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(54) **HEAT EXCHANGER**

(57) There is disclosed a heat exchanger comprising at least one set of channels having a proximal end and a distal end, the set of channels comprising: a first channel defined by a first skin and a wall; and a second channel defined by a second skin and the wall, wherein the

wall located between the first channel and the second channel comprises a first at least one aperture to allow fluid to pass through the wall from the first channel to the second channel.

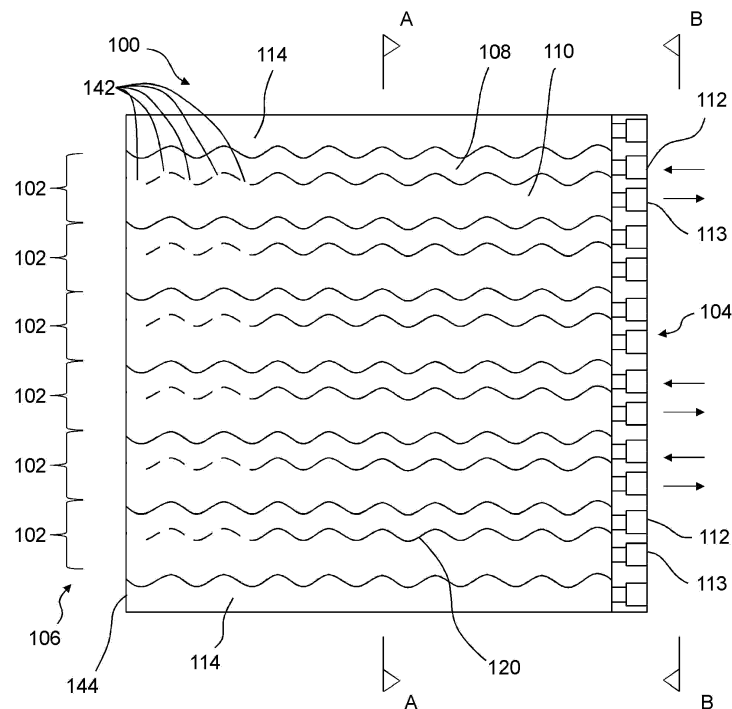


Figure 1

Description

[0001] The present disclosure relates to a heat exchanger. In particular, the disclosure is concerned with a heat exchanger for a land, sea or air vehicles subject to high temperatures or for a heat exchanger for a stationary structure or equipment. In this application the term vehicle may apply to any moving system (land, sea or air) and land-based system may apply to a vehicle or a stationary structure/equipment.

[0002] Vehicles and land-based systems may generate and be subject to significant amounts of heat in operation. Cooling systems have been used to reduce the temperatures in parts of vehicles or land-based systems. These cooling systems may take the form of active systems, such as heat exchangers, or passive systems.

[0003] Heat exchangers are systems that are designed to transfer heat between two different media. Typically, there is a heat exchanging medium in the heat exchanger for transferring the heat from one region to another region. The heat exchanging medium may be solid or a fluid. Heat exchangers may be used for vehicles or land-based systems to provide active cooling to structure and/or equipment or remove heat from heat sensitive equipment.

[0004] There is a need to create an improved "active" skin cooling system for use with vehicles and land-based systems that generate and be subject to significant amounts of heat in operation.

[0005] According to a first aspect, there is provided a heat exchanger comprising at least one set of channels having a proximal end and a distal end, the set of channels comprising: a first channel defined by a first skin and a wall; and a second channel defined by a second skin and the wall, wherein the wall located between the first channel and the second channel comprises a first at least one aperture to allow fluid to pass through the wall from the first channel to the second channel.

[0006] In one example, the heat exchanger comprises an inlet port for receiving said fluid and an outlet port for allowing the fluid to exit the heat exchanger.

[0007] In one example, the inlet port is coupled to the first channel and the outlet port is coupled to the second channel.

[0008] The inlet port and the outlet port may be arranged at the proximal end of the set of channels. In other examples the inlet port is arranged at the proximal end of the set of channels and the outlet port is arranged at the distal end of the set of channels.

[0009] In one example, the set of channels comprises a third channel defined by the first skin and the wall, wherein the wall located between the second channel and the third channel comprises a second at least one aperture to allow fluid to pass through the wall from the second channel to the third channel.

[0010] The inlet port may be connected to the first channel at the proximal end of the set of channels and the outlet port may be connected to the third channel at the distal end of the set of channels. The second at least one aperture may be located towards the proximal end of the set of channels. The first at least one aperture may be towards the distal end of the set of channels.

[0011] The set of channels may follow a non-linear path between the proximal end and the distal end. The first channel and the second channel may be parallel curves relative to each other. The non-linear path may be substantially sinusoidal. The wall may be bonded to the first skin and the second skin. The wall may be corrugated and comprise a first longitudinal section bonded to the first skin, a second longitudinal section bonded to the second skin and at least one an inclined section between the first longitudinal section and the second longitudinal section. The inclined section may be inclined at an angle of approximately 30 to 60 degrees relative to the first longitudinal section and the second longitudinal section. The wall may have a thickness of between 0.5mm and 6mm. The first skin and the second skin may be formed of a titanium alloy. The heat exchanger may comprise a plurality of sets of channels.

[0012] According to another aspect of the invention, there is provided a method of manufacturing a heat exchanger, wherein the heat exchanger is manufactured using diffusion bonding and superplastic forming.

[0013] Examples of the present disclosure will now be described with reference to the accompanying drawings, in which:

Figure 1 shows an example of a plan view of a cross section of a heat exchanger;

Figure 2 shows a cross sectional view of the heat exchanger along Section lines A-A shown in Figure 1;

Figure 3 shows a portion of a cross-section of a wall having a warren girder or corrugated profile;

Figure 4 shows an example of a portion of a wall between a first skin and second skin;

Figure 5 shows a section through a heat exchanger showing one or more apertures in the wall;

Figure 6 shows an example of an elevation B-B as indicated by markers B-B in Figure 1;

Figures 7A and 7B shows an example of fluid paths through a section of the heat exchanger;

Figure 8 shows an example of the a section of the heat exchanger; and

Figure 9 shows an example of the relationship between heat transfer and mass flow rate.

[0014] It will be appreciated that relative terms such as top and bottom, upper and lower, and so on, are used merely for ease of reference to the Figures, and these terms are not limiting as such, and any two differing directions or positions and so on may be implemented.

[0015] Figure 1 shows an illustrative example of a plan view of a heat exchanger 100. In the example shown, the heat exchanger 100 comprises a set of channels 102. There are six sets of channels 102 shown in the example in Figure 1, but in other examples, more or fewer than six sets of channels 102 may be used. The set of channels 102 has a proximal end 104 and a distal end 106.

[0016] The set of channels 102 comprises a first channel 108 and a second channel 110. The first channel 108 and the second channel 110 are fluidly coupled to allow fluid to pass from the first channel 108 to the second channel 110.

[0017] The set of channels 102 are located between a first skin 116 and a second skin 118 of the heat exchanger 100, which are shown in more detail in Figure 2.

[0018] In the example shown in Figure 1, in addition to the plurality of sets of channels 102 comprising the first channel 108 and the second channel 110, there are also two isolated channels 114 that do not receive fluid. The isolated channels 114 are exterior channels that may act as static pressure vessels and are not subjected to fluid flow, in use. In this example, the two additional channels 114 are located towards the side of the heat exchanger 100 such that the set of channels 102 is located between the two additional channels 114.

