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(54) High effectiveness gas to gas heat exchangers

(57) A recuperator (100) comprising:
a heat exchange assembly comprising a plurality of heat exchange plates (200);
an inlet for a first fluid (101), and an outlet for said first fluid (102);
an inlet for a second fluid (103) and an outlet for said second fluid (104);
a plurality of first fluid channels, extending along a plurality of first paths between the inlet for the first fluid (101) and the outlet for the first fluid (102);
a plurality of second fluid channels extending along a plurality of second paths between the inlet for the second fluid (103) and the outlet for the second fluid (104);
characterised in that said plurality of first fluid channels are arranged side by side with and to follow closely said plurality of second fluid channels, such that said first fluid flowing in said plurality of first fluid channels flows adjacent and in an opposite direction to said second fluid flowing in said plurality of second fluid channels, said first and second channels separated by at least one said heat exchange plate (200) such that heat transfers through said heat transfer plate between said first and second fluids.

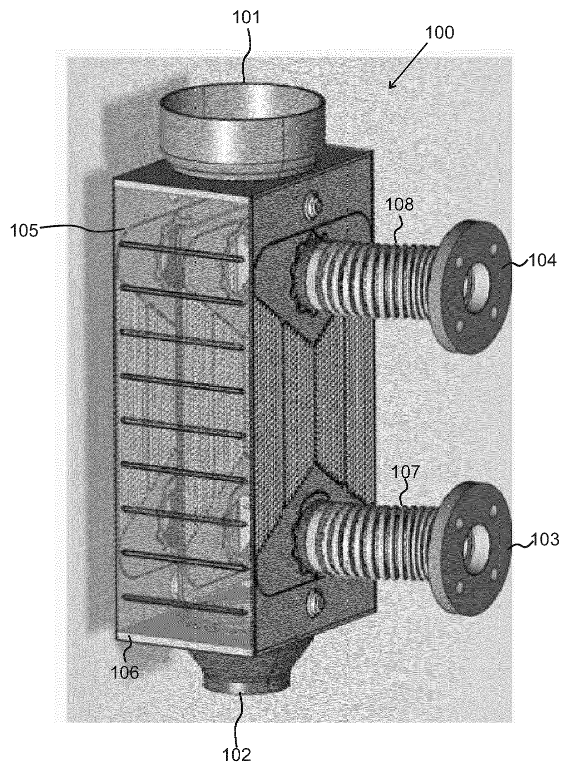

Fig. 1

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Description

Field of the Invention

[0001] The present invention relates to heat exchangers.

Background of the Invention

[0002] All industries and the world in general, need to use energy as efficiently as possible.

[0003] Machines such as gas turbines and solid oxide fuel cells have exhaust gas containing a high level of thermal energy; they also require the inlet air to be preheated prior to entry into combustor or fuel cell. A long used method of addressing both these problems is to have a gas to gas heat exchanger, also known as a recuperator, to transfer heat energy from the exhaust gas to the incoming air. The higher the effectiveness of the recuperator the more energy is recovered from the exhaust gas and thus the higher the overall efficiency of the plant will be.

[0004] Further to this, to minimise energy use, the pressure drop through the recuperator must be low. High pressure loss requires mechanical energy to push the gases through the recuperator and thus reduces over all plant efficiency.

[0005] As high temperatures are present in the gases the material for the heat exchange surfaces needs to be high temperature special alloy. This is expensive material and thus the less weight of material required the better.

[0006] With all heat exchangers that function from an ambient start up condition to a hot running condition the thermal expansion must be addressed to ensure durability of the heat exchanger.

[0007] An example of a known recuperator is contained in US 2002 185265.

Summary of the Invention

[0008] According to a first aspect of the present invention, there is provided a recuperator comprising:

a heat exchange assembly comprising a plurality of heat exchange plates;

an inlet for a first fluid, and an outlet for said first fluid;

an inlet for a second fluid and an outlet for said second fluid;

a plurality of first fluid channels, extending along a plurality of first paths between the inlet for the first fluid and the outlet for the first fluid;

a plurality of second fluid channels extending along a plurality of second paths between the inlet for the second fluid and the outlet for the second fluid;

characterised in that

said plurality of first fluid channels are arranged side by side with and to follow closely said plurality of second fluid channels, such that said first fluid flowing in said plurality of first fluid channels flows adjacent said second fluid flowing in said plurality of second fluid channels, said first and second channels separated by at least one said heat exchange plate such that heat transfers through said heat transfer plate between said first and second fluids;

wherein said first and second fluid channels are arranged in a contra-flow arrangement whereby said first fluid flows in said plurality of first fluid channels in an opposite direction to said second fluid flowing in said plurality of second fluid channels.

[0009] Other aspects are as set out in the claims herein.

[0010] The recuperator is designed to be highly effective, greater than 80%, with a low pressure drop across both fluid paths of less than 4% of inlet pressures. It also is designed to be light weight when compared to known recuperators.

[0011] To achieve this, the recuperator uses thin gauge strip less than 0.5mm thickness, with each heat exchange surface being formed from a single sheet of material to maximize heat transfer and reduce weight.

[0012] The first gas flows from one end of the heat exchange surface to the other end. The second gas is introduced to the heat exchange surface at the outlet end of the first gas flow, through a hole in the heat exchange surface at or near the centre line of the heat exchange surface, and exits at the opposite end of the surface through a hole at or near the centre line of the heat exchange surface. The centre portion of the heat exchange surface has a ribbed profile, with the ribs running in the direction of flow of the gases from end to end. Thus the recuperator is substantially contra flow, with the first gas flow being in an opposite direction to the second gas flow.

[0013] To achieve high effectiveness and low pressure drop the two gases must also be distributed relatively evenly across the width of the heat exchange surface. To achieve this, the profile around the inlet and/or outlet holes for the second fluid are designed to direct and guide flow of the second fluid across the whole width of the heat exchange surface. The profile, on the first fluid side, around the second fluid holes and the form of the centre portion ribbed profile is as such to distribute the first fluid relatively evenly across the width of the heat exchange surface.

[0014] To reduce the stresses potentially caused by the thermal expansion of the heat exchange surfaces, the outer casing that contains the surfaces may also be made from thin gauge material. The case, when within a temperature insulated environment will have a temperature profile very close to the heat exchange surfaces.

The outermost air cell plates may form two sides of the outer skin of the recuperator. The edges of the air cell may be joined together to form two sides of the outer skin of the recuperator and the first (fluid 1) channels

[0015] The three of the four inlets and outlets for the recuperator are connected to the recuperator by expansion joints. Thus the whole of the recuperator can expand, reducing thermal stresses and delivering a durable product.

Brief Description of the Drawings

[0016] For a better understanding of the invention and to show how the same may be carried into effect, there will now be described by way of example only, specific embodiments, methods and processes according to the present invention with reference to the accompanying drawings in which:

Figure 1 illustrates schematically a specific embodiment recuperator;

Figure 2 illustrates schematically a heat exchange plate comprising the recuperator of Figure 1 suitable for relatively low pressure application;

Figure 3 illustrates schematically a second heat exchange cell, according to a second specific embodiment, adapted for a relatively high pressure application;

Figure 4 illustrates schematically in isometric view, two heat exchange cells of a heat exchange assembly;

Figure 5 illustrates schematically in isometric view, a single heat exchange cell, illustrating how each of two fluids is introduced to the heat exchange surfaces of the cell;

Figure 6 illustrates schematically the recuperator of Figure 1 in view from a first end, and showing a first fluid inlet;

Figure 7A illustrates schematically in view from one side a pair of heat exchange cells located side by side;

Figure 7B illustrates schematically in view from one end, the pair of heat exchange cells of Figure 5;

Figure 8 illustrates schematically a result of a computerized fluid dynamics analysis of a first fluid flowing across a heat exchange cell;

Figure 9 illustrates schematically a computerized fluid dynamics analysis of a second fluid flowing between an inlet and outlet of a heat exchange cell;

Figure 10 illustrates schematically a portion of a central ribbed section of a heat exchange cell, showing channels for flow of the first and second fluids;

Figure 11A illustrates schematically a bar chart showing mass flow divided by path cross sectional area, in kg/m^{2}s, for a first fluid flowing in a first direction;

Figure 11B illustrates schematically a plot of mass flow divided by path cross sectional area in kg/m^{2}s for the second fluid, across the channels of half of a heat exchange cell;

Figure 12 illustrates schematically one embodiment of the recuperator where the outer most heat exchange plates form two sides of the skin of the recuperator and a separate thin wall component forms the other two sides of the skin;

Figure 13 illustrates schematically a further embodiment of the recuperator where the edges of the heat exchange cells are welded together to form two sides of the skin of the recuperator. Thus all four sides of the skin of the recuperator are formed from the heat exchange plates; and

Figure 14 illustrates schematically a further embodiment of the recuperator of figure 13, where the outer plate is manufactured from a simplified geometry plate.

Detailed Description of the Embodiments

[0017] There will now be described by way of example a specific mode contemplated by the inventors. In the following description numerous specific details are set forth in order to provide a thorough understanding. It will be apparent however, to one skilled in the art, that the present invention may be practiced without limitation to these specific details. In other instances, well known methods and structures have not been described in detail so as not to unnecessarily obscure the description.

[0018] In this specification the term "channel" is used to denote a fluid pathway between an inlet and an outlet, and it may be either fully enclosed in the form of a tube having a solid fluid impervious wall, or it may be partially enclosed allowing for some amount of leakage either into or out of the passage between the inlet and outlet. In some embodiments leakage between adjacent fluid channels may occur. The channel is guided by channel walls to guide the fluid along a pathway between an inlet and an outlet.

[0019] Figure 1 herein illustrates schematically a specific embodiment recuperator assembly. In this application the recuperator is mounted vertically.

