-sectional view cut along the line XIV-XIV in FIG. 11;
FIG. 15 is enlarged view of an essential part of the heat exchange plate according to the third embodiment of the present invention;
FIG. 16 is an enlarged view of a portion shown by the symbol "K" or "L" in FIG. 15;
FIG. 17 is a cross-sectional view cut along the line XVII-XVII in FIG. 16;
FIG. 18 is a cross-sectional view cut along the line XVIII-XVIII in FIG. 16;
FIG. 19 is a cross-sectional view cut along the line XIX-XIX in FIG. 16;
FIG. 20 is a cross-sectional view cut along the line XX-XX in FIG. 16;
FIG. 21 is a cross-sectional view cut along the line XXI-XXI in FIG. 16; and
FIGS. 22 and 23 are structural views of gaps provided above and below the heat exchange plate, respectively, according to the third embodiment of the present invention in a state in which the heat exchange plates are combined in parallel with each other.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] Now, the first embodiment of the present invention will be described in detail below with reference to FIGS. 1 to 9. FIG. 1 is a schematic structural view of a heat exchange plate according to the first embodiment of the present invention; FIG. 2 is an enlarged view of a portion shown by the symbol "A" or "B" in FIG. 1; FIG. 3 is a cross-sectional view cut along the line III-III in FIG. 2; FIG. 4 is a cross-sectional view cut along the line IV-IV in FIG. 2; FIG. 5 is a cross-sectional view cut along the line V-V in FIG. 2; FIG. 6 is a cross-sectional view cut along the line VI-VI in FIG. 2; FIG. 7 is a cross-sectional view cut along the line VII-VII in FIG. 2; FIGS. 8 and 9 are structural views of gaps provided above and below the heat exchange plate, respectively, according to the first embodiment of the present invention in a state in which the heat exchange plates are combined in parallel with each other.

[0022] As shown in the above-mentioned figures, the heat exchange plate 10 according to the first embodiment of the present invention is formed of a metallic plate having a rectangular shape. The metallic plate has a pattern of irregularity press-formed thereon, which includes a plurality of main protrusions 11 and a plurality of intermediate protrusions 12. Each of the main protrusions 11 protrude outward from one surface of the plate in the form of a truncated cone so as to be placed at a regular interval in an aligned configuration. Each of the intermediate protrusions 12 is placed in the form of protrusion between the opposing conical surfaces of two main protrusions 11 that are adjacent to each other at the shortest distance. The intermediate protrusion 12 is defined by a curved portion that extends to the opposing conical surfaces of the above-mentioned two main protrusions 11. Each of the intermediate protrusions 12 has a peak portion 12a that is placed in a lower position than the top 11a of the main protrusion 11. The main protrusions 11 having the shape of truncated cone, for forming the pattern of irregularity, are provided on the basis of a matrix arrangement in which the main protrusions 11 are aligned at regular intervals so that one main protrusion 11 is connected at four positions on the periphery thereof to four other main protrusions 11 through the above-mentioned intermediate protrusions 12, respectively. A straight line along which the intermediate protrusions are aligned so as to be placed between the adjacent two main protrusions 11 is inclined at an angle of 45 degrees relative to the respective sides of the plate having the rectangular shape. Apart from such a pattern of irregularity, the heat exchange plate may have the other pattern of irregularity in which a straight line along which the main protrusions 11 are aligned is perpendicular to or in parallel to the respective sides of the plate, or inclined at a desired angle relative thereto.

[0023] In addition, there is provided a plurality of non-protruded portions each of which is placed between adjacent intermediate protrusions of the plurality of intermediate protrusions 12, and more specifically between the main protrusion 11 and the other main protrusion 11 that is adjacent to the former main protrusion 11, not through the intermediate protrusion 12, at a slightly longer distance than the above-mentioned shortest distance. Each of the non-protruded portions is placed in a lowest position relative to a protruding direction of the main and intermediate protrusions 11, 12. These non-protruded portions provide recesses 13 each of which is surrounded by the conical surface of the main protrusion 11 and the curved surface of the intermediate protrusion 12. Connection of the conical surface of the main protrusion 11 to the curved surface of the intermediate protrusion 12 is placed in a higher position than the above-mentioned recess 13. The plate has such a curved structure that permits to disperse force applied to the plate, enhance strength so as to cope with a fluid having a high pressure and improve formability.

[0024] The above-described heat exchange plate 10 is placed on the other heat exchange plate having the same structure so that they face each other on the same side and the tops 11a of the main protrusions 11 of the former plate come into contact with the corresponding tops of the main protrusions of the latter plate, or projections formed on the rear sides of the recesses 13 surrounded by the main and intermediate protrusions 11, 12 of the former plate come into contact with corresponding projections formed on the rear sides of the recesses 13 surrounded by the main and intermediate protrusions 11, 12 of the latter plate, to form a combined unit, and then the thus formed combined unit is combined to the other combined units in the same manner, to form a heat exchanger that has gaps, i.e., passages each of which is defined by the adjacent two plates. The heat exchange fluids flow in these passages to make heat exchange between one of these fluids coming into contact with the upper surface of the plate and the other of these fluids coming into contact with the lower surface of thereof. The plates are combined integrally with each other in this manner so that the main protrusions or the projections come into contact with each other, thus enhancing strength. As a result, even when a high pressure is applied between the plates, the heat exchanger cannot be easily deformed. Variation in distance between the plates can be prevented, thus permitting to cope with a case in which there is a large difference in pressure between the heat exchange fluids.

[0025] In the gap 14 formed between the two adjacent plates of the thus combined plates, in which gap the main protrusions 11 and the intermediate protrusions 12 protrude, the intermediate protrusions 12 having a smaller height than the main protrusions 11 face each other with a predetermined distance kept therebetween and the recesses 13 having a further smaller height than the main protrusions 11 face each other with a predetermined distance kept therebetween. Gaps formed between the corresponding intermediate protrusions 12 communicate with gaps formed between the corresponding recesses 13 to form a straight passage. In such a passage, the flow passage area between the corresponding recesses 13 is larger than the flow passage area between the corresponding intermediate protrusions 12 so that the passage extends linearly, while expanding and reducing in a repeated manner. Such a passage intersects the other passages so as to communicate therewith, thus providing a braided passage structure (see FIG. 8 and FIG. 9).

[0026] On the other hand, in the gap 15 formed between the two adjacent plates of the thus combined plates, in which gap the main protrusions 11 and the intermediate protrusions 12 protrude do not protrude, the gaps between the corresponding main protrusions 11 communicate with each other through the gaps between the corresponding intermediate protrusions 12 to form a straight passage. In such a passage, the flow passage area between the corresponding main protrusions 11 is larger than the flow passage area between the corresponding intermediate protrusions 12 so that the passage extends linearly, while expanding and reducing in a repeated manner. Such a passage intersects the other passages so as to communicate therewith, thus providing a braided passage structure (see FIG. 8 and FIG. 9). When a heat exchanger composed of the plates as combined in a manner as described above is placed in use so that the plates stand upright and one of the both sides of each plate is placed horizontally or vertically, the passages each of which is defined by the alternating corresponding intermediate protrusions 12 and recesses 13, are kept in an inclined state.

[0027] The pattern of irregularity on the upper surface of the plate is not symmetrical relative to the pattern of irregularity on the lower surface of the plate and the plate is placed on the other plate so that they come into contact with each other on the same side, with the result that the above-described gaps 14 and 15 are different in configuration and size from each other. Therefore, such gaps 14, 15 provide different heat transfer performance in accordance with their configuration and size. The pattern of irregularity of the plate is set so as to obtain appropriate configuration and size of the gaps 14, 15, with consideration given to characteristic properties of two kinds of fluids between which heat exchange it to be made, thus providing suitable heat transfer performance for these fluids. The heat exchanger is subjected to specifications concerning the general structure therefore so that the heat exchange fluids are introduced into the gaps 14, 15 providing the predetermined transfer performance, respectively.

[0028] Now, description will be given below of operation of the heat exchanger that is composed of the heat exchange plates 10 according to the embodiment of the present invention. Heat exchange is made between the two kinds of heat exchange fluids by introducing one of these fluids into the gaps 14 formed between the two adjacent plates of the unit in which the plates are place paralelly one upon another and combined together, in which gaps the main protrusions 11 and the intermediate protrusions 12 protrude and discharging it therefrom, on the one hand, and by introducing the other of these fluids into the gaps 15 formed between the two adjacent plates of the unit, in which gaps the main protrusions 11 and the intermediate protrusions 12 do not protrude and discharging it therefrom, on the other hand.

[0029] The gaps 14, 15 that are defined between the plates by configurations of the protrusions 11, 12 extend continuously and linearly on the straight lines along which the protrusions 11, 12 are aligned. Even when a flowing relationship of the heat exchange fluids, which flow in the gaps 14, 15, respectively, is based on any one of a parallel flowing system, a counter-flowing system and a cross flowing system, it is therefore possible to cause the heat exchange fluids to behave in flow in substantially the same manner to provide substantially the same heat transfer performance. In addition, even when the heat exchange fluids flow on the basis of any combination of the flowing directions, it is possible to reduce pressure loss in the passages so as to ensure smooth flow in the gaps 14, 15, thus making effective heat exchange.