[0019] In the example shown in Figure 1, fluid may enter the heat exchanger 100 via one or more inlet ports 112 and exit the heat exchanger 100 via one or more outlet ports 113. In other examples, fluid may enter the heat exchanger via an opening the in first skin or the second skin.

[0020] Figure 1 shows that there may be one or more wall sections 120 separating the first channel 108 and the second channel 110 of each set of channels 102. The wall sections 120 between the first channel 108 and the second channel 110 of the set of channels 102 may comprise one or more holes or apertures 142 to enable fluid to pass from the first channel 108 to the second channel 110. The apertures are described in more detail in relation to Figure 5.

[0021] Figure 2 shows a section view through the example of the heat exchanger 100 in Figure 1 as taken along section markers A-A in Figure 1. Figure 2 shows an example of the first skin 116 and the second skin 118 with the at least one of pair of channels 102 located between the first skin 116 and the second skin 118.

[0022] In some examples, the first skin 116 is a lower skin located above the first channel 108 and the second channel 110 and the second skin 118 is an upper skin located below the first channel 108 and the second channel 110. The first skin 116 and the second skin 118 are shown as being substantially planar in this example, but in other examples, the profile of the skin platen 116 and second skin 118 may not be planar and may be shaped so as to fit the shape of the apparatus that requires cooling.

[0023] In some examples, the wall 120 is a single continuous element that extends across and defines a plurality of sets of channels 102. However, in the other examples, the wall 120 may comprise a plurality of discrete elements, with an element of the wall 120 located between adjacent first channels 108 and second channels 110.

[0024] The wall 120 may have a shaped profile so as to define the plurality of first and second channels 108, 110, together with the first skin 116 and the second skin 118, in the heat exchanger 100. In one example, the wall 120 comprises a warren girder profile in cross-section, as shown in detail in Figures 2, 3 and 4.

[0025] Figure 3 shows a portion of an example of a wall 120 having a warren girder or corrugated profile in cross section. In this example, the wall 120 is a continuous element comprising a plurality of longitudinal sections 122, 124 separated by a plurality of inclined sections or webs 126, 128. In this example, the plurality of longitudinal sections 122, 124 are arranged along two planes such that alternate longitudinal sections 122, 124 are arranged on different planes, i.e. a first longitudinal section 122 and a second longitudinal section 124 are arranged on different planes are connected by an inclined section 126, 128. A first set of alternating longitudinal sections 122 are arranged along a first plane and a second set of alternating longitudinal sections 124 are arranged along a second plane. In one example, the first set of alternating longitudinal sections 122 are coupled to or bonded with the first skin 116 and the second set of alternating longitudinal sections 124 are coupled to or bonded with the second skin 118.

[0026] The wall 120 may form a repeating pattern of first longitudinal sections 122 and second longitudinal sections 124 connected by one or more inclined webs 126, 128. In one example, the wall 120 is corrugated and the at least one set of channels 102 are defined by a first platen 116, a second platen 118 and the corrugated wall 120.

[0027] Figure 4 shows an example of a portion of the wall 120 between the first skin 116 and the second skin 118. The first channel 108 is defined by the wall 120 and the first skin 116 and the second channel 110 is defined by the wall 120 and the second skin 118. A first set of longitudinal sections 122 of the wall 120 are connected to or bonded with the second skin 118 and a second set of longitudinal sections 124 are connected to or bonded with the first platen 116. In some examples, the angle of the inclined section or web 126, 128 is approximately 45 degrees relative to the longitudinal

sections 122, 124 of the wall 120 and first skin 116 or second skin 118. However, in other examples, the angle of the incline section 126, 128 may range from approximately 30 degrees to approximately 60 degrees relative to the longitudinal sections 122, 124 of the wall 120 and first skin 116 or second skin 118. The geometry is applicable to DB/SPF manufacture as the angles result in manageable levels of superplastic strain in the wall 120. A 30degree angle of the inclined section or web 126, 128 would nominally result in an SPF strain of 100% and a halving of original thickness in the horizontal plane prior to forming.

[0028] Forming a heat exchanger from only three layers, in this case the first skin 116, the second skin 118 and the wall 120, means that ultrasonic testing can be carried out on the heat exchanger 100 to check the heat exchanger has formed correctly. Further, ultrasonic testing can be used to test for any structural irregularities during the life of the heat exchanger.

[0029] As shown in Figure 4, as the first channel 108 is defined by a first skin 116 and a wall 120; and the second channel 110 is defined by a second skin 118 and the wall 120. For example, as shown in Figure 4, the first channel 108 is defined by the longitudinal section 122 and the inclined sections 126, 128 of the wall 120 and the first skin 116. Further, the second channel 110 is defined by the longitudinal section 124 and the inclined sections 126, 128 of the wall 120 and the second skin 118. As a result of this example, fluid passing through the first channel 108 has a large contact surface area with the first skin 116. As such, if the first skin 116 is subject to the hot side of the heat exchanger 100 that requires cooling, then more of the heat can be absorbed by the fluid passing through the first channel 108. The fluid will then pass through the first at least one aperture 142 in the wall 120 separating the first channel 108 and the second channel 110. The second channel 110 has a large contact surface area with the second skin 118. As a result, some of the heat may be transferred from the fluid to the second skin 118, which may be at a lower temperature compared with the first skin 116 but with the intention that the cooling effect is high in channel 108 and that the higher proportion of the heat transferred from the first skin 116 will remain with the fluid as it then flows along the second channel 110 and is not transferred excessively into the cooler skin 118 but is instead transferred with the fluid as it exits the heat exchanger 100. In one example, the fluid that exits the heat exchanger 100 may pass into a secondary heat exchanging device (e.g. a radiator or similar).

[0030] In one example, the first skin 116 and the second skin 118 each have a thickness of approximately 2mm but in practice, any thickness may be considered depending on the application. The distance between the inside face of the first platen 116 and the inside face of the second platen may be approximately 16mm but could be perhaps as much as 100mm. The material thickness is designed to accommodate a pressure of approximately 20bar. The wall 120 may have a thickness of between about 0.5mm and 6mm depending on the application. For a ground-based cooling system where weight is not of consequence the wall 120 could be 6mm thick. For an air vehicle a wall would more typically be between 0.5mm and 2mm. This web thickness therefore de-risked the manufacturing quality to add strength to the channels under working conditions.

[0031] In one example, the first channel 108 is suitable for receiving a coolant fluid via an inlet port 112. The second channel 110 may be connected to an outlet port 113 for allowing the coolant fluid to leave the second channel 110. In some examples, the inlet port 112 may be integrated with the first channel 108 and the outlet port 113 may be integrated with the second channel 110. In other examples the inlet port 112 and the outlet port 113 may be plumbed using a pipe connector to the first channel 108 and the second channel 110.

[0032] In one example the inlet port 112 is substantially cylindrical. The outlet port 113 may be substantially cylindrical. The substantially cylindrical inlet port 112 includes an inner diameter 132, defining a hole 134, and an outer diameter 136. In one example, the inlet port has a hole 134 of approximately 8mm and an outer diameter of approximately 10mm.

[0033] The inlet port 112 provides a method for allowing a coolant fluid to transit from a source of fluid to the heat exchanger 100. Due to the significant pressures in use in the heat exchanger 100, associated pipework through which the coolant fluid is provided to the inlet port 112 may be welded to the interface of the inlet port 112. To be able to weld the associated pipework to the inlet port 112, an area around the welded location had to be created to accommodate the pipework, weld and associated heat generated during this process. These criteria generated the cross-sectional area required to securely support and manage the heat load during assembly.