[0020] The recuperator 100 comprises a first fluid inlet 101; a first fluid outlet 102; a second fluid inlet 103; a second fluid outlet 104; a plurality of heat exchange cells 105, arranged in parallel with each other; and an outer casing 106 surround the plurality of heat exchange cells.

[0021] A first fluid (fluid 1) enters the recuperator at the top of the assembly (second end of the recuperator) through a first expansion bellows (not shown) which connects to the first fluid inlet 101, flows around and between the cells and exits at the bottom of the assembly (first end of the recuperator) via the first fluid outlet 102. The first fluid inlet, first fluid outlet, second fluid inlet, and second fluid outlet are all located on a centre line of the recuperator along a main central axis of the recuperator.

[0022] A second fluid (fluid 2) enters the recuperator at the lower end of the assembly via second inlet 103, and a second expansion bellows 107 (this bellows is not always required) flows along the orifice formed by the inlet holes in each cell such that it supplies each individual cell, flows through the plurality of cells and exits through the outlet holes in the cells via a third expansion bellows 108 at the upper side of the assembly and through second outlet 104.

[0023] The overall direction of flow of the first fluid is substantially opposite to the overall direction of flow of the second fluid, so that the two fluids pass over the heat exchange cells in a contra-flow arrangement. This maximises the heat exchange between the first fluid and the second fluid, via the thin gauge metal walls of the heat exchange cells.

[0024] The paths of the first fluid channels are arranged side by side with and closely follow the paths of the second fluid channels, such that the first fluid in the plurality of first fluid channels flows parallel to and in an opposite direction to the second fluid flowing in a plurality of second fluid channels.

[0025] Figure 2 illustrates schematically a single heat exchange cell 105 viewed externally from the top (or bottom). This particular design is for relatively low pressure, for example pressures less than 1.5Bar A.

[0026] Each cell 105 comprises a pair of stamped or pressed metal plates 200, which are welded together around their external perimeter edges, the plates forming a fluid inlet 201 for the second fluid; a fluid outlet 202 for the second fluid; a central region 203, comprising a plurality of parallel substantially straight ribs or ridges 204, forming a plurality of channels which direct the first fluid flow in a direction right to left as shown in Figure 2, and the second fluid flow in a direction left to right, so that the two fluids flow in 180° opposite directions to each other across the central section of the cell; a first flat unchannelled region 205 at the first end of the cell; a first raised formation 206 surrounding the fluid inlet 201, for dispersing and directing the second fluid across the whole width of the cell, in the unchannelled region 205 at the first end of the cell; a second unchannelled region 207 at a second end of the cell; a second raised formation 208 which serves to allow entry of the second fluid at any position around the fluid outlet 202 of the second fluid, from the substantially planar surface of the second unchannelled region 207 at the second end of the plate.

[0027] The cell 105 consists of two heat exchange plates each having the same form, which form two halves of the heat exchange cell. Each plate has two heat exchange surfaces which are between the second fluid in the centre of the cell, and the first fluid flowing around the outside of the cell. The plates are welded together around the outer perimeter 200 of the cell and also at intervals 209 to 211 across the ribbed central channel section 203. The joint around the perimeter gives a leak tight cell that allows the second fluid (fluid 2) to enter and exit only through the inlet and outlet orifices 201, 202 respectively.

[0028] The centre section of the plate comprises a series of channels formed by ribs in the plates. The profile of the ribs may vary across the width to improve relative flow of each fluid through the channels. In this design three of the channel roots 209 to 211 are welded together. This is to give mechanical strength to the plate. The number of welds will depend on the fluid pressure of the application for which the recuperator is designed. In the ribbed channel section the two fluids are controlled to flow in opposite directions.

[0029] Around the inlet and outlet orifices are designed the forms 206, 208. The forms disperse and direct the second fluid (fluid 2) at the inlet such that the second fluid flows into all the ribbed channels across the plate. At the outlet, the forms enable smooth flow from the ribbed section into the outlet. The inlet and outlet are also designed to reduce fluid pressure drop to a minimum whilst still controlling the flow of the second fluid. The inlet for the second fluid has a peripheral lip portion 212 between the orifice and the plurality of second fluid channels, to prevent the second fluid from short circuiting across the smallest gap from the inlet to the channel, and to spread the second fluid in a direction across a width of the cell to fill the outermost second fluid channels.

[0030] Figure 3 herein illustrates schematically one end of a second embodiment of a single heat exchange cell 300 viewed externally from one side. The cell 300 comprises a pair of stamped or pressed metal plates, which are welded together around their external perimeter edges, the plates forming a fluid inlet 301 for the second fluid; a fluid outlet for the second fluid; a central region 302, comprising a plurality of parallel substantially straight channels 303 which direct the first fluid flow in a direction bottom to top as shown in Figure 3, and the second fluid flow in an downward direction as shown in Figure 3, so that the two fluids flow in 180° opposite directions across the central section of the cell; a raised formation 304 around the fluid inlet 301; a substantially flat planar region 305; and a further set of formations 306 extending in an arched formation towards the outer edges of the cell, for dispersing and directing the second fluid across the whole width of the interior of the cell, in the otherwise unchannelled flat region 305 at the first end of the cell; and a second raised formations at the other end of the plate (not shown) which serves to direct the second fluid towards the fluid outlet, from a substantially planar second unchannelled region at the second end of the cell.

[0031] This particular design in Figure 3 is for higher pressure applications. The difference between the lower pressure application heat exchange cell of Figure 2 and the higher pressure cell of Figure 3, is that all of the channel roots are welded in the higher pressure cell. There are also the flow control features 306 in the second fluid (fluid 2) distribution zones 305. For added mechanical strength these features are also joined together across the depth of the cell. The cell in figure 3 is capable of resisting fluid pressures up to 10 bar.

[0032] Figure 4 herein illustrates schematically an isometric view of two cells. The cells are joined to each other at the second fluid (fluid 2) inlet and outlet. The joints are leak tight such that the second fluid (fluid 2) can pass from one cell to the next. First fluid (fluid 1) flows between the adjacent cells, whereas the second fluid (fluid 2) flows through the cells. A plurality of cells, when joined together to form a heat exchange assembly, locate with each other such that the plurality of inlets form an inlet manifold for the second fluid, and a plurality of second fluid outlets perform an outlet manifold for the second fluid. Shown in Figure 4 is the second fluid (fluid 2) 400 flowing into the plurality of cells in a first direction 400, and a out of the cells in a second direction 401. First fluid 402 flows between the two cells.

[0033] Figure 5 herein illustrates schematically an isometric view of a single cell illustrating how each fluid is introduced to the heat exchange surfaces.

[0034] In the recuperator, the fluid contra-flows are arranged such that the hot first fluid enters the recuperator at the same end as the heated second fluid exits the recuperator. Similarly, at the opposite end, the first fluid, which is relatively cooler than when it entered the recuperator at the first end flows in an opposite direction to the second fluid which is inlet at the second end. Therefore, the hottest part of the first fluid enters the recuperator at the same end as the hottest part of the second fluid exits the recuperator, and the coolest part of the first fluid exits the recuperator at the same end as the coolest part of the second fluid enters the recuperator. The centre line of the cell is shown at 506.

[0035] By having the two fluids in a contra-flow arrangement, the two flows of fluids are exposed to each other over the maximum length of heat exchange surface, and therefore, relative to its size, the recuperator is more efficient.

[0036] Figure 6 herein illustrates schematically an end on view of the recuperator from the fluid 1 inlet end.

[0037] Inside the recuperator, the plurality of heat exchange cells 105 are arranged side by side, so that the first fluid entering the recuperator via the first fluid inlet 101 can pass through the assembly of heat exchange cells. Across the first fluid flow path at the first fluid inlet end, there is positioned the second fluid outlet manifold, which comprises the plurality of raised formations 208, as shown in Figures 2, 3, 4 and 5 herein, which abut each other to form a gas tight substantially cylindrical manifold for the second fluid. The first fluid must pass around this substantially cylindrical obstruction, either side, in order to enter the channelled regions of the cells and pass between adjacent touching cells towards the other end of the recuperator.

[0038] The first fluid flows in a plurality of channels 600 formed between the individual cells in the heat exchange assembly whereas the second fluid flows inside each sealed cell.

[0039] An end view in the opposite direction, from the first fluid outlet end is similar to that shown in Figure 6 herein, since the main body of the recuperator is symmetric. At the other (outlet) end of the recuperator, the gases flowing through the channels 600 between the heat exchange cells must pass around the substantially cylindrical second fluid inlet manifold in order to reach the circular first fluid outlet at the other (first fluid outlet) end of the recuperator. In order to optimise the first fluid flow both into and out of the main body of the recuperator, both the first fluid inlet aperture and the first fluid outlet aperture are each circular, and extend substantially across a whole depth of the recuperator.

[0040] Figures 7A and 7B herein illustrate schematically an edge view of two cells, 7A from the side and 7B from the end.

[0041] Referring to Figure 7A herein, there is illustrated schematically in view from one side, a pair of heat exchange cells in contact with each other, as they would appear in use inside the recuperator. At a first end 700 the raised formations 206 around the second fluid inlet abut each other in order to form an inlet manifold. At a second end 701, the raised formations 208 at the second end of the heat exchange cells abut each other, to form a tubular substantially cylindrical outlet manifold for the second fluid. Between the two adjacent cells, in a direction along a length of the cells, there are formed the plurality of channels 600 through which the first fluid can flow from one end of the recuperator to the other.