[0030] In an example case in which heat exchange fluids flow in accordance with the counter-flowing system, there is formed, in the gap 14 formed between the two adjacent plates of the combined plates, in which gap the main protrusions 11 and the intermediate protrusions 12 protrude, a flow braided passage mainly including passage sections that extend obliquely along the straight lines on which the protrusions 11, 12 are aligned, between the corresponding recesses 13 having the lowest projection height and between the corresponding intermediate protrusions 12 having the intermediate projection height so that the heat exchange fluid flows in this flow braided passage. On the other hand, in the gap 15 formed between the two adjacent plates of the combined plates, in which gap the main protrusions 11 and the intermediate protrusions 12 protrude do not protrude, a flow braided passage mainly including passage sections that extend obliquely along the straight lines on which the protrusions 11, 12 are aligned, between the corresponding recesses 13, which are provided on the back side of the main protrusions 11, and between the corresponding back sides of the intermediate protrusions 12 so that the other heat exchange fluid flows in this flow braided passage. As a result, the heat exchange fluids introduced into the combined plates flows in the oblique direction on the opposite surfaces of the heat transfer plate 10, respectively, while repeating divergence and confluence to spread smoothly over every area of the plate.

[0031] It is therefore possible to cause the heat exchange fluid to spread over the entire area of the plate to facilitate the heat transfer between the heat exchange fluids and improving the heat exchange rate. In addition, the heat transfer fluids respectively flow in the flow braided passages that have specific configurations enabling the heat exchange fluids to flow, while repeating divergence and confluence and have heat transfer performance as set in contemplation of the characteristic properties of the heat exchange fluids on the opposite surfaces of the plate. As a result, heat transfer between the heat exchange fluids through the heat transfer plate 10 effectively progresses, thus remarkably enhancing heat exchange efficiency between the fluids.

[0032] In the heat exchange plate according to the first embodiment of the present invention, the heat exchange plate 10 has the pattern of irregularity in which the main protrusions 11 having the truncated conical shape and the intermediate protrusions 12 defined by the curved portion are formed on the metallic plate. When the heat exchange plate is combined to the other heat exchange plate having the same structure so that they face each other on the same side and the tops 11a of the main protrusions 11 of the former plate come into contact with the corresponding tops 11a of the main protrusions 11 of the latter plate, or projections formed on the rear sides of the recesses 13 surrounded by the main protrusions 11 and the intermediate protrusions 12 of the former plate come into contact with corresponding projections formed on the rear sides of the recesses surrounded by the main and intermediate protrusions 11, 12 of the latter plate, to form a combined unit, and then the thus formed combined unit is combined to the other combined units in the same manner, a gap 14(15) in which wide and narrow areas repeatedly continue along lines along which the protrusions are aligned on the plate is formed between the respective adjacent two plates. As a result, the gaps 14,15 having different configuration and size are provided on the opposite surfaces of the plate. Such gaps provide different passages, thus achieving different heat transfer performance. As a result, appropriate selection of the passages in accordance with characteristic property of the heat exchange fluids makes it possible to progress heat transfer between the plate and the respective fluids in a remarkably effective manner, thus providing an effective heat exchange between the heat exchange fluids. In addition, the plate is constructed in the combined form of curved bodies by defining each of the main protrusions by the truncated cone and each of the intermediate protrusions by the one or more curved portions. It is therefore possible to reduce pressure loss and achieve smooth flow of the heat exchange fluids and smooth heat transfer, thus improving heat exchange efficiency. In addition, such a curved structure permits dispersion of force applied to the plate, thus enhancing strength to cope with a fluid having a high pressure and improving formability. When seawater is used as one of the heat exchange fluids, which is introduced into the passage between the plates, such a curved structure prevents fouling from attaching thereto, thus avoiding deterioration of performance for a long period of time.

[0033] The heat exchange plate according to the first embodiment of the present invention may have any desired structure, except for the heat transfer sections having the pattern of irregularity. More specifically, the heat exchange plate may be used as a heat exchange plate for a plate-type heat exchanger in which the plates are welded together at their edges or for a plate-type heat exchanger in which the plates are combined together through gasket members provided between the adjacent two plates.

[0034] In the heat exchange plate according to the first embodiment of the present invention, the plate has a structure in which the main protrusions 11 are aligned so that each of the main protrusion 11 is provided at four positions on its periphery with the four corresponding intermediate protrusions 12. The present invention is not limited only to such an arrangement, and the plate may have, for example, a structure in which the main protrusions 16 are aligned a shown in FIG. 10 so that each of the main protrusion 16 is provided at six positions on its periphery with the six corresponding intermediate protrusions 17 or recesses 18, so as to form a staggered arrangement in the main protrusions 16 and the tops 16a thereof. The plate may have any desired type of structure with arrangement in which each of the main protrusions is combined with a predetermined number of adjacent main protrusions in this manner. It is therefore possible to make precise adjustment so that the flow braided passages defined by the adjacent two plates have suitable heat transfer performance for the characteristic properties of the heat transfer fluids introduced into the passages.

[0035] Now, the second embodiment of the present invention will be described in detail below with reference to FIGS. 11 to 14. FIG. 11 is enlarged view of an essential part of the heat exchange plate according to the second embodiment of the present invention; FIG. 12 is a cross-sectional view cut along the line XII-XII in FIG. 11; FIG. 13 is a cross-sectional view cut along the line XIII-XIII in FIG. 11; FIG. 14 is a cross-sectional view cut along the line XIV-XIV in FIG. 11.

[0036] As shown in the above-mentioned figures, the heat exchange plate 20 according to the second embodiment of the present invention is formed of a metallic plate having a rectangular shape in the same manner as the first embodiment of the present invention. The metallic plate has a pattern of irregularity press-formed thereon, which includes a plurality of main protrusions 21 each of which protrudes outward from one surface of the plate in the form of a truncated cone. However, the plate 20 according to the second embodiment differs from the plate 10 according to the first embodiment in that the adjacent two main protrusions 21 are connected to each other directly at conical surface edges thereof, without providing any intermediate protrusion between the adjacent two main protrusions 21.

[0037] The main protrusions 21 having the shape of truncated cone, for forming the pattern of irregularity, are provided on the basis of a matrix arrangement in which the main protrusions 21 are aligned at regular intervals so that one main protrusion 21 is connected at four conical surface edges thereof to four other main protrusions 21. More specifically, each of the main protrusions 21 is provided at a foot portion thereof with alternating first and second groups of four conical surface edges. Two main protrusions 21 that are adjacent to each other at the shortest distance are connected to each other at the first conical surface edge so that each of the main protrusions 21 are connected to four main protrusions 21 through two or more first conical surface edges. A plurality of non-protruded portions each of which is placed between the second conical surface edges of the other two main protrusions 21 that are adjacent to each other at a longer distance than the above-mentioned shortest distance. Each of the non-protruded portions is placed in the lowest position relative to a protruding direction of the main protrusions 21. Such non-protruded portions provide recesses 23 surrounded by the main protrusions 21. The connection line' 22 along which the corresponding first conical surface edges of the two main protrusions 21 that are adjacent to each other at the shortest distance are connected to each other is placed in a higher level than the recess 23 relative to the protruding direction of the main protrusions 21.

[0038] The above-described heat exchange plate 20 is placed, in the same manner as the first embodiment of the present invention, on the other heat exchange plate having the same structure so that they face each other on the same side and the tops 21a of the main protrusions 21 of the former plate come into contact with the corresponding tops of the main protrusions of the latter plate, or projections formed on the rear sides of the recesses 23 surrounded by the main protrusions 21 of the former plate come into contact with corresponding projections formed on the rear sides of the recesses 23 surrounded by the main protrusions 21 of the latter plate, to form a combined unit, and then the thus formed combined unit is combined to the other combined units in the same manner, to form a heat exchanger that has gaps, i.e., passages each of which is defined by the adjacent two plates. The heat exchange fluids flow in these passages to make heat exchange between one of these fluids coming into contact with the upper surface of the plate and the other of these fluids coming into contact with the lower surface of thereof.

[0039] In the combined state of the plates, a gap between the adjacent two plates, excepting the contact area of these plates, forms a passage for the heat exchange fluid. The passage extends in the predetermined directions along the upper surface of the plate, while repeating expansion and contraction for example by increasing the flow passage area between the corresponding recesses 23 and the flow passage area between the rear surfaces of the corresponding main protrusions 21. The other passage extends in the predetermined directions along the lower surface of the plate in the same manner. Even when a flowing relationship of the heat exchange fluids is based on any one of a parallel flowing system, a counter-flowing system and a cross flowing system, it is therefore possible to reduce pressure loss and achieve smooth flow of the heat exchange fluids and smooth heat transfer, thus improving heat exchange efficiency.

[0040] The pattern of irregularity on the upper surface of the plate 20 is not symmetrical relative to the pattern of irregularity on the lower surface of the plate and the plate is placed on the other plate so that they come into contact with each other on the same side, with the result that the gaps are different in configuration and size from each other. Accordingly, a flow of the heat exchange fluids in these passages makes it possible to progress heat transfer between the plate 20 and the respective fluids in an effective manner, thus providing an effective heat exchange between the heat exchange fluids.