[0034] In one example, the at least one inlet port 112 and the at least one outlet port 113 are alternately arranged at the proximal end 104 of the at least one set of channels 102, such that an outlet port 113 is arranged in between two inlet ports 112.

[0035] In the example shown in Figure 1, the inlet and outlet ports 112, 113 are connected directly into the set of channels 102. However, in other examples, the inlet ports 112 and outlet ports 113 are connected through the first skin 116 and/or second skin 118.

[0036] In other examples, the set of channels 102 comprises a plurality of channels such that the fluid and the outlet port may be at either the proximal or distal end of the set of channels 102. Alternatively, the inlet or outlet ports 112, 113 may be arranged such that the fluid is transferred through the external platens or the ends of the channels.

[0037] Figure 5 shows an example of one or more apertures 142 in the wall 120 between the first channel 108 and the second channel 110 of the set of channels 102. In one example, the first channel 108 and the second channel 110

are fluidly coupled via the one or more apertures 142 located in the wall 120 between the first channel 108 and the second channel 110. The one or more apertures 142 may be formed in the inclined section 128 of the wall 120. In Figure 5, the apertures 142 are shown as being circular shaped, but other shapes are envisaged.

[0038] In some examples, the one or more apertures 142 are arranged towards the distal end of the at least one set of channels 102. In one example, there are a plurality of apertures 142 spaced at between 10mm and 20mm along the wall between the inlet channel and outlet channel, but other sizes are envisaged depending on the application of the heat exchanger.

[0039] The apertures may be of variable size depending on the required fluid transfer rates and pressures. Specifically, in the case where there is a plurality of apertures the apertures may optimally be smaller towards the proximal end and progressively increase in size towards the distal so as to ensure that each aperture permits the desired share of the total flow to pass. In one example, the apertures will be made circular at the stage of manufacturing the wall 120 (or core sheet) in the DB/SPF process, but the effect of superplastic forming will then cause the circular form to be uniaxially extended to an ellipse shape. Alternatively, an elliptical hole with the major axis transverse to the superplastic strain direction such that a circular final hole form will result after forming. The thickness of the material at the location where the gas transfer holes are introduced may also be of additional thickness in order that the tendency for local thinning due to superplastic straining is counteracted.

[0040] One method of manufacturing the heat exchanger is using a DB/SPF process. The apertures 142 will be "gas transfer holes" introduced in the core pack by simple hole drilling of the core sheet (which results in the wall 120 in the heat exchanger 100) at the detail manufacturing stage and before the application of stop-off compound to locally prevent the diffusion bonding of sheets so as to facilitate the subsequent formation of three dimensional structure by superplastic inflation of the core pack within an SPF tool cavity. There are various techniques to manage the apertures 142 so as to avoid excessive elongation during SPF. In the example of the heat exchanger 100 being used with an air vehicle, avoiding excessive elongation could be important as the core sheet will be as thin as possible for light weighting reasons. For ground-based systems the core thickness may be substantial and strain around the holes should not be excessive. The DB stage can cause the first platen 116 to form into the hole in the core sheet, which forms the wall 120, and then seal the hole and potentially diffusion bond together (noting that the area has a layer of stop-off applied).

[0041] The example of Figure 5 also shows an example of a chamfer located at the distal end of the heat exchanger 100. In one example, the chamfer is angled between 30 to 60 degrees, more particularly between 40 degrees and 50 degrees. The chamfer may result from the build orientation of Selective Laser Melting manufacturing, which may be used to manufacture the heat exchanger 100. The heat exchanger may be built in the vertical direction upwards. The nature of this build orientation provides a self-supporting method of manufacture which is optimised at 45 degrees.

[0042] Figure 6 shows an example of an elevation B-B as indicated by markers B-B in Figure 1. In this example, the inlet ports 112 and the outlet ports 113 are arranged in an alternating nature at the proximal end 104 of the at least one set of channels 102. For conciseness, not all of the inlet ports 112 and outlet ports 113 have been indicated with reference signs. Further, the centre line through the inlet ports 112 may be offset from a centre line of the outlet ports 113 by approximately 2mm.

[0043] Referring to Figure 1, there is shown a plan cross-sectional view of the heat exchanger 100. The arrows in Figure 1 indicate the flow of fluid, such as coolant fluid, into the first channel 108, through the at least one aperture 142 in the wall 120, and out of the second channel 110 via an inlet port 112 and the outlet port 113 respectively. Note that for conciseness, not all inlet ports 112 and outlet ports 113 include arrows indicating fluid flow. However, in practise, each of the inlet ports 112 may receive a fluid flow and each of the outlet ports 113 may eject the fluid. In this example, the apertures 142 located towards the distal end of the set of channels 102, i.e. towards the opposite end of the set of channels 102 from the inlet port 112. In the example shown in Figure 1, there are five apertures 142 shown in the wall 120 between the first channel 108 and the second channel 110. However, in other examples, there may be more or fewer than five apertures 142 between each wall 120 separating the first channel 108 and the second channel 110 of the set of channels 102.

[0044] As can be seen in Figure 1, each set of channels 102 is separated by a section of wall 120 that does not contain an aperture. Therefore, each set of channels 102 is fluidly isolated from the other sets of channels 102.

[0045] In one example, as fluid enters that heat exchanger 100 via the inlet port 112, it travels along the first channel 108 from the proximal end of the set of channels 102 towards the distal end of the set of channels channel 102. The apertures in the wall 120 between the first channel 108 and the second channel 110 enable the fluid to pass through the wall 120 comprising the apertures 142.

[0046] Once the fluid has passed to the second channel 110, it moves from the distal end of the set of channels 102 to proximal end of the set of channels 102, i.e. the part of the second channel 110 that is adjacent to the outlet port 113. The fluid then exits the heat exchanger 100 via the outlet port 113.

[0047] In one example a boundary wall 144 bounds the heat exchanger 100 such that as the fluid approaches the extreme distal end of the first channel 108, any fluid that has not already passed through the one or more apertures 142 will impinge upon the boundary wall 144 and then pass through the one or more apertures 142, for example, the most

distal aperture 142.

[0048] Figure 7A shows an alternative example of a part of a heat exchanger 100. The heat exchanger 100 may have a different arrangement of apertures 142, inlet ports 112 and outlet ports 113 such that the fluid may take a different path through the heat exchanger 100. For example, as shown in Figure 7A, the fluid may enter the first channel 102 at the proximal end 104 of the set of channels 102 and pass through a section of the first channel 108. The fluid may then pass through the at least one aperture 142 in the wall 120 located between the first channel 108 and the second channel 110. In this example, the fluid will then continue in substantially the same direction from the proximal end 104 to the distal end 106 of the set of channels 102 along the second channel 110 and exit the second channel 110 at the distal end 106 of the set of channels 102. In this example, the fluid effectively travels from the proximal end 104 to the distal end 106 of the set of channels 102 without turning back on itself. The inlet port 112 may be coupled with the first channel 102 at the proximal end 104 of the set of channels 102 and the outlet port 113 may be coupled with the second channel 110 of the set of channels 102 at the distal end 106 of the set of channels 102.