[0042] Referring to Figure 7B herein, there is illustrated schematically the pair of heat exchange cells of Figure 7A, in view from one end. Each cell has a plurality of elongate ribs or ridges 702 which protrude on the outside of the cell, such that when two cells are in contact with each other, the ridges contact each other, forming a fluid channel 600 for passage of the first fluid along a length of the cells. Similarly, the protruding formations 206, 208 of adjacent cells meet each other, such that the first fluid cannot ingress between two adjacent cells an into the interior of a cell, and therefore cannot mix with the second fluid flow inside each cell. Rather, the first fluid flow is directed around the formations 206, which in combination form the second fluid inlet manifold (or formations 208 which form the second fluid outlet manifold at the other end of the cells).

[0043] Figure 8 herein illustrates schematically a computerized flow diagram of velocity vectors illustrating how first fluid (fluid 1) flows over a heat exchange surface of a cell between adjacent cells.

[0044] Shown in Figure 8 is a vector flow diagram in the plane between two adjoining cells. Since the cell is symmetric about a central axis along its length, the other side of the cell will have an equivalent mirror image vector flow.

[0045] The first fluid entering at the second end 800 of the heat exchange assembly flows around the outlet 208 for the second fluid flow, and into the plurality of channels 600. Once in the channels, the gas flows linearly along the length of the channels, and exits the channels into the cavity 205 at the first end 801 of the heat exchanger assembly.

[0046] Figure 9 herein illustrates schematically a computerized flow diagram plot of velocity vectors illustrating how the second fluid (fluid 2) flows through the interior of a cell.

[0047] The second fluid enters the cell at the first fluid inlet 201, and flows around the circular portions 900 around a perimeter of the second fluid inlet, and around the welded lip portion 901, filling the substantially flat cavity 902, and entering into the plurality of channels 204. In this case, the computerized flow diagram is for the first embodiment heat exchange cell optimized for relatively low pressure fluids where an amount of fluid flow between the individual adjacent channels 204 is permitted, since the troughs 904 between adjacent channels are not all welded to each other along their entire length.

[0048] The second fluid flows out of the second fluid outlet 202, passing between the pillars 905 which extend internally across the depth of the cell.

[0049] Figure 10 herein illustrates schematically a diagram of the centre ribbed section of the cell.

[0050] Half of a single cell is shown in part cut away view, in contact with an adjacent half cell. Each cell occupies a rectangular volume 1000 having a length l, a depth d, and a width w. Across the cell, there are 38 first fluid channels in total (19 cells across half of the cell) in which the first fluid flows between the adjacent cells, and 36 second fluid channels (18 channels in half a cell) through with the second fluid flows through the individual cell. The plurality of channels for the first fluid, which are formed between adjacent cells are surrounded by the plurality of second fluid channels in the cells adjacent and either side of the plurality of first fluid channels. Similarly, the plurality of second fluid channels within each cell are surrounded by separate sets of first fluid channels either side of the cell, the first fluid channels and second fluid channels being separated by the thin metal walls of the cell typically having thickness of the order of less than 0.5mm, so that heat transfer occurs through the metal wall of the cell between the first fluid channels and the second fluid channels and vice versa.

[0051] Also shown in Figure 10, is the internal structure of the cell in the area around the second fluid inlet and second fluid outlet. Since the two sides of each cell must be separated and spaced apart from each other to form an end cavity through which the second fluid flows, and since the region around the second fluid inlet and second fluid outlet need to be rigid under compressive force, there are provided a plurality of cylindrical pillars 1001 around the circumference of the substantially circular inlet and outlet apertures. At the second fluid inlet aperture 201, there is also provided a substantially arcuate baffle region 1002, which prevents the second fluid flowing directly from second fluid inlet, directly into the centermost plurality of second fluid channels along the length of the cell. The baffle region 1002 forces the second fluid flow to travel across the width of the cell towards the outermost second fluid channels, as shown in Figure 9 herein.

[0052] Referring to Figure 11A herein, there is illustrated schematically a plot of fluid flow measured as mass flow/cross sectional area in kg/m^{2}s, across 19 of the first fluid channels, across half the width of the individual cells of the heat exchange assembly as shown in Figure 10 herein. The first fluid channels are formed between adjacent individual cells.

[0053] The ideal with the first fluid flow, is to achieve an uninterrupted fluid flow which is substantially uniform across the width of the cell. This needs to be balanced with the practicalities of size and complexity.

[0054] In this case, the cell has a relatively larger fluid channel (channel 10) a quarter way across the distance w of the cell, as well as relatively larger first fluid channels at the edge of the cell (channel 1) and along a central axis of the cell channel 19. The fluid flow in the other half of the cell is a mirror image to that shown in Figure 11A.

[0055] An ideal fluid flow for the first fluid may be to have an equal fluid flow through each first fluid channel, across the heat exchanger assembly, or in other words, to have all of the individual heights of the channel flows shown in Figure 11A to be the same height. Using the channel arrangement and formations as described herein, the first fluid flow along and across the heat exchange unit is relatively uniform as shown in Figure 11A herein, but with a slightly lower rate of fluid flow along the innermost first fluid channels between the second fluid inlet and outlet, where the flow of first fluid through the heat exchange unit is disrupted by the inlet and outlet.

[0056] Referring to Figure 11 B herein, there is illustrated schematically a plot of fluid flow mass flow/divided by cross sectional area (kg/m^{2}s) for 18 of the second fluid channels across one half of the width of an individual cell. Ideally, the object would be to distribute the second fluid across the width of the cell, such that the fluid flow across each second fluid channel is approximately the same, giving substantially uniform fluid flow along the device.

[0057] As shown in Figure 11 B, the rate of fluid flow along the second fluid channels at the outer edges of the cell are relatively lower (less than 50%) of the rate of fluid flow of second fluid along the inner most second fluid channels in the cell.

[0058] Referring to Figure 12 herein, there is illustrated schematically in end on view, one side of a heat exchange assembly 1200 comprising a plurality of heat exchange cells 1201 - 1210, each comprising a pair of heat exchange plates 1211. In this embodiment, the outermost heat exchange plates 1212, 1213 form two sides of the outer skin of the recuperator. At a further two sides of the recuperator, the casing is formed from two separate sheets, one of which 1214 is shown in Figure 12. Another similar plate is provided at an opposite side of the heat exchange assembly, so that the pair of externally presented heat exchange plates 1212, 1213 and the side plates 1214 form the outer casing of the recuparator.

[0059] The plurality of first fluid channels 1215 are enclosed by the outermost cells 1201, 1210, and the metal side plates 1214. In the embodiment shown, the heat exchange plates of individual cells are shown touching each other in the assembly. However, it is not necessary or essential that each of the individual first fluid channels 1215 are fully separated from each other, and in other embodiments, there may be cross flow and leakage of first fluid between adjacent first fluid channels 1215. In some embodiments, the individual cells may be slightly spaced apart from each other, so that there may be a small amount of fluid transfer between adjacent first fluid channels 1215 along the length of the cell assembly 1200.

[0060] Referring to Figure 13 herein, there is illustrated schematically in view from on end, one side of a further embodiment heat exchange assembly 1300 comprising a plurality of heat exchange cells 1301 - 1310, each comprising a pair of heat exchange plates 1311. In this embodiment, the outermost heat exchange plates 1312, 1313 form two sides of the outer skin of the recuperator. Another two sides 1314 of the heat exchange assembly are formed by connecting the sides of the adjacent plates. The sides of the heat exchange plates are connected together in a fluid sealed manner so that first fluid cannot escape out of the sides of the heat exchanger. Adjacent troughs in the heat exchange cells are welded, brazed or soldered together to form the sides of the heat exchange assembly.

[0061] In the embodiment shown in Figure 13, the heat exchange plates of individual cells are shown touching each other in the assembly. However, it is not necessary or essential that each of the individual first fluid channels 1315 are fully separated from each other, and in other embodiments, there may be leakage of first fluid between adjacent first fluid channels 1315. In some embodiments, the individual cells may be slightly spaced apart from each other, except at their connected sides, so that there may be a small amount of fluid transfer between adjacent first fluid channels 1315 along the length of the cell assembly 1300.

[0062] Referring to Figure 14 herein, there is illustrated schematically one side of a third embodiment heat exchange assembly in view from one end. The heat exchange assembly 1400 comprises a plurality of heat exchange cells 1401 - 1410, each comprising a pair of heat exchange plates 1411. In this embodiment, the outermost heat exchange plates 1212 have connected to them a further substantially flat outer plate 1413, which acts as an outer casing to the heat exchange assembly and to the recuperator.

[0063] The other two sides of the heat exchange assembly may be formed by joining together adjacent cells as shown in Figure 13 herein, or by an additional side plate as shown in Figure 12 herein.

[0064] In the embodiment shown, the heat exchange plates of individual cells are shown touching each other in the assembly. However, it is not necessary or essential that each of the individual first fluid channels 1414 are fully separated from each other, and in other embodiments, there may be leakage of first fluid between adjacent first fluid channels 1414. In some embodiments, the individual cells may be slightly spaced apart from each other, so that there may be a small amount of fluid transfer between adjacent first fluid channels 1414 along the length of the cell assembly.

[0065] In the embodiments shown, the first fluid channels and second fluid channels are straight linear channels having substantially unobstructed straight flow paths. However in other embodiments, the first and second fluid channels may follow a curved or serpentine path, or may have a series of depressions or dimples to create turbulent fluid flow. In the other possible embodiments, the first and second fluid channels are each positioned adjacent to each other separate by a thin gauge material to allow efficient heat transfer between the first and second fluids.

Claims

1. A recuperator comprising:

a heat exchange assembly comprising a plurality of heat exchange plates;
an inlet for a first fluid, and an outlet for said first fluid;
an inlet for a second fluid and an outlet for said second fluid;
a plurality of first fluid channels, extending along a plurality of first paths between the inlet for the first fluid and the outlet for the first fluid;
a plurality of second fluid channels extending along a plurality of second paths between the inlet for the second fluid and the outlet for the second fluid;
characterised in that
said plurality of first fluid channels are arranged side by side with and to follow closely said plurality of second fluid channels, such that said first fluid flowing in said plurality of first fluid channels flows adjacent said second fluid flowing in said plurality of second fluid channels, said first and second channels separated by at least one said heat exchange plate such that heat transfers through said heat transfer plate between said first and second fluids;

wherein said first and second fluid channels are arranged in a contra-flow arrangement whereby said first fluid flows in said plurality of first fluid channels in an opposite direction to said second fluid flowing in said plurality of second fluid channels.