[0041] Now, the third embodiment of the present invention will be described in detail below with reference to FIGS. 15 to 23. FIG. 15 is enlarged view of an essential part of the heat exchange plate according to the third embodiment of the present invention; FIG. 16 is an enlarged view of a portion shown by the symbol "K" or "L" in FIG. 15; FIG. 17 is a cross-sectional view cut along the line XVII-XVII in FIG. 16; FIG. 18 is a cross-sectional view cut along the line XVIII-XVIII in FIG. 16; FIG. 19 is a cross-sectional view cut along the line XIX-XIX in FIG. 16; FIG. 20 is a cross-sectional view cut along the line XX-XX in FIG. 16; FIG. 21 is a cross-sectional view cut along the line XXI-XXI in FIG. 16; and FIGS. 22 and 23 are structural views of gaps provided above and below the heat exchange plate, respectively, according to the third embodiment of the present invention in a state in which the heat exchange plates are combined in parallel with each other.

[0042] As shown in the above-mentioned figures, the heat exchange plate 30 according to the third embodiment of the present invention is formed of a metallic plate having a rectangular shape. The metallic plate has a pattern of irregularity press-formed thereon, which includes a plurality of main protrusions 31 and a plurality of intermediate protrusions 32. Each of the main protrusions 31 protrude outward from one surface of the plate in the form of a truncated pyramid so as to be placed at a regular interval in an aligned configuration. Each of the intermediate protrusions 32 is placed in the form of protrusion between the opposing flat surfaces of two main protrusions 31 that are adjacent to each other at the shortest distance. Each of the intermediate protrusions 32 has two mound portions that are placed on a straight line, which is perpendicular to a reference line along which the adjacent two main protrusions 31 are aligned so that the intermediate protrusion 32 is placed between the surfaces of the adjacent main protrusions 31. Each of the mound portions has a height that is smaller than one-half of a height of the main protrusion 31.

[0043] The main protrusions 31 having the shape of truncated pyramid, for forming the pattern of irregularity, are provided on the basis of a matrix arrangement in which the main protrusions 31 are aligned at regular intervals so that one main protrusion 31 is connected at four positions on the periphery thereof to four other main protrusions 31 through the above-mentioned intermediate protrusions 32, respectively, in the same manner as the first embodiment of the present invention. A straight line along which the intermediate protrusions 32 are aligned so as to be placed between the adjacent two main protrusions 31 is inclined at an angle of 45 degrees relative to the respective sides of the plate having the rectangular shape (ridgelines of the main protrusions 31 is in parallel to or perpendicular to the respective sides of the plate.

[0044] The intermediate protrusion 32 is defined by the two mound portions that are placed on the straight line, which is perpendicular to the reference line along which the adjacent two main protrusions 31 are aligned so that the intermediate protrusion 32 is placed between the surfaces of the adjacent main protrusions 31. Each of the mound portions has the height that is smaller than one-half of the height of the main protrusion 31, as described above.

[0045] In addition, there is provided a plurality of non-protruded portions each of which is placed between adjacent intermediate protrusions of the plurality of intermediate protrusions 32, and more specifically between the main protrusion 31 and the other main protrusion 31 that is adjacent to the former main protrusion 31, not through the intermediate protrusion 32, at a slightly longer distance than the above-mentioned shortest distance. Each of the non-protruded portions is placed in a lowest position relative to a protruding direction of the main and intermediate protrusions 31, 32. These non-protruded portions provide recesses 33 each of which is surrounded by the flat surfaces of the main protrusions 31 and the flat surfaces of the intermediate protrusions 32. Connection of the surface of the main protrusion 31 to the surface of the intermediate protrusion 32 is placed in a higher position than the above-mentioned recess 33.

[0046] The above-described heat exchange plate 30 is placed on the other heat exchange plate having the same structure so that they face each other on the same side and the tops 31a of the main protrusions 31 of the former plate come into contact with the corresponding tops of the main protrusions of the latter plate, or projections formed on the rear sides of the recesses 33 surrounded by the main and intermediate protrusions 31, 32 of the former plate come into contact with corresponding projections formed on the rear sides of the recesses 33 surrounded by the main and intermediate protrusions 31, 32 of the latter plate, to form a combined unit, and then the thus formed combined unit is combined to the other combined units in the same manner, to form a heat exchanger that has gaps 34, 35, i.e., passages each of which is defined by the adjacent two plates. In the gap 34 formed between the two adjacent plates of the thus combined plates, in which gap the main protrusions 31 and the intermediate protrusions 32 protrude, the gap between the corresponding intermediate protrusions 32 is slightly smaller than the gap between the corresponding recesses 33. The passage formed by the gaps between the corresponding intermediate protrusions 32 and the gaps between the corresponding recesses 33 has a small variation in flow passage area. Such a passage extends linearly, while expanding and reducing in a repeated manner. Such a passage intersects the other passages so as to communicate therewith, thus providing a braided passage structure (see FIG. 22 and FIG. 23).

[0047] On the other hand, in the gap 35 formed between the two adjacent plates of the thus combined plates, in which gap the main protrusions 31 and the intermediate protrusions 32 protrude do not protrude, the other passage for the heat exchange fluid is formed by the gaps between the rear surfaces of the corresponding intermediate protrusions 32 and the gaps between the rear surfaces of the corresponding recesses 33. In this passage, the flow passage area between the rear surfaces of the corresponding intermediate protrusions 32 is remarkably smaller than the flow passage area between the rear surfaces of the corresponding main protrusions 31. Such a passage extends linearly, while expanding and reducing in a repeated manner with a high rate of change in an alignment direction of the main protrusions 31. Such a passage intersects the other passages so as to communicate therewith, thus providing a braided passage structure (see FIG. 22 and FIG. 23). When a heat exchanger composed of the plates as combined in a manner as described above is placed in use so that the plates stand upright and one of the both sides of each plate is placed horizontally or vertically, the passages each of which is defined by the alternating corresponding intermediate protrusions 32 and recesses 33, are kept in an inclined state.

[0048] The pattern of irregularity on the upper surface of the plate is not symmetrical relative to the pattern of irregularity on the lower surface of the plate and the plate is placed on the other plate so that they come into contact with each other on the same side, with the result that the above-described gaps 34 and 35 are different in configuration and size from each other. Therefore, such gaps 34, 35 provide different heat transfer performance in accordance with their configuration and size. The pattern of irregularity of the plate is set so as to obtain appropriate configuration and size of the gaps 34, 35, with consideration given to characteristic properties of two kinds of fluids between which heat exchange it to be made, thus providing suitable heat transfer performance for these fluids. The heat exchanger is subjected to specifications concerning the general structure therefore so that the heat exchange fluids are introduced into the gaps 34, 35 providing the predetermined transfer performance, respectively.

[0049] Now, description will be given below of operation of the heat exchanger that is composed of the heat exchange plates 30 according to the embodiment of the present invention. Heat exchange is made between the two kinds of heat exchange fluids by introducing one of these fluids into the gaps 34 formed between the two adjacent plates of the unit in which the plates are place paralelly one upon another and combined together, in which gaps the main protrusions 31 and the intermediate protrusions 32 protrude and discharging it therefrom, on the one hand, and by introducing the other of these fluids into the gaps 35 formed between the two adjacent plates of the unit, in which gaps the main protrusions 31 and the intermediate protrusions 32 do not protrude and discharging it therefrom, on the other hand.

[0050] The gaps 34, 35 that are defined between the plates by configurations of the protrusions 31, 32 extend continuously and linearly on the straight lines along which the protrusions 31, 32 are aligned. Even when a flowing relationship of the heat exchange fluids, which flow in the gaps 34, 35, respectively, is based on any one of a parallel flowing system, a counter-flowing system and a cross flowing system, it is therefore possible to cause the heat exchange fluids to behave in flow in substantially the same manner to provide substantially the same heat transfer performance. In addition, even when the heat exchange fluids flow on the basis of any combination of the flowing directions, it is possible to reduce pressure loss in the passages so as to ensure smooth flow in the gaps 34, 35, thus making effective heat exchange.

[0051] In an example case in which heat exchange fluids flow in accordance with the counter-flowing system, there is formed, in the gap 34 formed between the two adjacent plates of the combined plates, in which gap the main protrusions 31 and the intermediate protrusions 32 protrude, a flow braided passage mainly including passage sections that extend obliquely along the straight lines on which the protrusions 31, 32 are aligned, between the corresponding recesses 33 and between the corresponding intermediate protrusions 32 so that the heat exchange fluid flows in this flow braided passage. On the other hand, in the gap 35 formed between the two adjacent plates of the combined plates, in which gap the main protrusions 31 and the intermediate protrusions 32 protrude do not protrude, a flow braided passage mainly including passage sections that extend obliquely along the straight lines on which the protrusions 31, 32 are aligned, between the corresponding recesses 33, which are provided on the back side of the main protrusions 31, and between the corresponding back sides of the intermediate protrusions 32 so that the other heat exchange fluid flows in this flow braided passage. As a result, the heat exchange fluids introduced into the combined plates flows in the oblique direction on the opposite surfaces of the heat transfer plate 30, respectively, while repeating divergence and confluence to spread smoothly over every area of the plate. thus leading to a facilitated heat transfer between the plate and the respective heat exchange fluids.