[0049] Figure 7B shows an alternative example of a part of the heat exchanger 100. In this example, the set of channels 102 comprises a first channel 108, a second channel 110 and a third channel 115. The third channel 115 is defined by the first skin 116 and the wall 120. The wall 120 located between the second channel 110 and the third channel 115 comprises a second at least one aperture 142 to allow fluid to pass through the wall 120 from the second channel 110 to the third channel 115. The heat exchanger 100 may have a different arrangement of apertures 142, inlet ports 112 and outlet ports 113 such that the fluid may take a different path through the heat exchanger 100. For example, as shown in Figure 7B, the fluid may enter the first channel 102 at the proximal end 104 of the set of channels 102 and pass through a section of the first channel 108. The fluid may then pass through the at least one aperture 142 in the wall 120 located between the first channel 108 and the second channel 110. In one example, the at least one aperture 142 between the first channel 108 and the second channel 110 of the set of channels 102 is located towards the distal end 106 of the set of channels 102. In this example, the fluid will then impinge on an end wall and travel along the second channel 110 from the distal end 106 to the proximal end 104 of the heat exchanger 100. The fluid may then pass through the one or more apertures 142 located between the second channel 108 and a third channel 115. In one example, the at least one aperture 142 located between the second channel 110 and the third channel 115 may be located toward the proximal end 104 of the set of channels 102. In this example, the fluid will then travel from the proximal end 104 to the distal end 106 along the third channel 115 and exit through the heat exchanger 100 at an outlet port 113.

[0050] In other examples, the set of channels 102 may include a fourth channel (not shown) and the fluid may pass through at least one aperture in a wall located between the third channel 115 and the further channel and then reverse in direction again. The fluid may travel to the other end of the heat exchanger and exit through an outlet port 113.

[0051] In one example, the fluid may follow a substantially linear path as it flows in the channels, i.e. the walls 120 of the channels are straight. However, in other examples, as shown in Figure 1, the set of channels 102 may follow a non-linear path, i.e. the first channels 108 are non-linear as they extends from right to left in Figure 1 and the second channels 110 are non-linear as they extend from left to right in Figure 1. The non-linear path of the inlet channel 108 and the outlet channel 110 introduces a turbulence to the fluid flow, which is required to follow a non-linear path through the first channel 108 and the second channel 110. In other words, the set of channels 102 may have a non-linear path.

[0052] As shown in Figure 1, the inlet channel 108 and the outlet channel 110 may comprise parallel curves relative to each other. In other words, the inlet channel 108 and the outlet channel 110 are substantially the same shape, but are translated relative to each other.

[0053] The manufacturing method of DB/SPF is capable of making non-linear channels simply through the adoption of a stop-off pattern of suitable geometry. Conversely, linear channels may also be formed.

[0054] As shown in Figure 1, the fluid follows a substantially meandering path as it travels through the first channel 108 and the second channel 110. In other words, the fluid may follow a non-linear path in the heat exchanger 100. Figure 8 shows an example of the detail of the path of the first channel 108 and the second channel 110 in more detail. In the example shown in Figure 8, the first channels 108 and second channels 110 follow a substantially sinusoidal path, defined by substantially sinusoidal walls 120. In this example, the wall 120 is corrugated in a first direction to form a plurality of sets of channels 102 and non-linear in a second direction such that the plurality of sets of channels 102 are non-linear.

[0055] The non-linear or meandering path followed by the walls 120 (and hence the set of channels 102) creates a turbulent fluid path for the coolant fluid to increase heat transfer of the heat exchanger 100. The turbulent fluid flow is more efficient for heat transfer compared with the laminar fluid flow because effectively, in laminar flow, fluid is moving in distinct streamlines. That means that the heat transfer is from one "layer" of the fluid to a cooler one, essentially by heat conduction. In contrast, in turbulent flow the fluid particles are not moving along streamlines but are mixing from one layer to others, which means that there is physical transport of fluid from higher to lower temperatures and vice versa, which significantly increases the heat transfer.

[0056] The non-linear or meandering path followed by the first channel 108 and the second channel 110 increases the turbulence in the fluid flow by preventing or reducing the formation of laminar layers of fluid. As such, the heat

exchanger works 100 to effectively remove heat from a region on one side of the heat exchanger 100, for example, from the region adjacent the first skin 116 and transferred via the heat exchanger 100 to the region adjacent the second skin 118.

[0057] In one example, the coolant fluid used with the heat exchanger 100 is Argon. However, for a light-weight application, a liquid phase coolant would run at a much lower operating pressure and so have less penalty in terms of structural weight. In one example the liquid phase coolant is Syltherm 800 heat transfer fluid. The use of Syltherm 800 heat transfer fluid enables the pressure in the heat exchanger to be substantially reduced.

[0058] In the example shown in Figure 1, there are two additional channels 114 located towards the edges or sides of the heat exchanger 100. These additional channels 114 may or may not be associated with a port to enable a fluid to be received in the additional channels 114. These outer additional channels 114 may be the result of the manufacturing method, which requires additional space around the at least one plurality of pairs of channels 102. These outer channels 114 do not form an active part of the heat exchanger 100.

[0059] In one example, the plurality of channels 102 are made from three sheets of material formed into a tool cavity, i.e. the first skin 116, the second skin 118 and the wall 120. In one example, the first skin 116, the second skin 118 and the wall 120 is a titanium diffusion bonded titanium alloy, such as Ti-6Al-4V, as this has excellent creep performance at a desired operating temperature, for example 350 degrees Celsius, of the heat exchanger 100, allowing a high skin temperature. A temperature of 350 degrees Celsius represents the region of stagnated flow around leading edge aircraft skins for hypersonic flight, at the set test conditions. The titanium alloy material, therefore reducing load on cooling system solution. Further, Ti-6Al-4V retains its material strength under the high temperature conditions. In addition, Ti-6Al-4V is also compatible with the Diffusion Bonding and Superplastic Forming method, which may be used for the manufacture of the heat exchanger 100.

[0060] DB/SPF (Diffusion Bonding and Superplastic Forming) is a process for the economic production of three-dimensional objects and sandwich structures. One characteristic of DB/SPF is an extremely high level of formability. A separating agent or "stop-off", such as yttria is placed on defined areas between material sheets, such as titanium alloys. In the example shown in Figure 4, the stop-off 130 is applied to the sections of the first skin 116 and the second skin 118 at the flat-sheet details stage prior to assembly of the sheets for diffusion bonding. This then results in sections of the wall 120 being unbonded in the final product. In contrast, the areas of the first skin 116 and the second skin 118 in which the stop-off material 130 is not applied results in a diffusion bond between the wall 120 and the first skin 116 and the second skin 118 in the finished product 100. Once the stop-off has been applied to the relevant internal sections of the first skin 116 and the second skin 118, temperatures of over 900 °C and pressure are applied and the unmasked areas are bonded by Diffusion Bonding. In the example shown in Figure 4, the first set of alternating longitudinal sections 122 of the wall 120 are bonded to the second skin 118 and the second set of alternating longitudinal sections 124 of the wall 120 are bonded to the first skin 116. The sections of the first skin 116 and the second skin 118 to which the stop-off 130 is applied are not bonded to the wall 120. This technique provides broad freedom for an operator to produce geometry of the heat exchanger 100 to suit the design. The diffusion bonded "flat-pack" so produced is assembled in a Superplastic Forming tool and with a means of introducing argon gas for the purposes of inflating the structure so as to cause the skin sheets to form outwards into an internal die mould tool and in so doing cause the internal walls 120 to be stretched from their initial horizontal planar aspect into inclined angular walls 120. The holes 142 that are subsequently to be used for the transfer of fluid between the channels may conveniently be used to facilitate the transfer of forming gas across the heat exchanger during the SPF part of the manufacturing process. The pressurised forming gas itself may be introduced through the same ports as will subsequently be used for the entry and exit of the heat exchanger media.