2. The recuperator as claimed in claim 1, comprising at least one heat exchange cell, wherein each said cell comprises:

a pair of heat exchange plates;
each said plate having a plurality of ribs defining a said plurality of first fluid channels and a said plurality of second fluid channels;
wherein in use said first fluid flows around said heat exchange cell and said second fluid flows within said heat exchange cell, said heat exchange plates separating said first and second fluid flows.

3. The recuperator as claimed in any one of the preceding claims, wherein said inlet for the first fluid, said outlet for the first fluid, said inlet for the second fluid, and said outlet for the second fluid are all located on or near to a main central length axis of the recuperator.

4. The recuperator as claimed in any one of the preceding claims having:

a heat transfer effectiveness of more than 85%; and
a fluid flow pressure loss of less than 4% of inlet pressure for each of said first and second fluids.

5. The recuperator as claimed in any one of the preceding claims, wherein:

said inlet for the first fluid and said outlet for the second fluid are located substantially at a second end of a said heat exchange plate; and
said outlet for the first fluid and said inlet for the second fluid are located substantially at a first end of said heat exchange plate.

6. The recuperator as claimed in any one of the preceding claims, wherein, each said heat exchange plate comprises a centre section having a profile that directs substantially all of the first fluid flowing along said heat exchange plate from near the second end to near the first end and also directs substantially all of the second fluid flowing along said heat exchange plate from near the first end to near the second end, and having no further components introduced to act as secondary heat transfer surfaces.

7. The recuperator as claimed in any one of the preceding claims, with a first fluid distribution in a centre section of the heat exchange plate which does not vary between flow paths defined by the channels by more than a ratio of 2.5 of mass flow/path cross sectional area.

8. The recuperator as claimed in any one of the preceding claims, with a second fluid distribution in the centre section of the heat exchange plate which does not vary between flow paths defined by the channels by more than a ratio of 2.5 of mass flow/path cross sectional area.

9. The recuperator as claimed in any one of the preceding claims, with one or more orifice(s) in the heat exchange plate end that introduces and aids the distribution of a fluid in a relatively even manner in the centre section of the heat exchange plate.

10. The recuperator as claimed in any one of the preceding claims comprising one or a plurality of formations around said inlet for the second fluid that direct and control the direction and volume of flow of the second fluid entering the said plurality of second fluid channels.

11. The recuperator as claimed in any one of the preceding claims having a heat exchange cell having an inlet for the second fluid, in one end of the cell, which is shaped to out flow and aid the distribution of the second fluid in a relatively even manner in the centre section of the heat exchange cell.

12. The recuperator as claimed in any one of the preceding claims, having a heat exchange cell with an outlet orifice for the second fluid, and with forms around the orifice that direct and control the direction and volume of flow of the second fluid exiting the heat exchange cell.

13. The recuperator as claimed in any one of the preceding claims comprising a heat exchange cell having start and end formations which direct fluid to and from a central ribbed section of the cell, so as to that aid the distribution of a fluid in a relatively even manner in the centre section of the heat exchange cell.

14. The recuperator as claimed in any one of the preceding claims, wherein said heat exchange plates have a thickness of less than 0.5mm.

15. The recuperator as claimed in any one of the preceding claims, comprising an outer skin manufactured from thin wall gauge material of the same or near the same gauge as the heat exchange plates.

16. The recuperator as claimed in claim 15, wherein the outermost heat exchange plates also form two sides of said skin.

17. The recuperator as claimed in claim 15 wherein the edges of the heat exchange cells form two sided of said outer skin.

18. The recuperator as claimed in any one of the preceding claims wherein said heat exchange cell comprises two heat exchanger plates joined together to form said cell, and that has sufficient strength to resist a fluid pressure of up to 10 bar gauge.

Amended claims in accordance with Rule 137(2) EPC.

1. A recuperator (100) comprising:

a heat exchange assembly comprising a plurality of heat exchange plates (105);
an inlet (101) for a first fluid, and an outlet (102) for said first fluid;
an inlet (103, 201) for a second fluid and an outlet (104, 202) for said second fluid;
a plurality of first fluid channels (600), extending along a plurality of first paths between the inlet for the first fluid and the outlet for the first fluid;
a plurality of second fluid channels (204) extending along a plurality of second paths between the inlet for the second fluid and the outlet for the second fluid;
characterised in that:

said plurality of first fluid channels (600) are arranged side by side with and to follow closely said plurality of second fluid channels (204), such that said first fluid flowing in said plurality of first fluid channels flows adjacent said second fluid flowing in said plurality of second fluid channels, said first and second channels separated by at least one said heat exchange plate (200) such that heat transfers through said heat transfer plate between said first and second fluids;
wherein said first and second fluid channels are arranged in a contra-flow arrangement whereby said first fluid flows in said plurality of first fluid channels in an opposite direction to said second fluid flowing in said plurality of second fluid channels; and
wherein said first and second fluids are distributed relatively evenly across the width of the surface of the heat exchange plate (200).

2. The recuperator as claimed in claim 1, wherein said first and second fluid channels are arranged in a contra-flow arrangement whereby said first fluid flows in said plurality of first fluid channels parallel to and in an opposite direction to said second fluid flowing in said plurality of second fluid channels.

3. The recuperator as claimed in claim 1, comprising at least one heat exchange cell, wherein each said cell comprises:

a pair of heat exchange plates;
each said plate having a plurality of ribs defining a said plurality of first fluid channels and a said plurality of second fluid channels;
wherein in use said first fluid flows around said heat exchange cell and said second fluid flows within said heat exchange cell, said heat exchange plates separating said first and second fluid flows.

4. The recuperator as claimed in any one of the preceding claims, wherein said inlet for the first fluid, said outlet for the first fluid, said inlet for the second fluid, and said outlet for the second fluid are all located on or near to a main central length axis of the recuperator.

5. The recuperator as claimed in any one of the preceding claims having:

a heat transfer effectiveness of more than 80%; and
a fluid flow pressure loss of less than 4% of inlet pressure for each of said first and second fluids.

6. The recuperator as claimed in any one of the preceding claims, wherein:

said inlet for the first fluid and said outlet for the second fluid are located substantially at a second end of a said heat exchange plate; and
said outlet for the first fluid and said inlet for the second fluid are located substantially at a first end of said heat exchange plate.

7. The recuperator as claimed in any one of the preceding claims, wherein, each said heat exchange plate comprises a centre section having a profile that directs substantially all of the first fluid flowing along said heat exchange plate from near the second end to near the first end and also directs substantially all of the second fluid flowing along said heat exchange plate from near the first end to near the second end, and having no further components introduced to act as secondary heat transfer surfaces.

8. The recuperator as claimed in any one of the preceding claims, with a first fluid distribution in a centre section of the heat exchange plate which does not vary between flow paths defined by the channels by more than a ratio of 2.5 of mass flow/path cross sectional area.

9. The recuperator as claimed in any one of the preceding claims, with a second fluid distribution in the centre section of the heat exchange plate which does not vary between flow paths defined by the channels by more than a ratio of 2.5 of mass flow/path cross sectional area.

10. The recuperator as claimed in any one of the preceding claims, with one or more orifice(s) in the heat exchange plate end that introduces and aids the distribution of a fluid in a relatively even manner in the centre section of the heat exchange plate.

11. The recuperator as claimed in any one of the preceding claims, comprising one or a plurality of formations around said inlet for the second fluid that direct and control the direction and volume of flow of the second fluid entering the said plurality of second fluid channels.

12. The recuperator as claimed in any one of the preceding claims, having a heat exchange cell having an inlet for the second fluid, in one end of the cell, which is shaped to out flow and aid the distribution of the second fluid in a relatively even manner in the centre section of the heat exchange cell.

13. The recuperator as claimed in any one of the preceding claims, having a heat exchange cell with an outlet orifice for the second fluid, and with forms around the orifice that direct and control the direction and volume of flow of the second fluid exiting the heat exchange cell.

14. The recuperator as claimed in any one of the preceding claims, comprising a heat exchange cell having start and end formations which direct fluid to and from a central ribbed section of the cell, so as to that aid the distribution of a fluid in a relatively even manner in the centre section of the heat exchange cell.

15. The recuperator as claimed in any one of the preceding claims, wherein said heat exchange plates have a thickness of less than 0.5mm.

16. The recuperator as claimed in any one of the preceding claims, comprising an outer skin manufactured from thin wall gauge material of the same or near the same gauge as the heat exchange plates.

17. The recuperator as claimed in claim 15, wherein the outermost heat exchange plates also form two sides of said skin.

18. The recuperator as claimed in claim 15, wherein the edges of the heat exchange cells form two sides of said outer skin.

19. The recuperator as claimed in any one of the preceding claims wherein said heat exchange cell comprises two heat exchanger plates joined together to form said cell, and that has sufficient strength to resist a fluid pressure of up to 10 bar gauge.