[0052] The heat transfer fluids respectively flow, in the same manner as the first embodiment of the present invention, in the flow braided passages that have specific configurations enabling the heat exchange fluids to flow, while repeating divergence and confluence in the gaps 34, 35 and have heat transfer performance as set in contemplation of the characteristic properties of the heat exchange fluids on the opposite surfaces of the plate. Especially, the small height of the intermediate protrusion 32 makes the flow passage area at the intermediate protrusion 32 in the gap 34 larger than that in the gap 35 so as to permit the fluids to flow in the respective gaps 34, 35 with remarkably different amounts thereof. This can cope with a case in which the fluids between which heat exchange is to be made are remarkably different in flow rate (e.g., a liquid-phase fluid and a gaseous-phase fluid are used), to provide a facilitated heat transfer between the plates and the heat exchange fluids. In addition, the gap 35 between the corresponding intermediate protrusions 32 is excessively smaller to form a narrow passage, thus making the flow velocity of the heat exchange fluid flowing in this area in the gap 35 high, to progress heat transfer between the plate and the respective fluids in a remarkably effective manner. It is therefore possible to make effectively heat exchange between the heat exchange fluids without loss by causing the fluids to flow in the respective passages as optimized to provide a proper heat transfer between the plates and the respective fluids.

[0053] In the heat exchange plate according to the third embodiment of the present invention, each of the main protrusions 31 has a shape of the truncated pyramid, and each of the intermediate protrusions 32 is defined by the flat portions, to construct the plate in the combined form of flat surface bodies, on the one hand, and the passage configurations provided on the opposite surfaces of the plate are made different from each other by decreasing the height of each of the intermediate protrusions 32, on the other hand, so that the flow passage area in the gap formed between the two adjacent plates of the combined plates, in which gap the protrusions protrude becomes larger than the flow passage area in the gap formed between these plates, in which gap the protrusions do not protrude, thus coping with a case where the two kinds of heat exchange fluids with which heat exchange is to be made are remarkably different from each other in amounts of the fluids flowing into and discharging from the heat exchanger, to achieve heat transfer, thus improving the heat exchange efficiency.

[0054] In the heat exchange plate according to the above-described embodiment of the present invention, the main protrusion 31 has a shape of the truncated pyramid. However, the present invention is not limited only to such an embodiment, and the main protrusion may have the shape of another truncated pyramid such as a truncated pentagonal pyramid or a truncated six-sided pyramid so as to provide a pattern of irregularity in which a positional alignment of the main protrusions is made in accordance with the number of side surfaces of the truncated pyramid.

[0055] In the heat exchange plate according to the above-described embodiment of the present invention, there is applied the pattern of irregularity in which the straight line along which the intermediate protrusions 31 are aligned so as to be placed between the adjacent two main protrusions 31 is inclined at an angle of 45 degrees relative to the respective sides of the plate having the rectangular shape. However, the present invention is not limited only to such an embodiment, there may be applied the pattern of irregularity in which the straight line along which the intermediate protrusions 31 are aligned so as to be placed between the adjacent two main protrusions 31 is in parallel with or perpendicular to the respective sides of the plate having the rectangular shape, or inclined at a predetermined angle relative thereto.

Claims

1. A heat exchange plate, which is formed of a metallic plate and has a predetermined pattern of irregularity, the heat exchange plate being placed on another heat exchange plate having a same structure so as to come into contact with each other on a same side of the heat exchange plate to provide a pair of heat exchange plates, the pair of heat exchange plates being combined to one or more other pair of heat exchange plates integrally with each other to form a heat exchanger in which heat exchange is to be made between first and second heat exchange fluids that come into contact with opposite surfaces of the heat exchange plate, respectively, the heat exchange plate comprising:

    a plurality of main protrusions (11,16,31) that protrude outward from one surface of the heat exchange plate (10,30) in a form of a truncated cone or a truncated pyramid, the protrusions being placed in predetermined positions based on a predetermined pattern on the heat exchange plate (10,30);

    a plurality of intermediate protrusions (12,17,32) each of which is placed between two main protrusions (11,16,31) that are adjacent to each other at a shortest distance so that each of the main protrusions (11,16,31) is connected to two or more other main protrusions (11,16,31) through two or more intermediate protrusions (12,17,32), each of the intermediate protrusions (12,17,32) being defined by one or more flat or curved portions that extend to opposing surfaces of the two main protrusions (11,16,31), and each of the intermediate protrusions (12,17,32) having one or more peak portions that are placed in a lower position than a top (11a,16a, 31a) of the main protrusion (11,16,31); and

a plurality of non-protruded portions each of which is placed between adjacent intermediate protrusions (12,17,32) of the plurality of intermediate protrusions (12,17,32), each of the plurality of non-protruded portions being placed in a lowest position relative to a protruding direction of the main and intermediate protrusions (11,12,16,17,31,32), the plurality of non-protruded portions providing recesses (13,18,33) surrounded by the main and intermediate protrusions (11,12,16,17,31,32).

2. The heat exchange plate as claimed in Claim 1, wherein:

each of the main protrusions (11,16) has a shape of the truncated cone; and each of the intermediate protrusions (12,17) is defined by the one or more curved portions.

3. The heat exchange plate as claimed in Claim 1, wherein:

each of the main protrusions (31) has a shape of the truncated pyramid; and each of the intermediate protrusions (32) is defined by the one or more flat portions.

4. The heat exchange plate as claimed in any one of Claims 1 to 3, wherein:

each of the intermediate protrusions (32) has two or more mound portions that are placed on a straight line, which is perpendicular to a reference line along which the adjacent two main protrusions (31) are aligned so that the intermediate protrusion (32) is placed between the surfaces of the adjacent two main protrusions (31), each of the mound portions having a height that is smaller than one-half of a height of the main protrusion (31).

5. A heat exchange plate, which is formed of a metallic plate and has a predetermined pattern of irregularity, the heat exchange plate being placed on another heat exchange plate having a same structure so as to come into contact with each other on a same side of the heat exchange plate to provide a pair of heat exchange plates, the pair of heat exchange plates being combined to one or more other pair of heat exchange plates integrally with each other to form a heat exchanger in which heat exchange is to be made between first and second heat exchange fluids that come into contact with opposite surfaces of the heat exchange plate, respectively, the heat exchange plate comprising:

a plurality of main protrusions (21) that protrude outward from one surface of the heat exchange plate (20) in a form of a truncated cone, the protrusions being placed in predetermined positions based on a predetermined pattern on the heat exchange plate (20), each of the main protrusions (21) being provided at a foot portion thereof with alternating first and second conical surface edges, two main protrusions (21) that are adjacent to each other at a shortest distance are connected to each other at the first conical surface edge (22) so that each of the main protrusions (21) are connected to two or more other main protrusions (21) through two or more first conical surface edges (22); and

a plurality of non-protruded portions each of which is placed between the second conical surface edges of other two main protrusions (21) that are adjacent to each other at a longer distance than the shortest distance, each of the plurality of non-protruded portions being placed in a lowest position relative to a protruding direction of the main protrusions (21), the plurality of non-protruded portions providing recesses (23) surrounded by the main protrusions (21).