[0061] The SPF/DB process enables the production of thin-walled but rigid designs. The process is governed by specifically developed SPF-parameters and an advanced tooling concept in which the thickness of the panel is controlled as required. This method conforms to the best replication of the actual environment to which the heat exchanger 100 would be exposed.

[0062] A test has been conducted to determine the heat transfer by the heat exchanger 100. A John Shaw 600 Tonne press may be arranged with a first platen and second platen areas with a fixed base and a moving upper "slide" operated from a central singular double-acting hydraulic cylinder able to open and close the press and apply a closure force of up to 600 Tonnes. In one example, the first platen and the second platen is made up of five individual segments running left to right and with each segment further sub-divided into three zones front to rear.

[0063] Hence, in this example, each platen (first and second platens) comprises 15-off individual temperature control zones (30 in total). In this example the platen area is 1950 x 1450mm with an effective heated area of 1750 x 1250mm, where temperature is controlled to within $\pm 3^{\circ}\text{C}$. The heater power is nominally set at 4.5W/cm² per platen surface. The platens are heated by embedded electric cartridge elements with each zone controlled via a pair of thermocouples also embedded within each zone of the platen body. The press displays the set point temperature and actual temperature of each individual platen zone together with the percentage of maximum power being input to each zone.

[0064] The press has three independent argon gas pressure lines. Gas pressures of up to -650 psi (45 Bar) may be applied on each gas line using Tescom gas control valves. Each gas line has a gas flow meter to record flow, as well as pressure monitoring gauges. The SPF-DB tooling is maintained in a closed position using tonnage that is modulated

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based on the pressure applied and the plan view area that the gas pressure is applied over together with an over-arching "seal force" that maintains a programmable net closure force regardless of pressure. The "hot zone" of the press is closed via vertically moving front and rear access doors and non-moving side panels that provide a blast-proof working zone capable of withstanding an un-contained rupture of the component. However, unanticipated movement of the upper slide structure due to inadequate hydraulic force would also provide automatic cycle abort to vent the working pressure.

[0065] A description of the testing of the heat exchanger 100 is described below. The test was conducted by:

- Using the Superplastic Forming - Diffusion Bonding press to hold the first platen 116 of the heat exchanger 100 at a constant temperature representative of an actively cooled aircraft skin surface in a normal operation at the hypersonic flight condition.
- Pass the coolant fluid into the heat exchanger 100 and measure the level of thermal energy extracted from the heat exchanger 100 into the coolant flow, which will be measured based on the temperature difference of the coolant fluid between the inlet port 112 and outlet port 113.

[0066] During the initial phase of the experiment the coolant gas was incrementally increased to the following flow rates: 100, 200 & 440 Standard Litres Per Minute. In order to maintain the desired pressure in the system it was necessary to increase the demanded pressure from the Argon farm from 20 bar (300psi) to 24 bar (350psi). At each of the flow rates it was necessary to adjust the throttle valve to balance the flow and pressure in the system. The first platen 116 may be subject to a temperature of approximately 350 degrees Celsius in use.

[0067] Heaters were used to simulate temperatures that the first skin 116 and the second skin 118 may experience in use. The test was to expose the heat exchanger 100 to a representative environment of a hypersonic flight envelope (thermodynamic only) as indicated below. Note that each number in the table represents a corresponding plan view area of the first platen and the second platen respectively.

First Platen:

230	250	350	250	230
230	250	350	250	230
230	250	350	250	230

Second Platen:

210	210	190	210	210
210	210	235	210	210
210	210	235	210	210

[0068] Test runs of at least 30 minutes were completed at the nominal condition (440 Standard Litres Per Minute, 20 barg, approximately 190°C inlet temperature for the coolant fluid entering the inlet ports 112), and the two flow rate variations of 420 Standard Litres Per Minute and 400 Standard Litres Per Minute (SLPM).

Parameter	Inlet Temperature (Range) / °C	Flow Rate (Range) / SLPM	Pressure (Range) / barg
Nominal	190 (18.7, ±5%)	440 (44, ±5%)	20.0 (2.0, ±5%)
440 SLPM Run 1	182.7 (0.7)	440.2 (1.9)	19.37 (0.18)
440 SLPM Run 2	183.0 (0.9)	440.2 (1.2)	19.29 (0.15)

[0069] In this test example, the coolant fluid was Argon gas. At 440SLPM there was a temperature increase of the coolant fluid between the inlet port 112 and the outlet port 113 of just less than 100°C, which demonstrates that the tested heat exchanger 100 is capable of drawing thermal energy imparted by press platen into the coolant fluid while maintaining an acceptable temperature of the structure of the heat exchanger. The coolant fluid outlet temperature is approximately 280°C.

[0070] Utilising the gas temperature and pressure it is possible to determine the thermodynamic and transfer properties of the coolant fluid, in particular the specific heat at constant pressure (Cp), with which when combined with the mass

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flow rate (m) and change in gas temperature across the test article (ΔT) it is possible to calculate the heat transferred into the gas (Q). In both cases for 440SLPM there was approximately 0.49kW transferred into the gas stream.

$$Q = \dot{m} C_p \Delta T$$

[0071] The test was run again at 420SLPM. The runs were conducted as follows:

Parameter	Temperature (Range) / °C	Flow Rate (Range) / SLPM	Pressure (Range) / barg
Nominal	190 (18.7, $\pm 5\%$)	420 (42, $\pm 5\%$)	20 (2, $\pm 5\%$)
420 SLPM Run 1	184.8 (0.8)	420 (1.9)	19.37 (0.19)
420 SLPM Run 2	185.0 (0.4)	420 (2.2)	19.27 (0.19)

[0072] At 420SLPM there was a temperature increase of the coolant fluid between the inlet port 112 and the outlet port 113 of just under 100°C, and approximately 1°C less than at 440SLPM. This clearly demonstrates that the heat exchanger 100 is capable of drawing thermal energy imparted by press platen into the gas stream while exhibiting a small difference to the 440SLPM runs.

[0073] Utilising the gas temperature and pressure it is possible to determine the thermodynamic and transfer properties of the Argon gas. With which when combined with the flow rate and change in gas temperature across the test article it is possible to calculate the heat transferred into the gas. In both cases for 420SLPM there was approximately 0.46kW transferred into the gas stream. This is approximately 0.03kW less than at 440SLPM.

[0074] The test was run again at 400SLPM. The runs were conducted as follows:

Parameter	Temperature (Range) / °C	Flow Rate (Range) / SLPM	Pressure (Range) / barg
Nominal	190 (18.7, $\pm 5\%$)	400 (40, $\pm 5\%$)	20 (2, $\pm 5\%$)
400 SLPM Run 1	187.0 (0.8)	400 (1.9)	19.34 (0.14)
400 SLPM Run 2	187.3 (0.4)	400 (1.4)	19.4 (0.18)

[0075] At 400SLPM there was a temperature increase of the coolant fluid between the inlet port 112 and the outlet port 113 of just less than 100°C, and approximately a further 1°C less than at 420SLPM. This clearly demonstrates that the heat exchanger was capable of drawing thermal energy imparted by press platen into the gas stream while exhibiting a small difference to the 420SLPM runs. Additionally this supports the trend of a reduction of 20SLPM resulting in a 1°C decrease in the gas temperature difference across the heat exchanger.