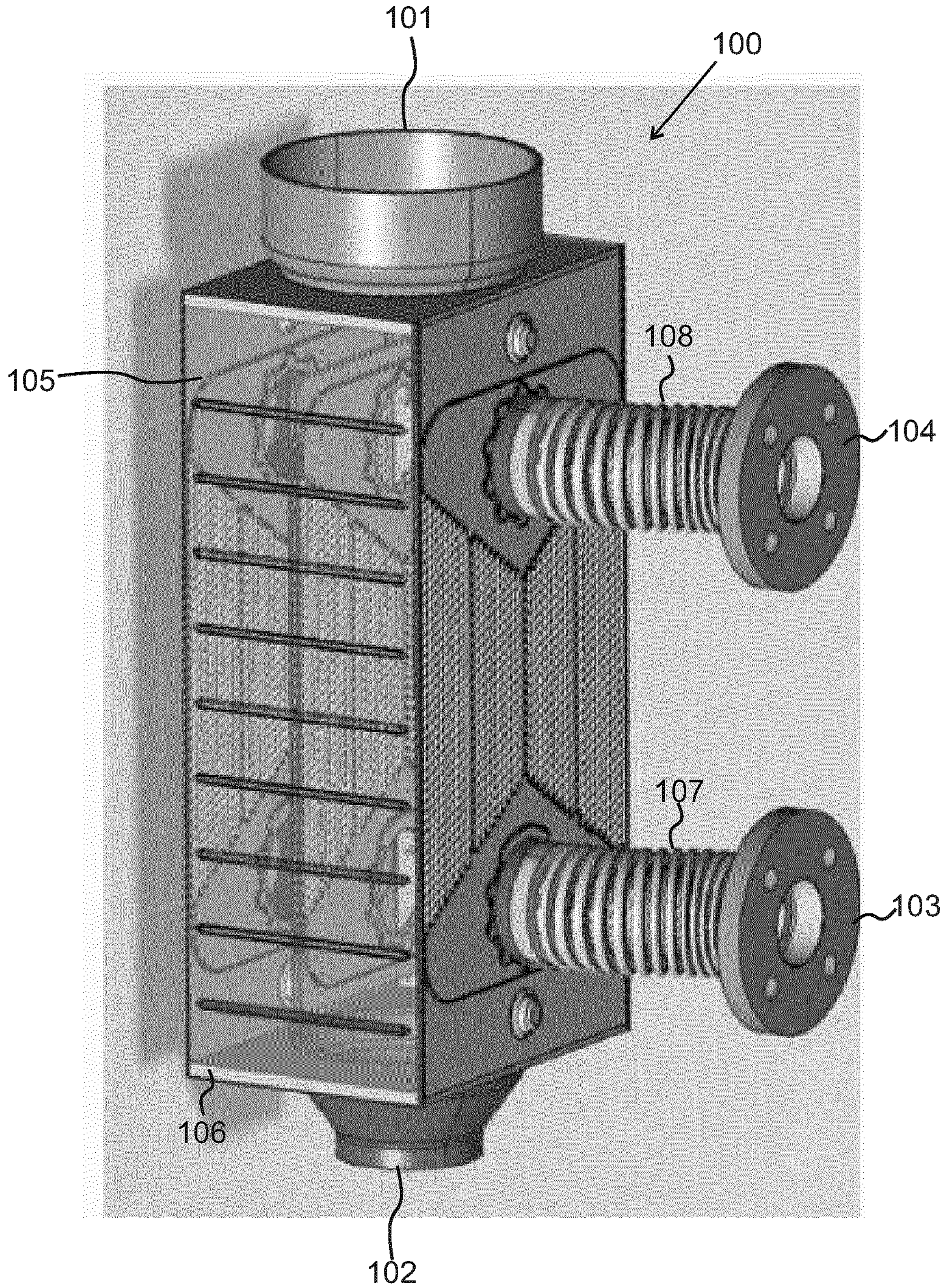

Fig. 1

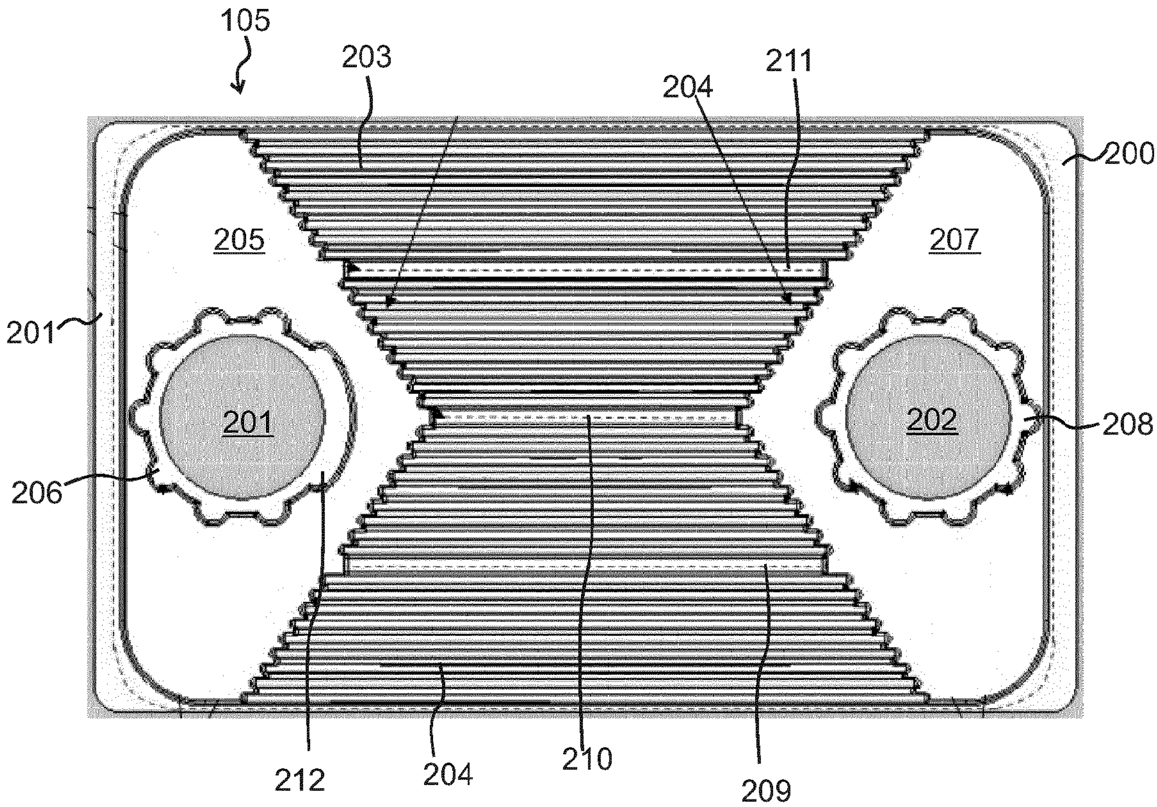
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Fig. 2

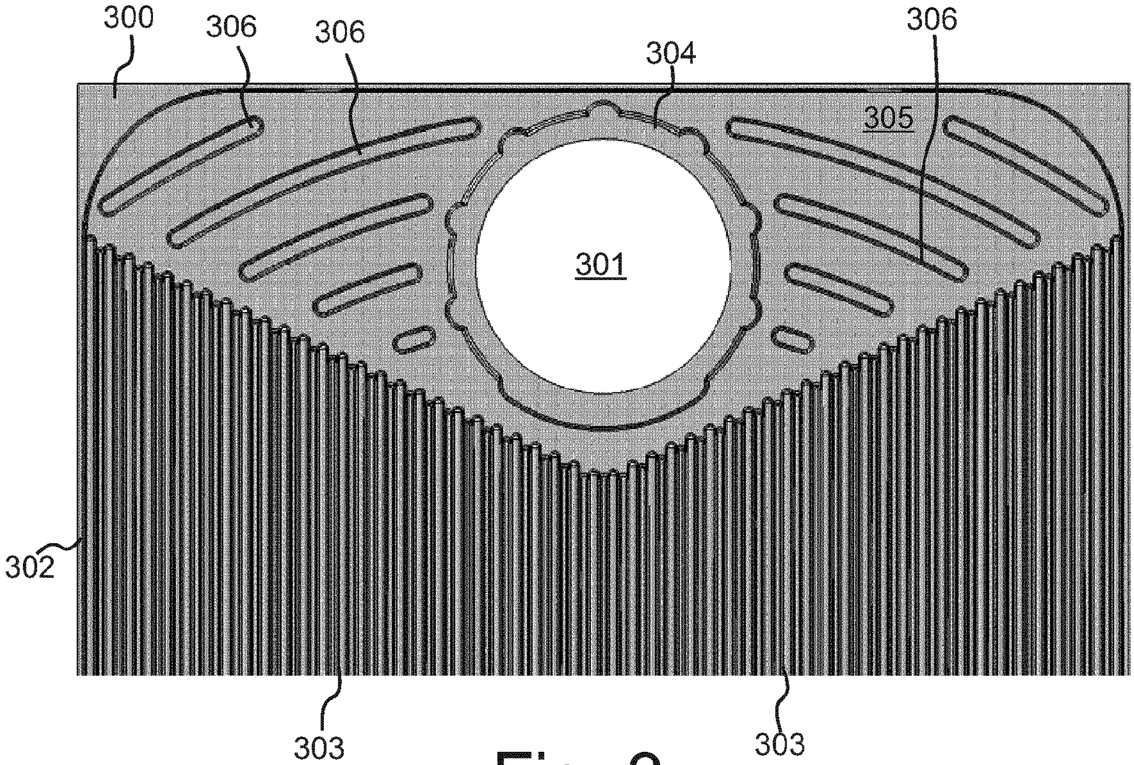
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Fig. 3