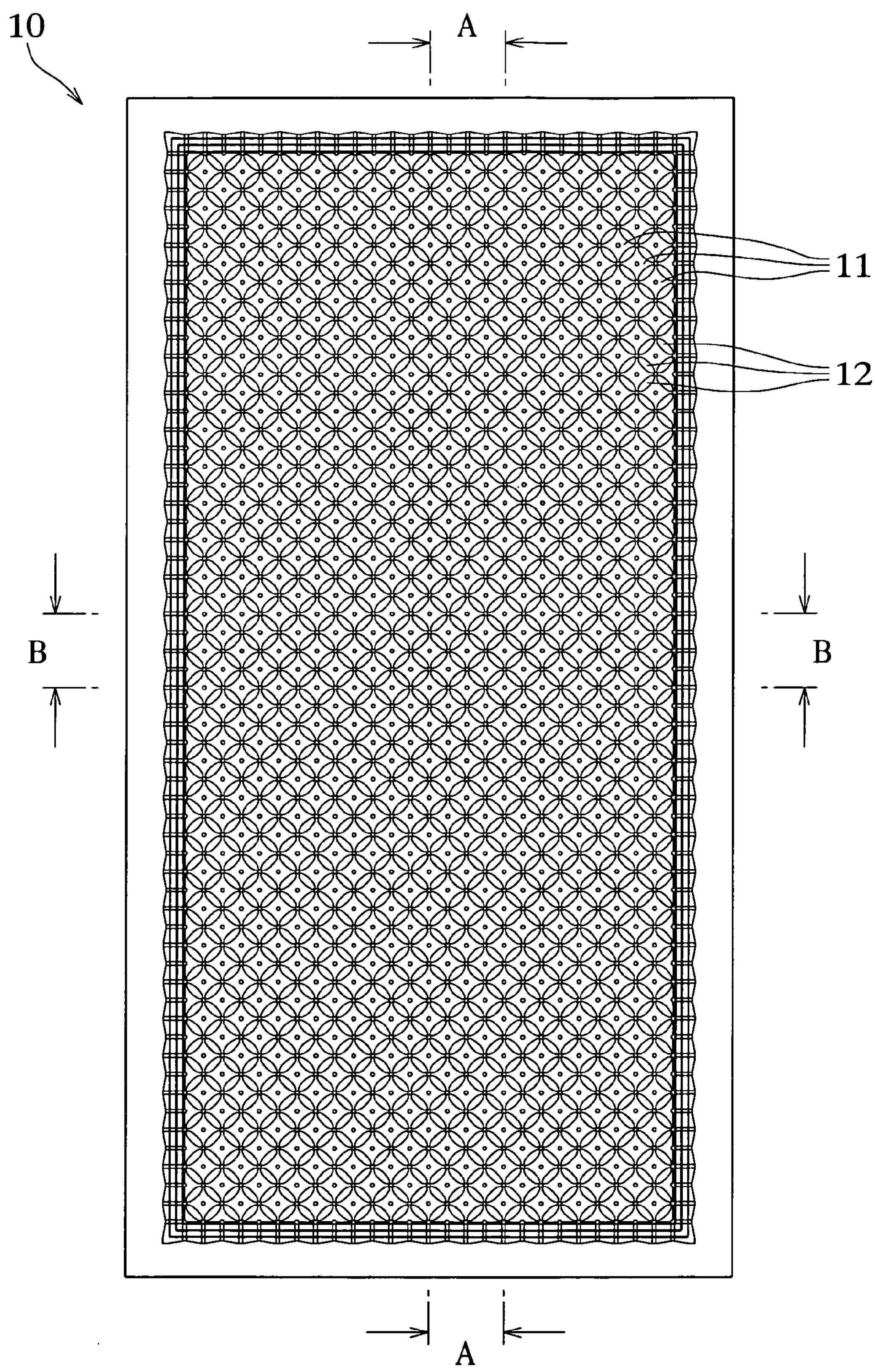


FIG.1

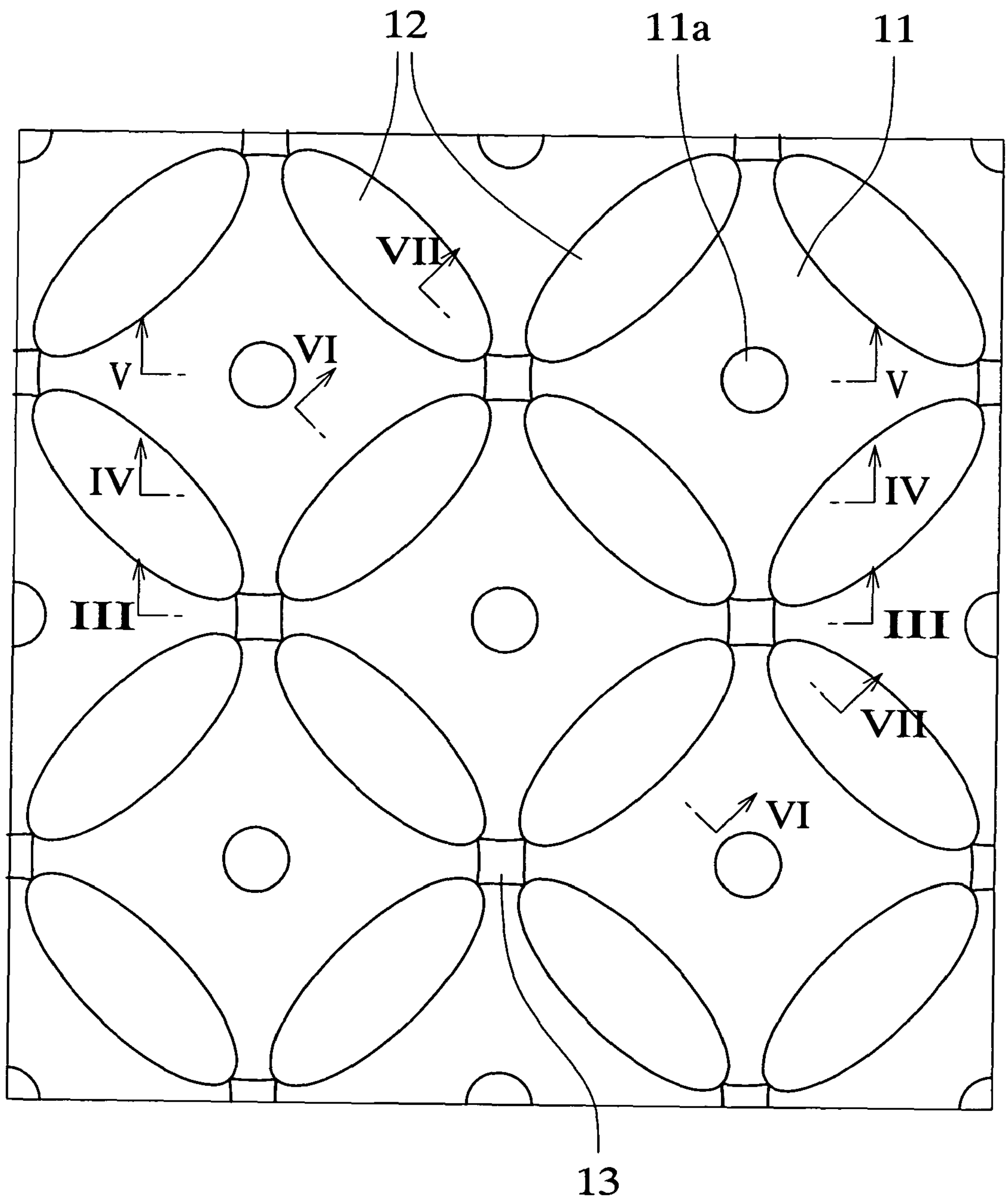


FIG.2

FIG.3

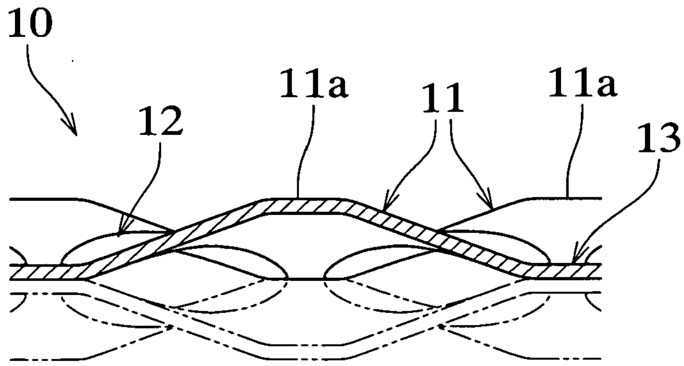


FIG.4

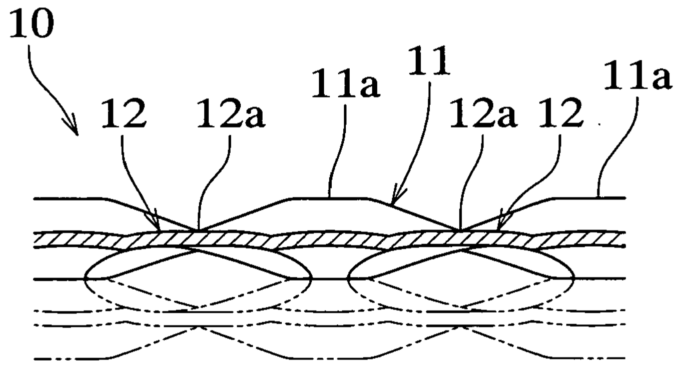


FIG.5