[0076] Utilising the gas temperature and pressure it is possible to determine the thermodynamic and transfer properties of the coolant fluid. With which when combined with the flow rate and change in gas temperature across the test article it is possible to calculate the heat transferred into the gas. In both cases for 400SLPM there was approximately 0.43kW transferred into the gas stream. This is approximately 0.03kW less than at 420SLPM and approximately 0.06kW less than at 440SLPM.

[0077] Based on the initial calculations of the heat transfer into the gas flow a linear relationship to the mass flow is evident.

[0078] The table below is a Summary of Heat Transfer Calculated for Various Flow Rates:

Flow/SLPM	Mass Flow / kg/s	Approximate Heat Transfer to Gas Flow / W
440	0.01208	490
420	0.01153	460
400	0.01098	430

[0079] Figure 9 shows an example of the relationship between heat transfer and mass flow rate. As can be seen from Figure 9, the heat transfer to the coolant fluid follows a linear relationship dependent upon mass flow.

[0080] Attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all

such papers and documents are incorporated herein by reference.

[0081] All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

[0082] Each feature disclosed in this specification (including any accompanying claims, abstract and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

[0083] The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Claims

1. A heat exchanger comprising at least one set of channels having a proximal end and a distal end, the set of channels comprising:

a first channel defined by a first skin and a wall; and
a second channel defined by a second skin and the wall,

wherein the wall located between the first channel and the second channel comprises a first at least one aperture to allow fluid to pass through the wall from the first channel to the second channel.

2. The heat exchanger according to claim 1, wherein the heat exchanger comprises an inlet port for receiving said fluid and an outlet port for allowing the fluid to exit the heat exchanger.

3. The heat exchanger according to claim 2, wherein the inlet port is coupled to the first channel and the outlet port is coupled to the second channel.

4. The heat exchanger according to claim 3, wherein the inlet port and the outlet port are arranged at the proximal end of the set of channels.

5. The heat exchanger according to claim 3, wherein the inlet port is arranged at the proximal end of the set of channels and the outlet port is arranged at the distal end of the set of channels.

6. The heat exchanger according to claim 2, wherein the set of channels comprises a third channel defined by the first skin and the wall, wherein the wall located between the second channel and the third channel comprises a second at least one aperture to allow fluid to pass through the wall from the second channel to the third channel.

7. The heat exchanger according to claim 6, wherein the inlet port is connected to the first channel at the proximal end of the set of channels and the outlet port is connected to the third channel at the distal end of the set of channels.

8. The heat exchanger according to claim 7, wherein the second at least one aperture is located towards the proximal end of the set of channels.

9. The heat exchanger according to any one of the preceding claims, wherein the first at least one aperture is towards the distal end of the set of channels.

10. The heat exchanger according to any preceding claim, wherein the set of channels follow a non-linear path between the proximal end and the distal end.

11. The heat exchanger according to claim 10, wherein the first channel and the second channel are parallel curves relative to each other.

12. The heat exchanger according to any of claims 10 or 11, wherein the non-linear path is substantially sinusoidal.

13. The heat exchanger according to any preceding claim, wherein the wall is bonded to the first skin and the second skin.

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14. The heat exchanger according to claim 13, wherein the wall is corrugated and comprises a first longitudinal section bonded to the first skin, a second longitudinal section bonded to the second skin and at least one inclined section between the first longitudinal section and the second longitudinal section.

5 **15.** The heat exchanger according to claim 14, wherein the inclined section is inclined at an angle of approximately 30 to 60 degrees relative to the first longitudinal section and the second longitudinal section.

16. The heat exchanger according to any of the preceding claims, wherein the wall has a thickness of between 0.5mm and 6mm.

10 **17.** The heat exchanger according to any of the preceding claims, wherein the first skin and the second skin are formed of a titanium alloy.

18. The heat exchanger according to any of the preceding claims comprising a plurality of sets of channels.

15 **19.** The method of manufacturing a heat exchanger as described in any previous claim, wherein the heat exchanger is manufactured using diffusion bonding and superplastic forming.

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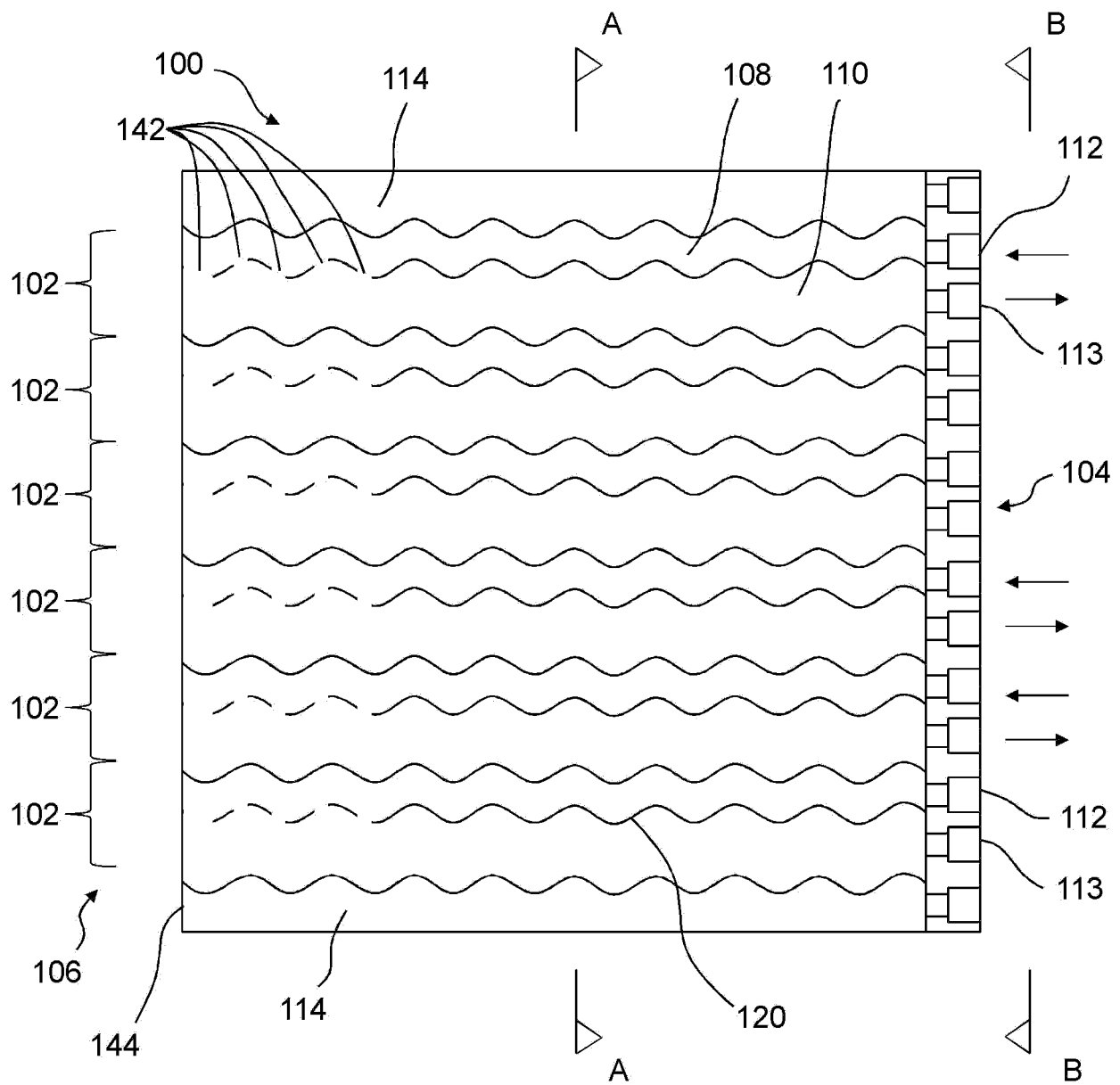