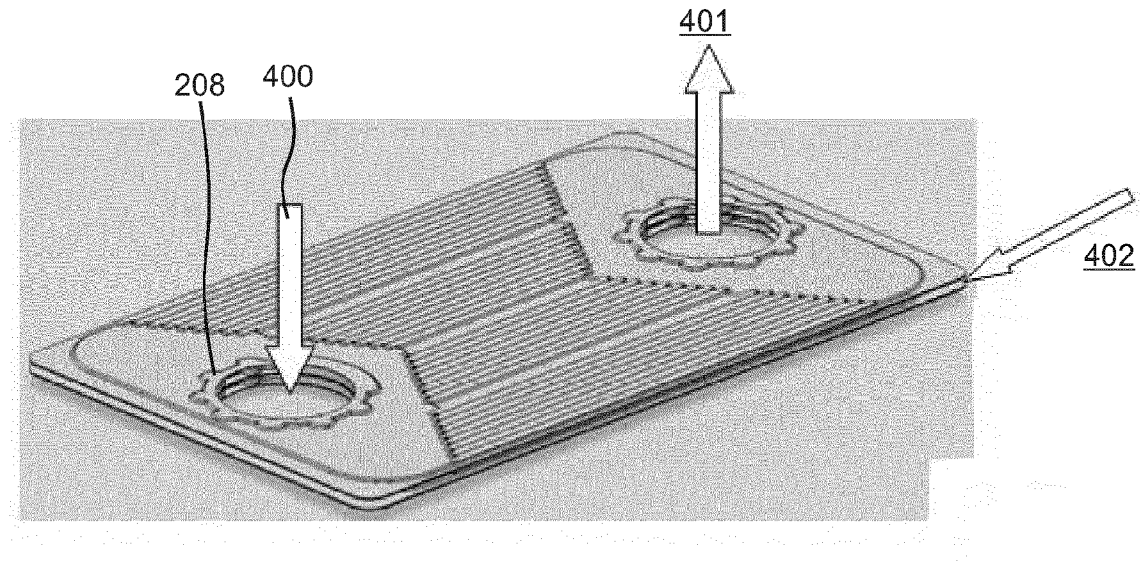
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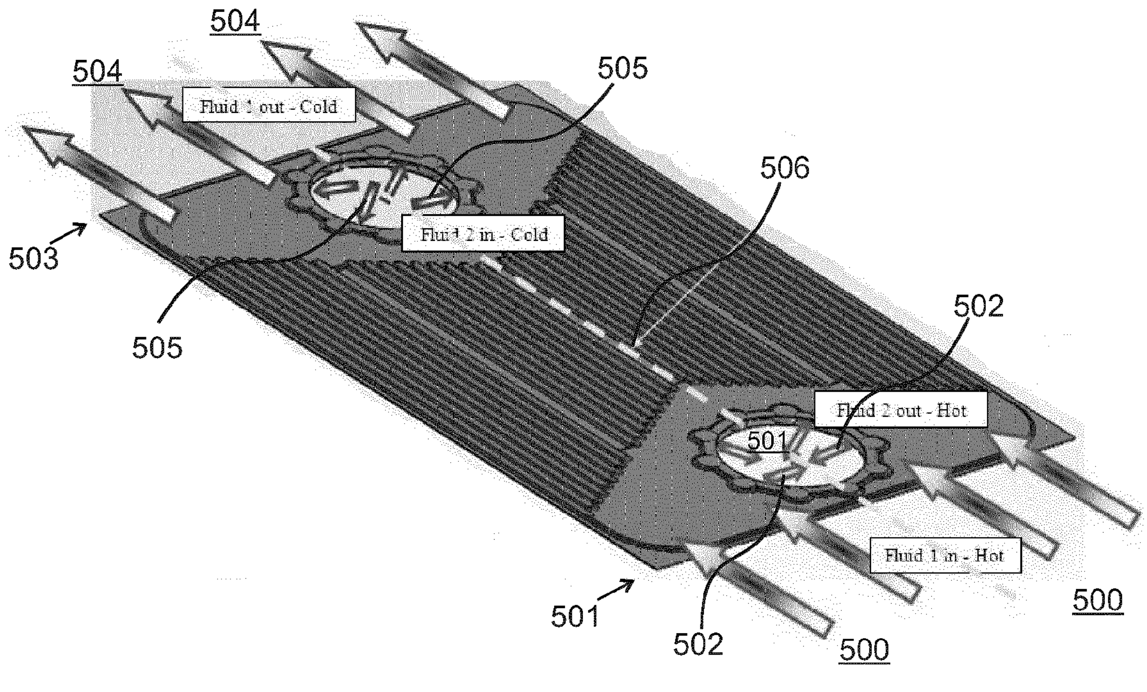
Fig. 4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Fluid 1 out - Cold
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Fluid 2 in - Cold
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Fluid 2 out - Hot
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Fluid 1 in - Hot
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Fig. 5