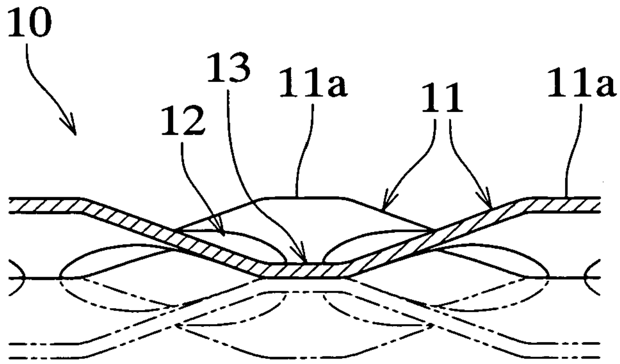


FIG.6

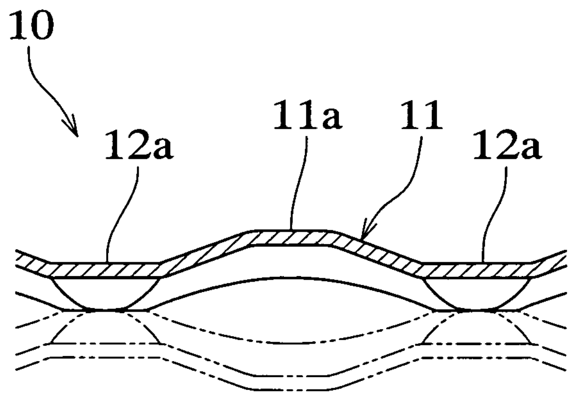


FIG.7

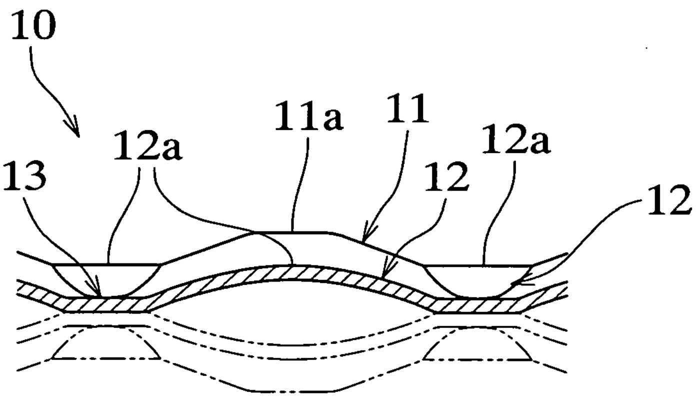


FIG.8

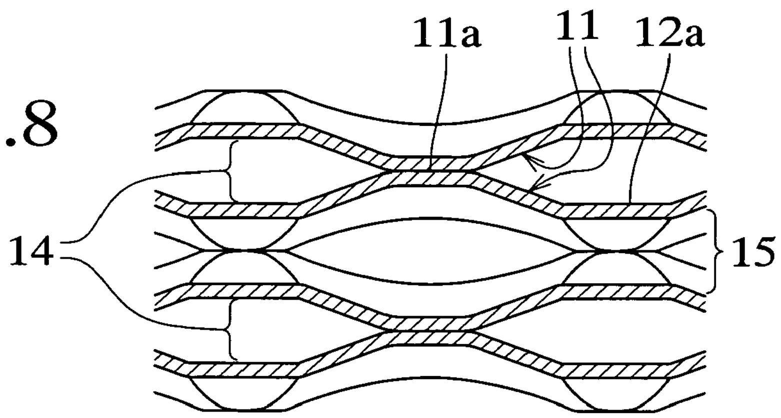
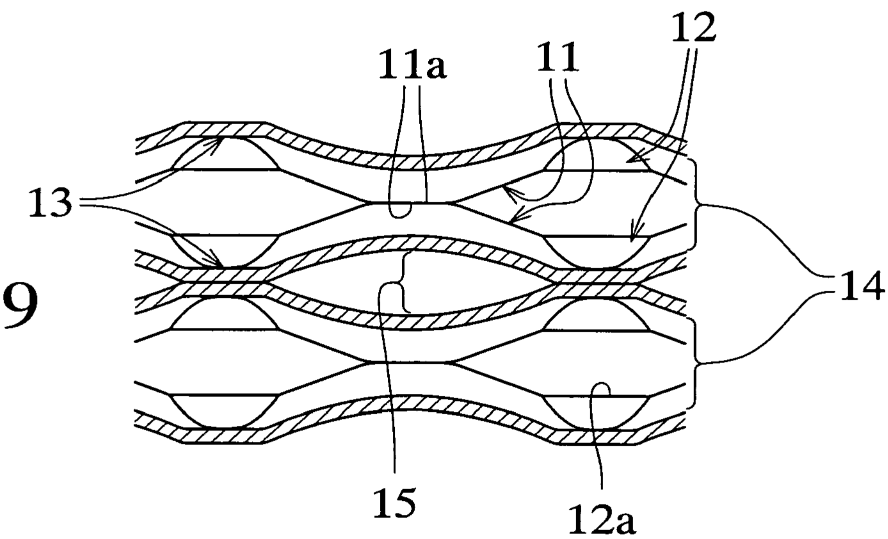