Figure 1

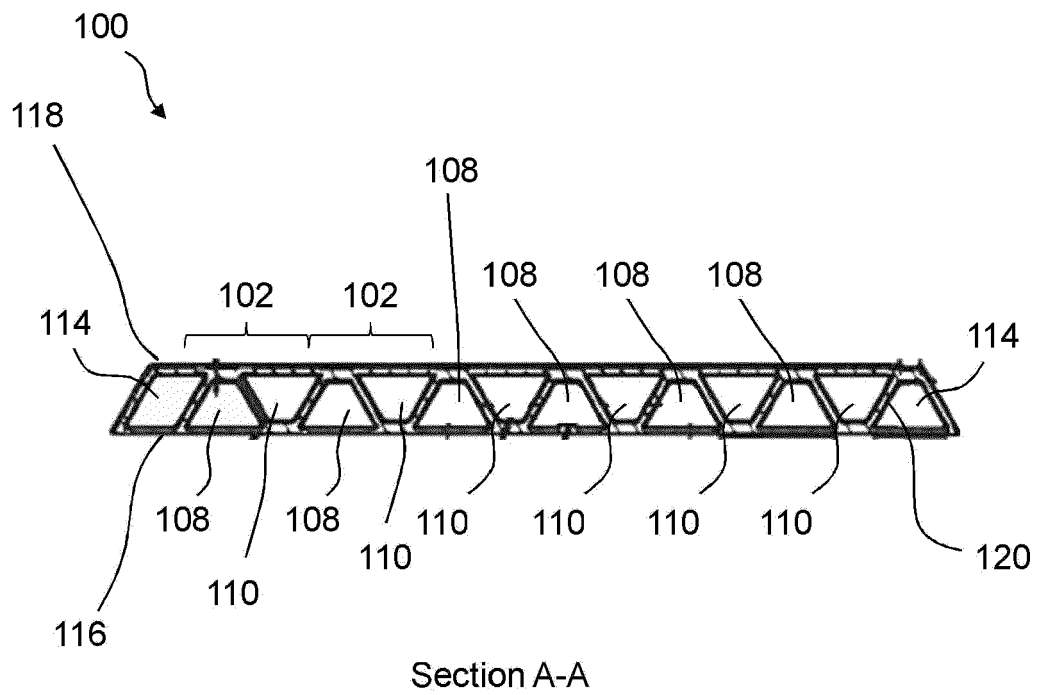


Figure 2

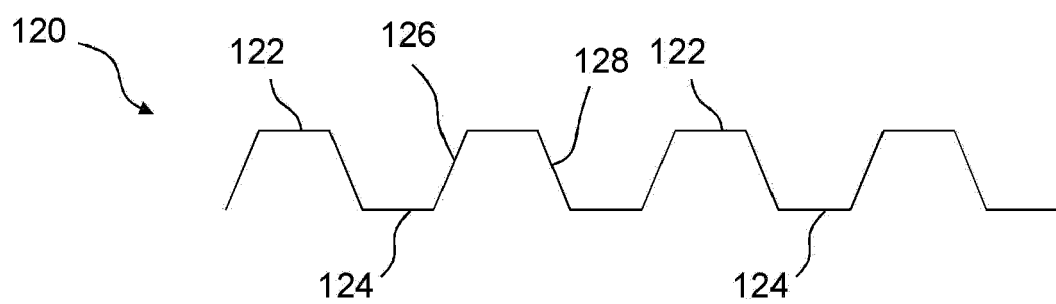


Figure 3

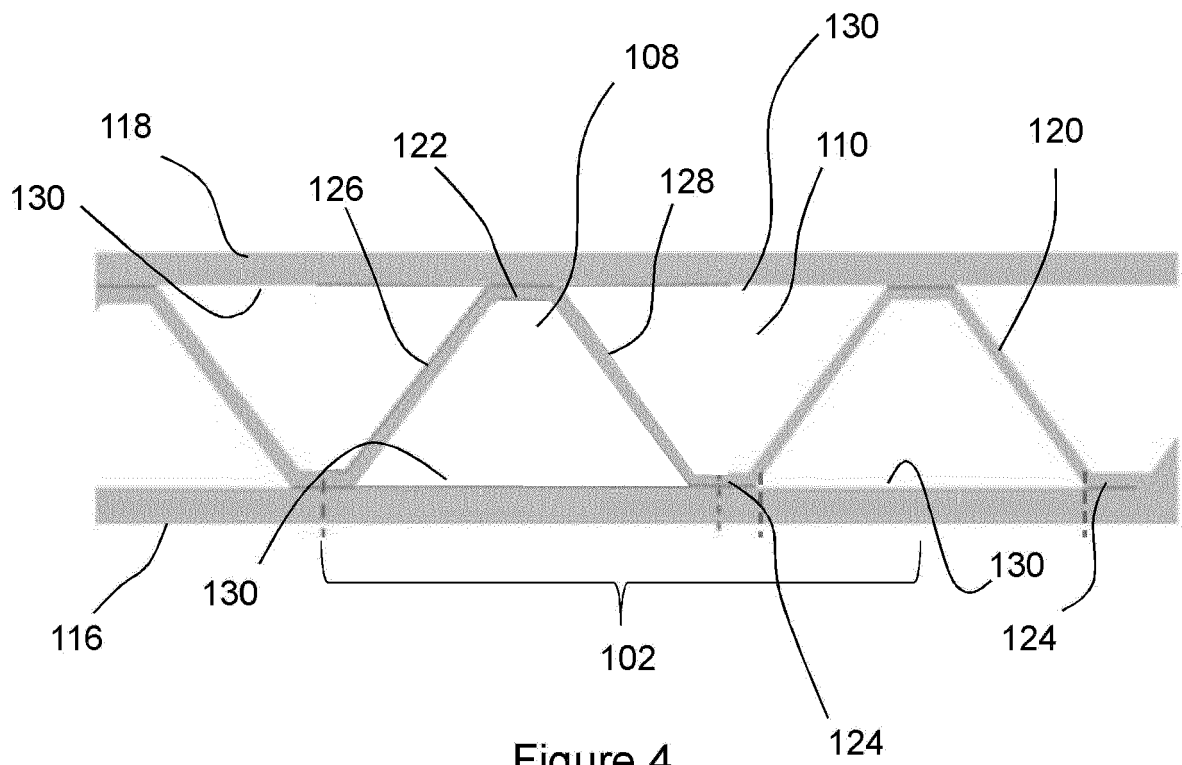


Figure 4

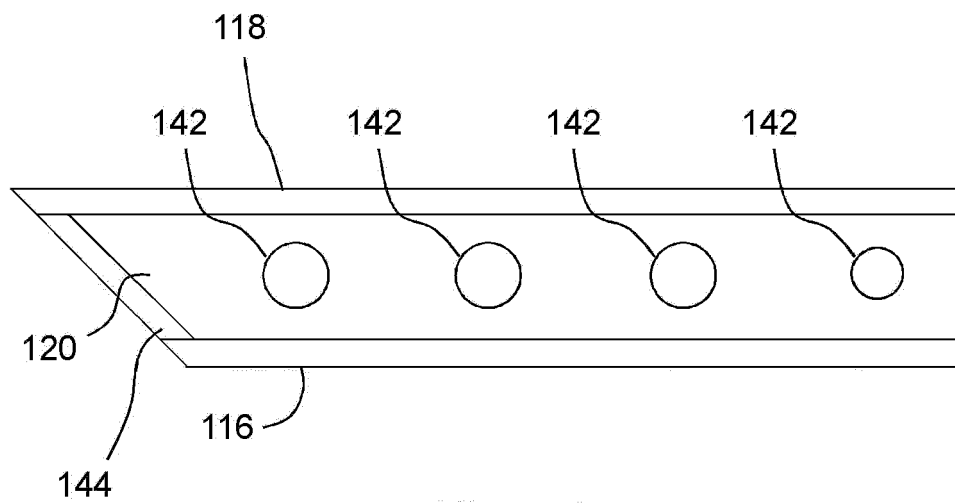