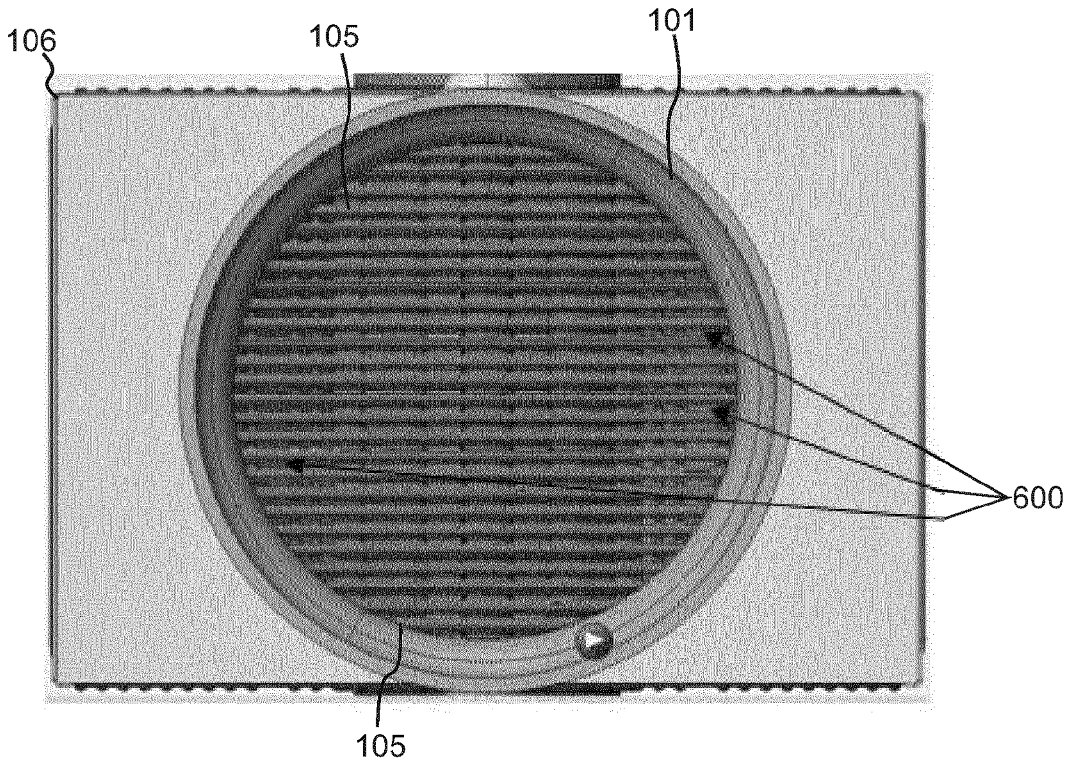

Fig. 6

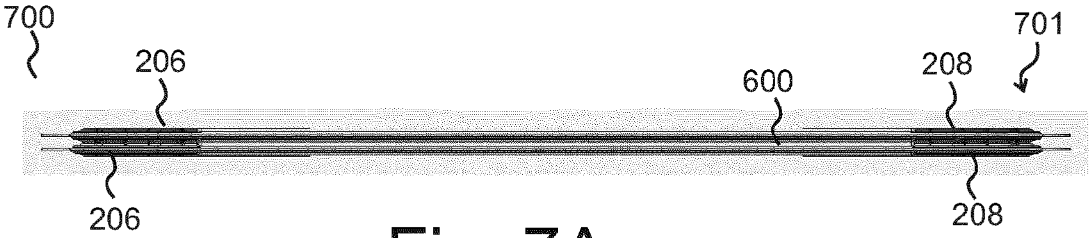

Fig. 7A

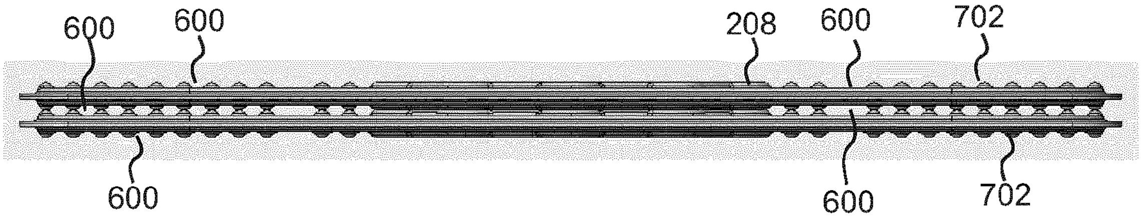

Fig. 7B

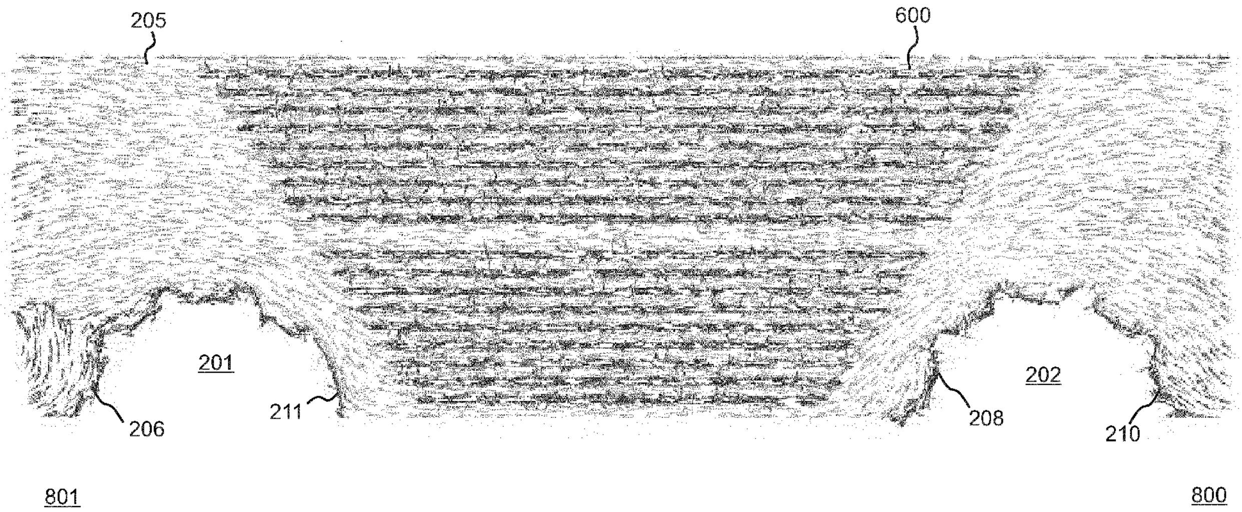

Fig. 8

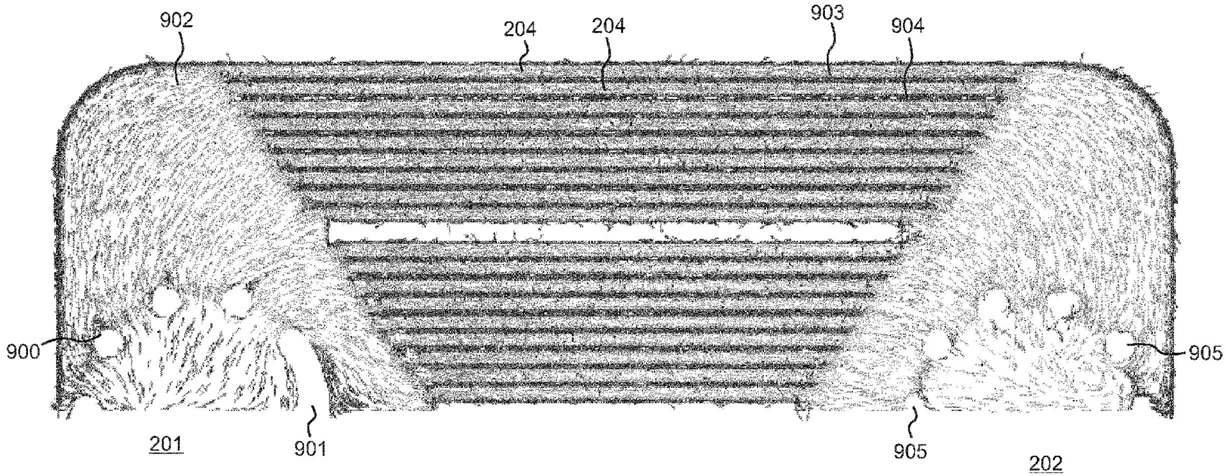

Fig. 9

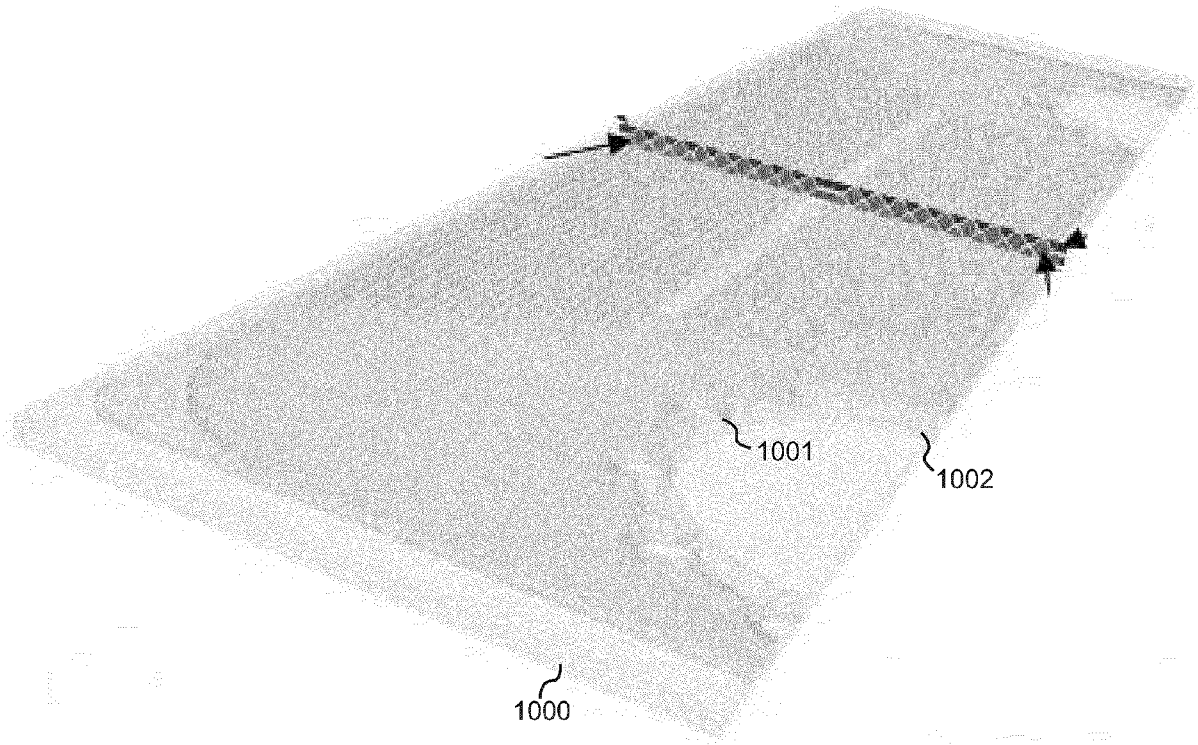

Fig. 10

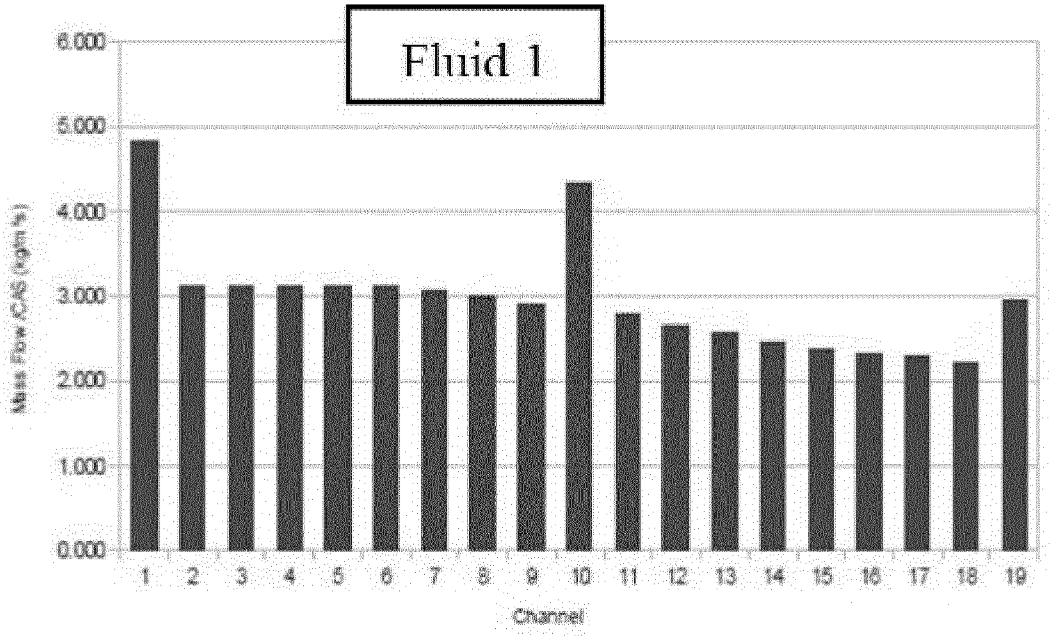

Fig. 11A

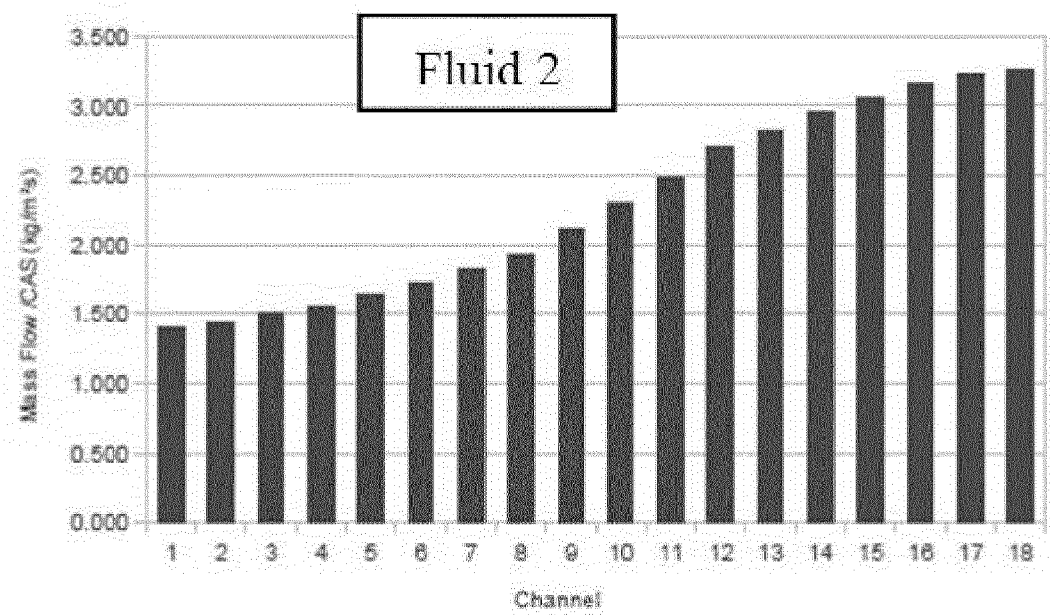

Fig. 11B

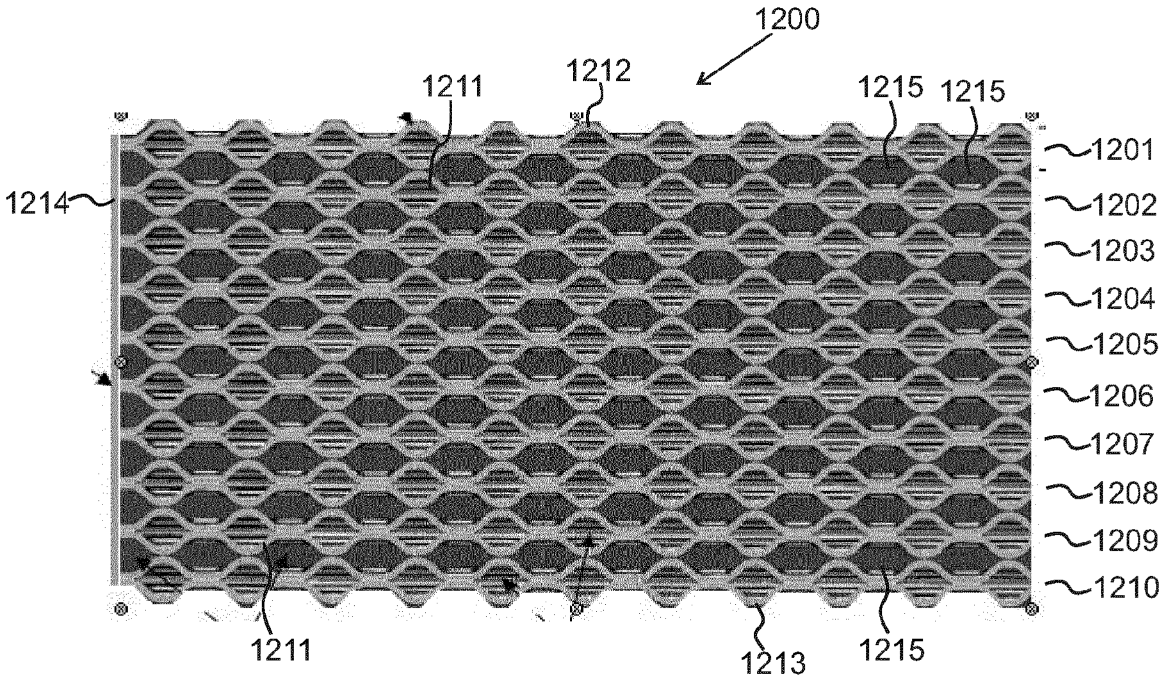
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Fig. 12

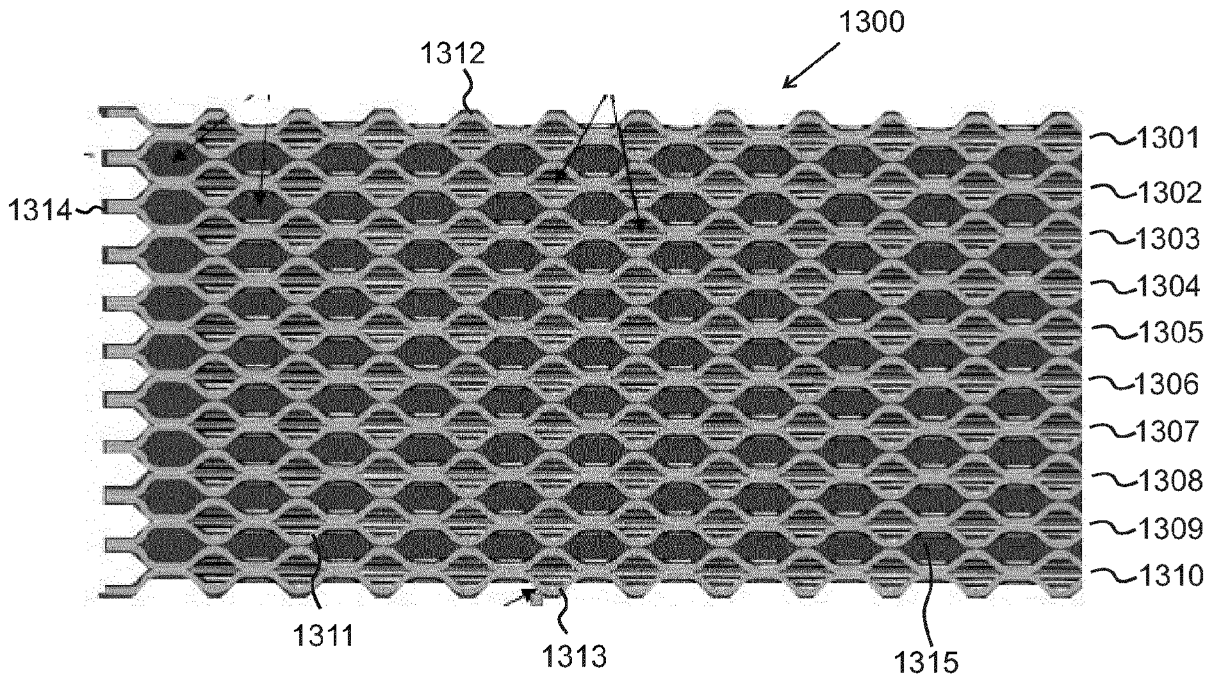
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Fig. 13

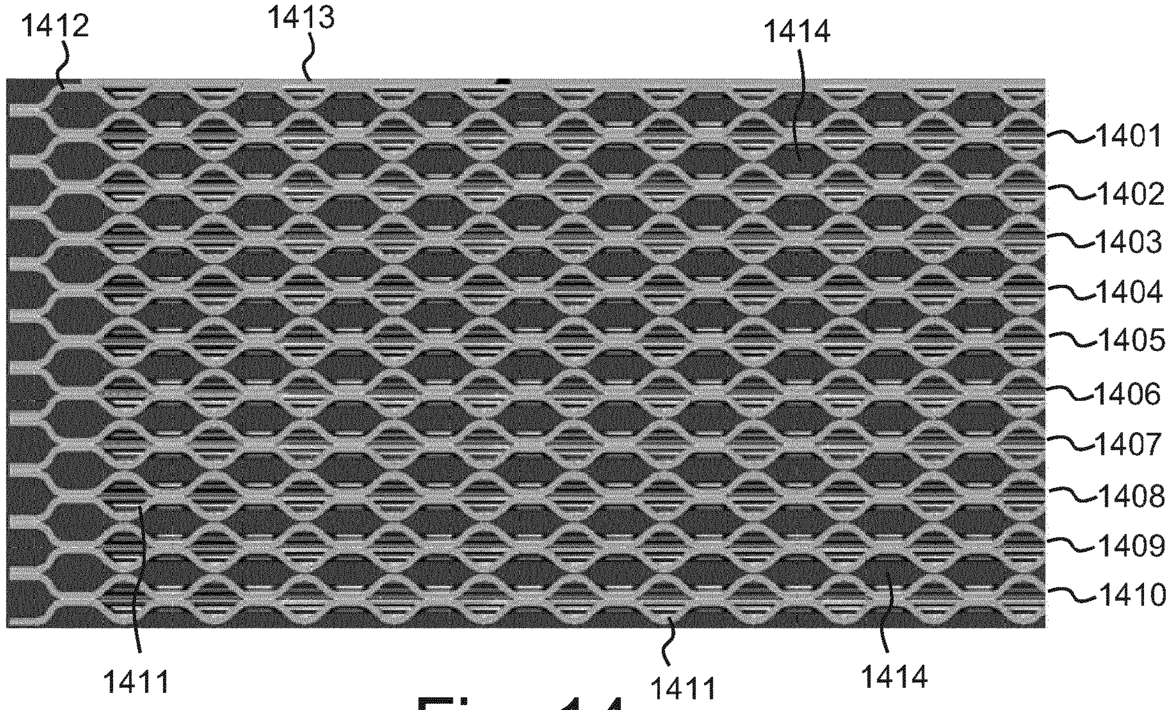
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Fig. 14

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EUROPEAN SEARCH REPORT

Application Number
EP 11 19 4253

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 01/98723 A1 (SERCK HEAT TRANSFERT LTD [GB]; GROVES CHRISTOPHER [GB]; STONEHOUSE MAT) 27 December 2001 (2001-12-27) * figures 2, 3, 6, 11 * * page 10, line 9 - line 11 * * page 14, line 16 - line 20 * -----	1-3,5,6,9	INV. F28D9/00 F28F3/04
X	EP 2 136 175 A1 (SCHULT JOACHIM [DE]) 23 December 2009 (2009-12-23) * figures 1B, 2, 3 * * paragraph [0005] * * paragraph [0031] * -----	1,2,5,6,9,10,12,13,18	
A	US 2004/069475 A1 (BROST VIKTOR [DE] ET AL) 15 April 2004 (2004-04-15) * figures * -----	1-18	
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TECHNICAL FIELDS SEARCHED (IPC)
F28D F28F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	7 May 2012	Fernandez Ambres, A

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07-05-2012

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US 2004069475	A1	15-04-2004	NONE		
EP 1936310	A1	25-06-2008	NONE		

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