FIG.9



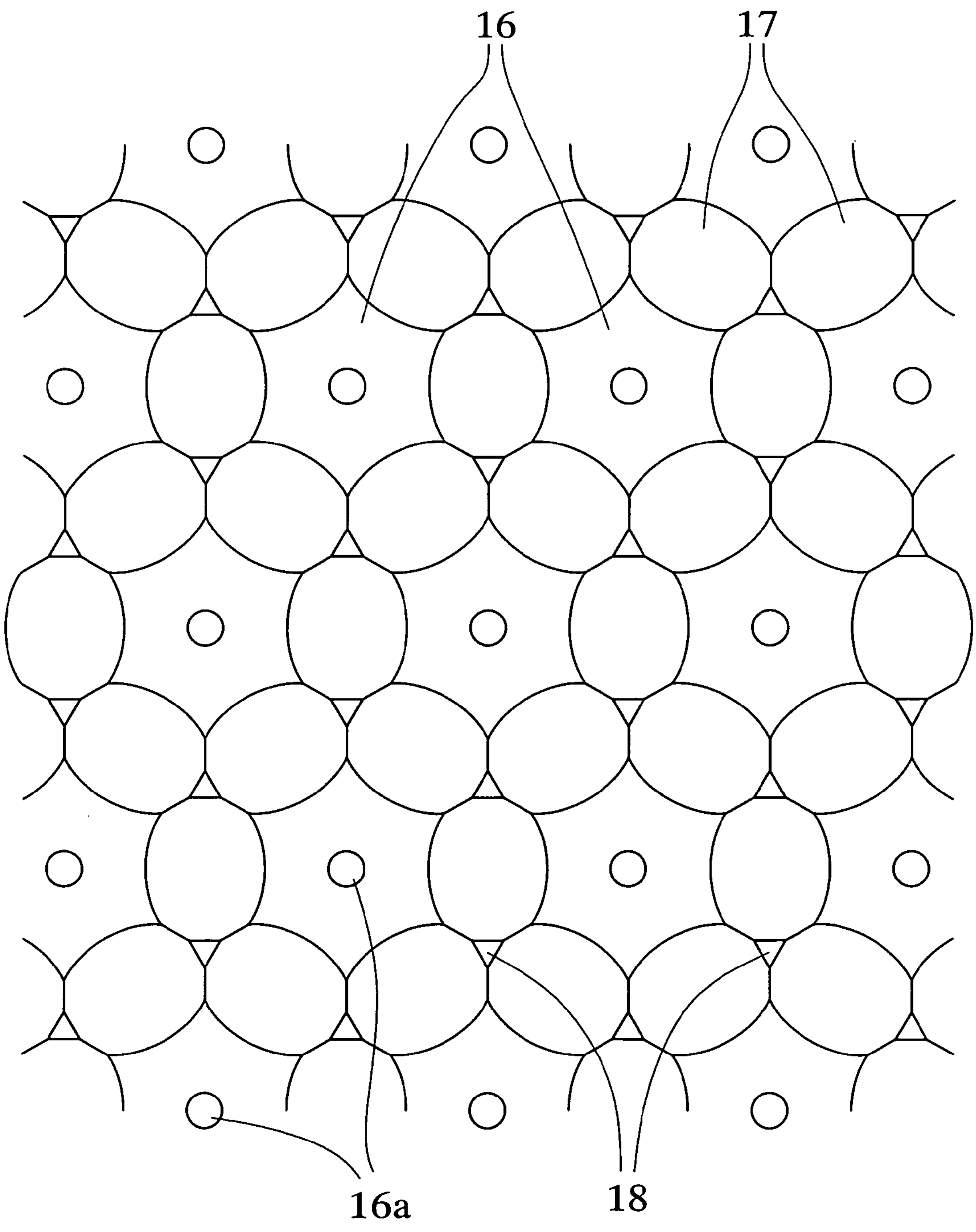


FIG.10

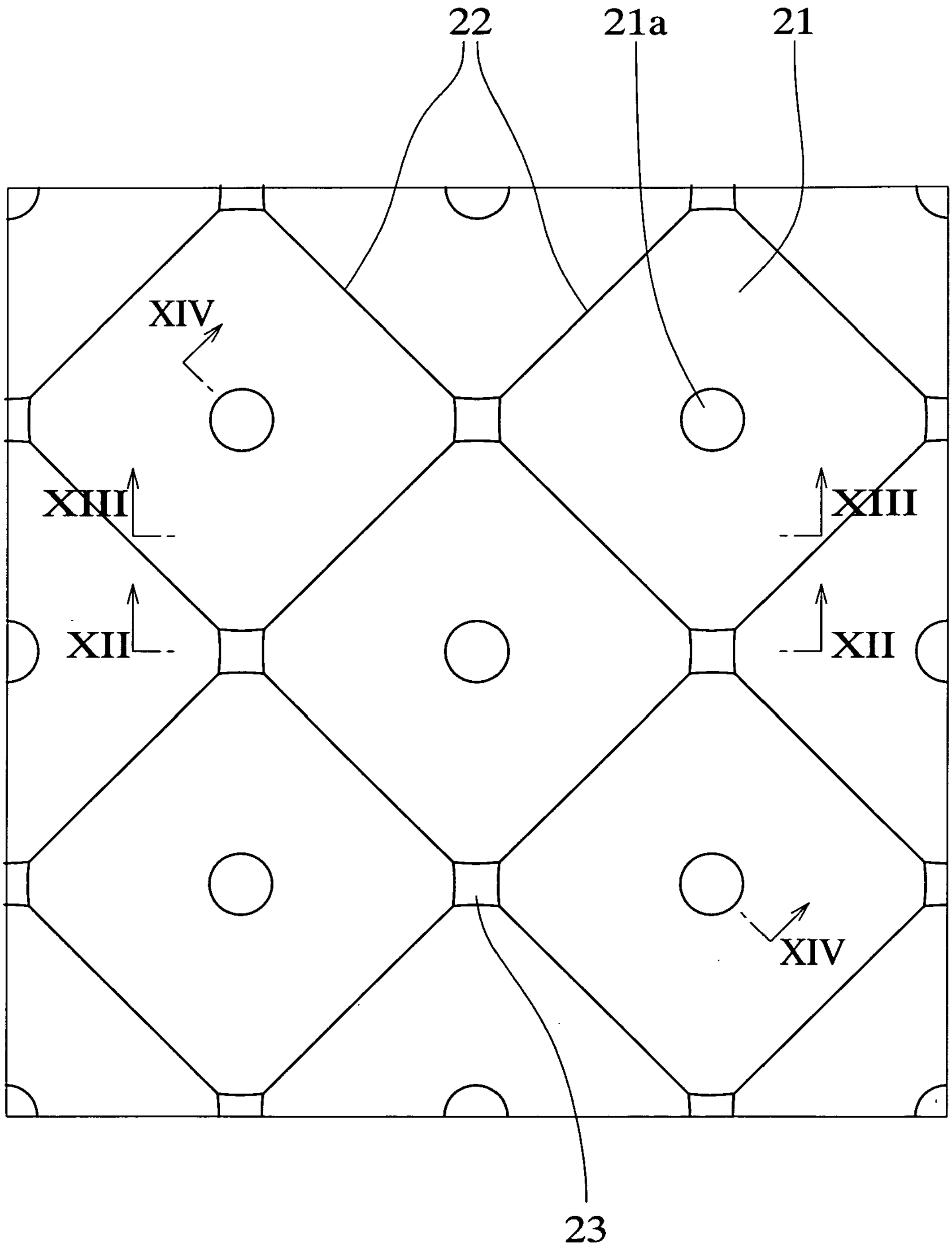


FIG.11

FIG.12

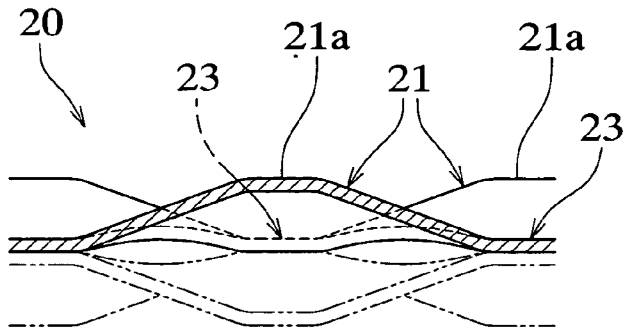
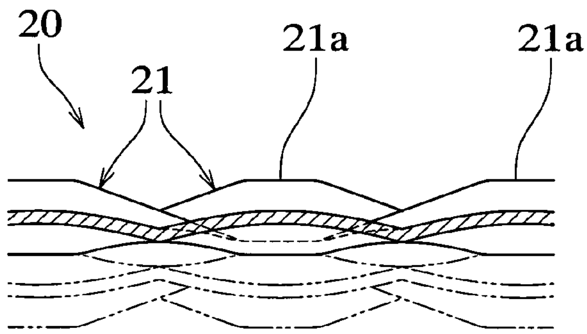


FIG.13



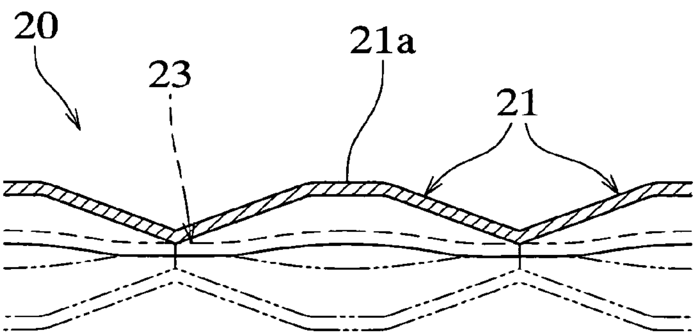


FIG.14

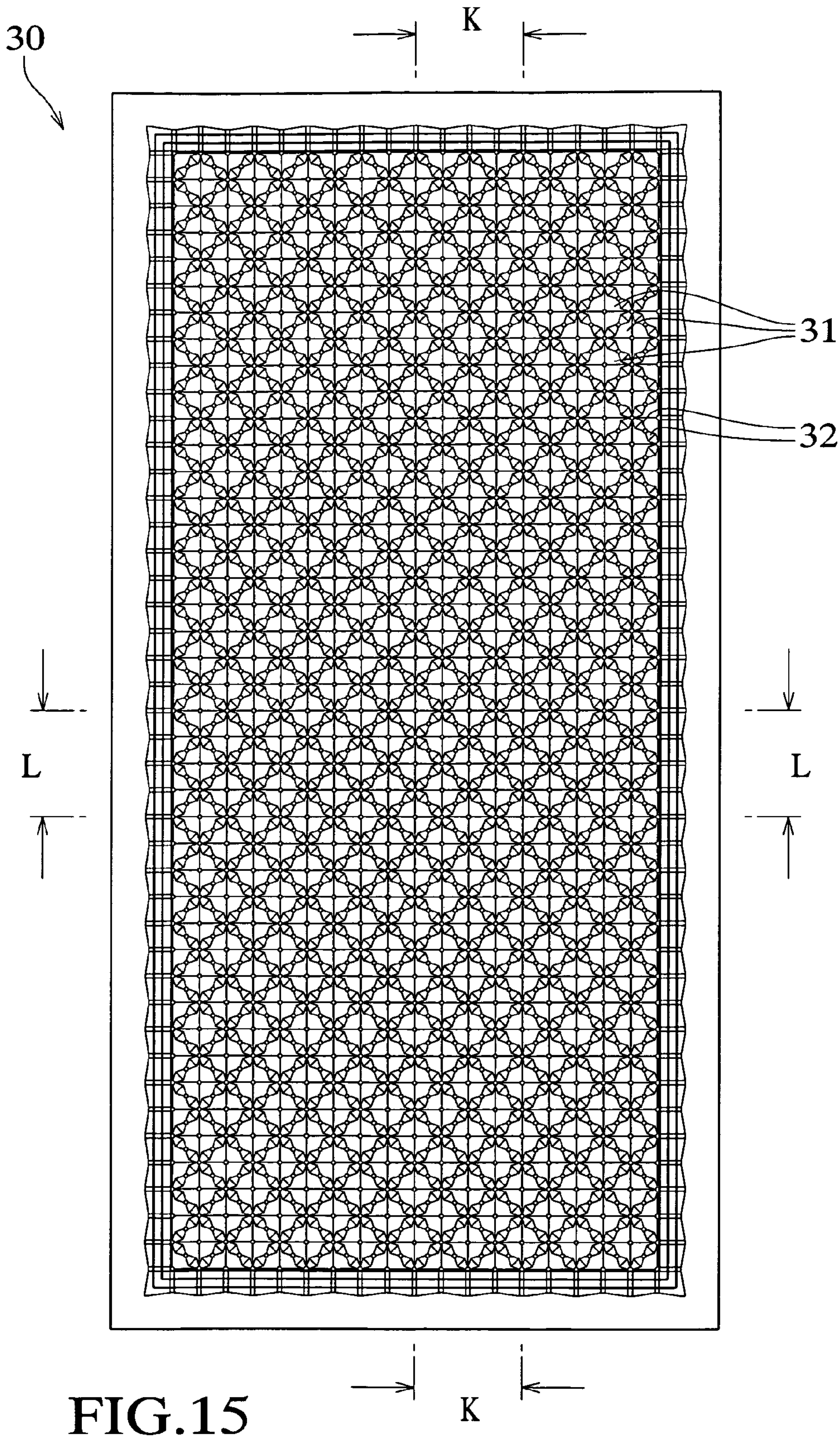


FIG.15

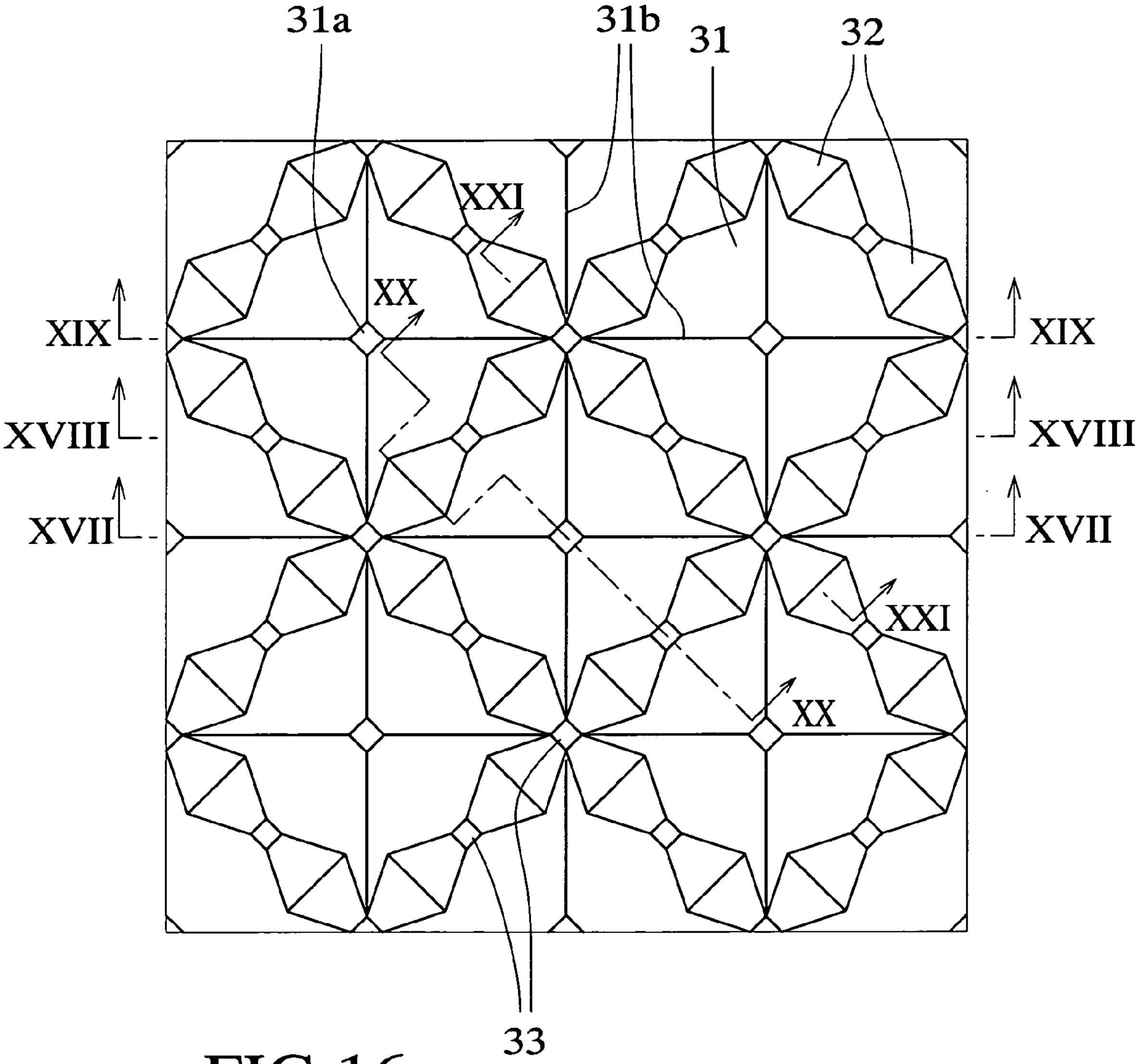


FIG.16

FIG.17

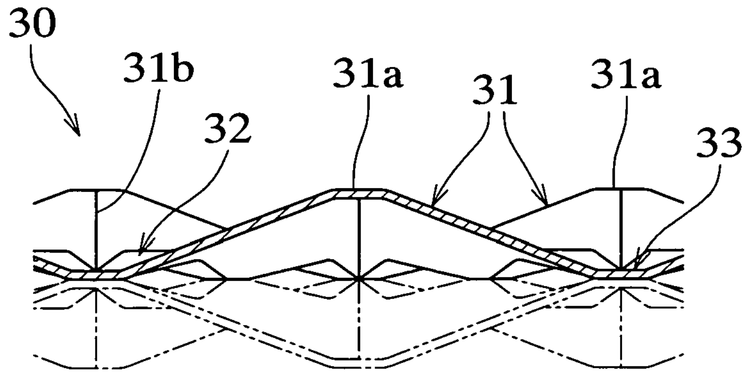


FIG.18

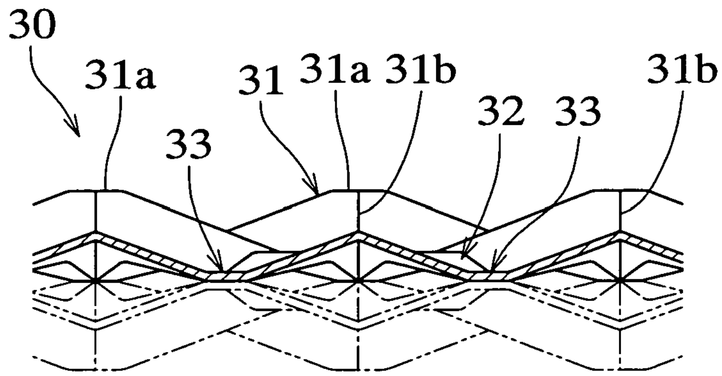


FIG.19

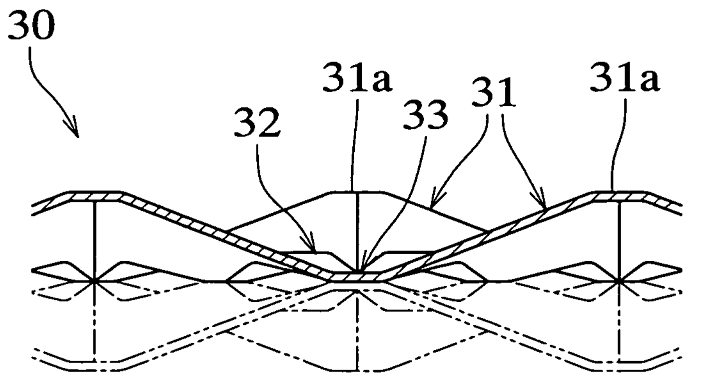


FIG.20

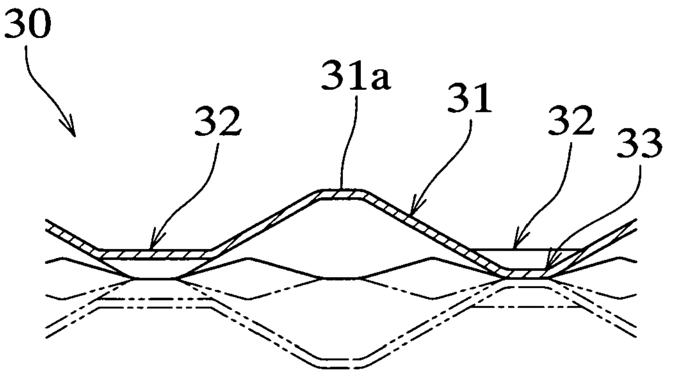


FIG.21

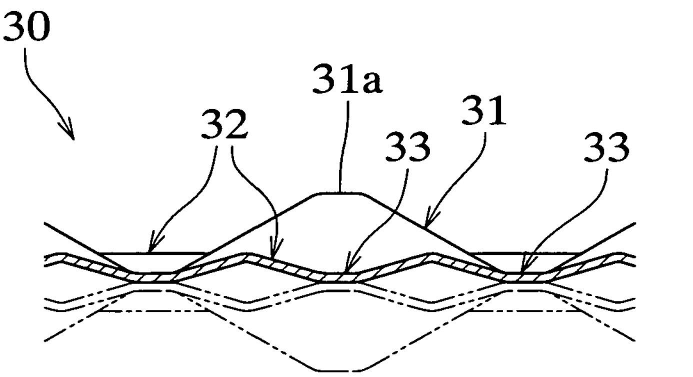


FIG.22

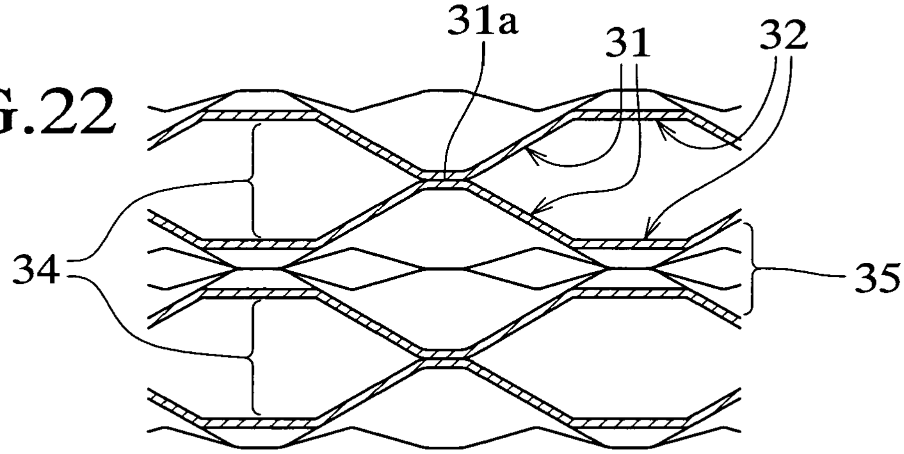


FIG.23