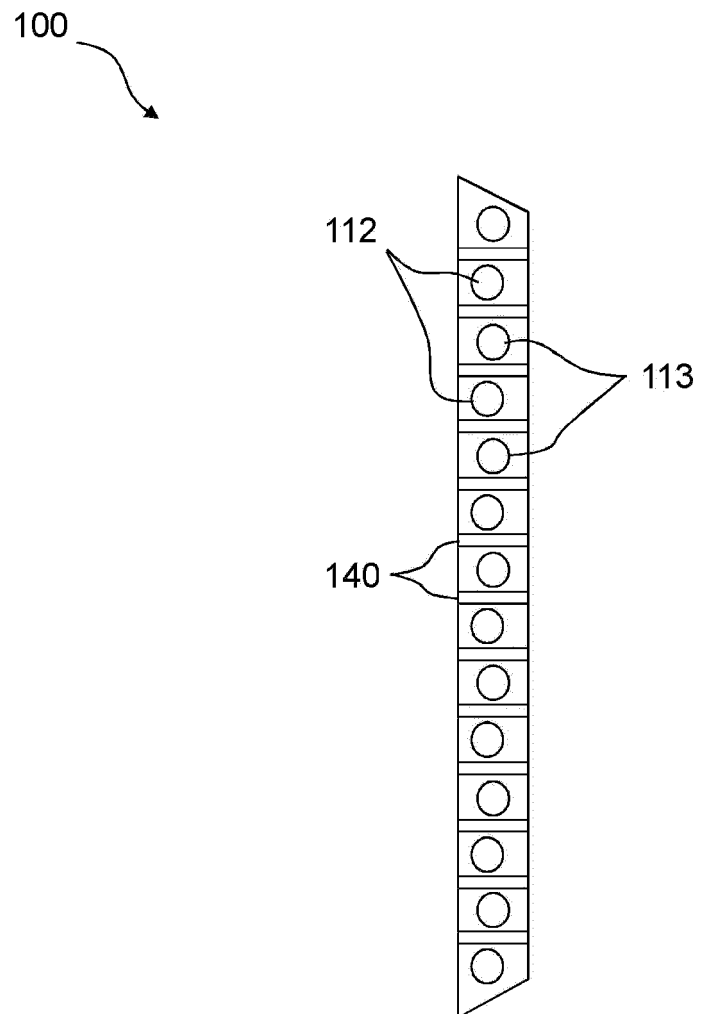


Figure 5



Elevation B-B

Figure 6

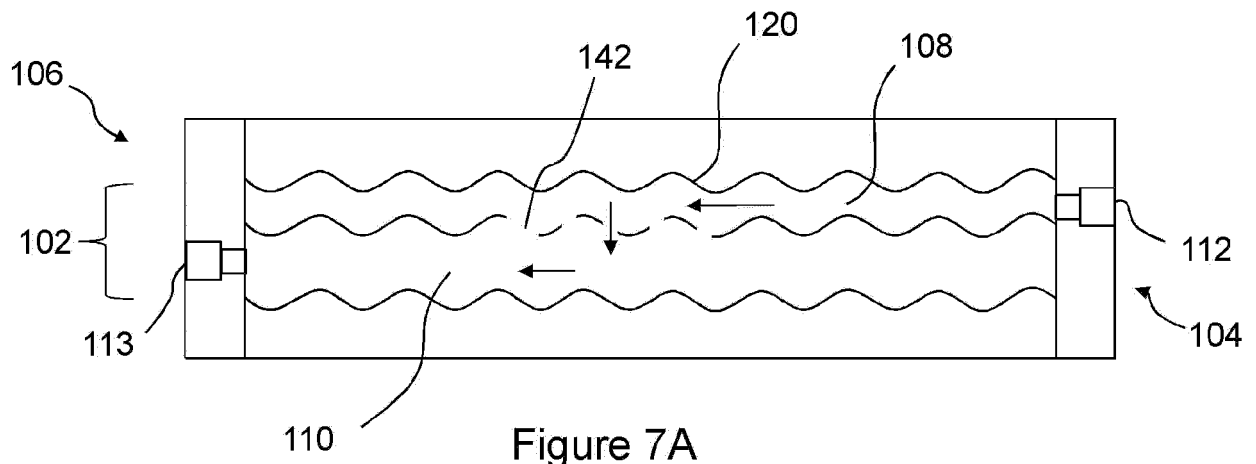


Figure 7A

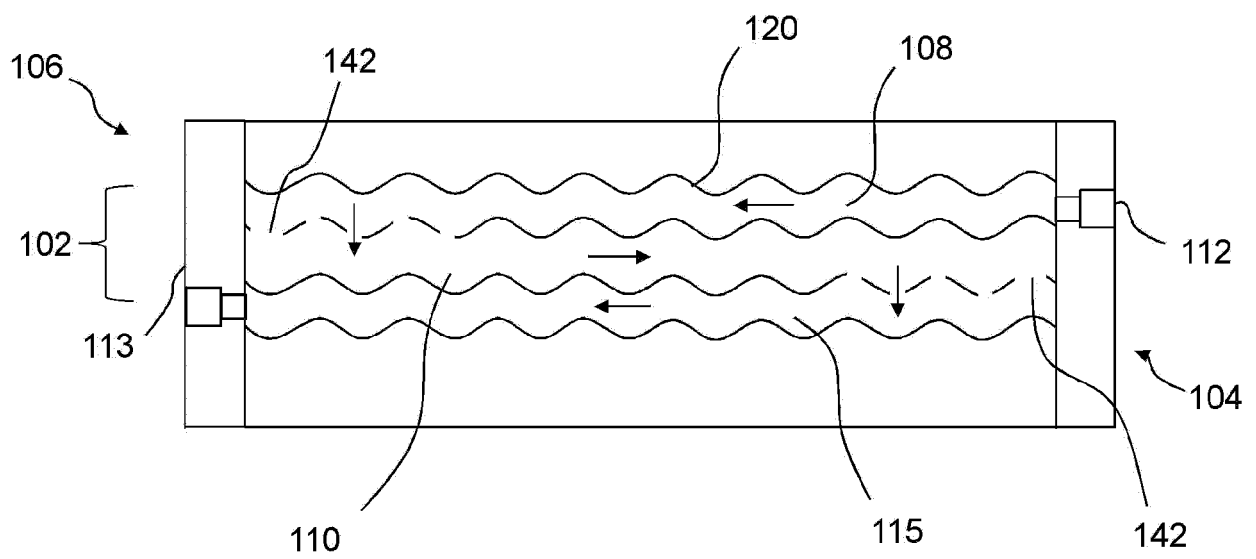


Figure 7B

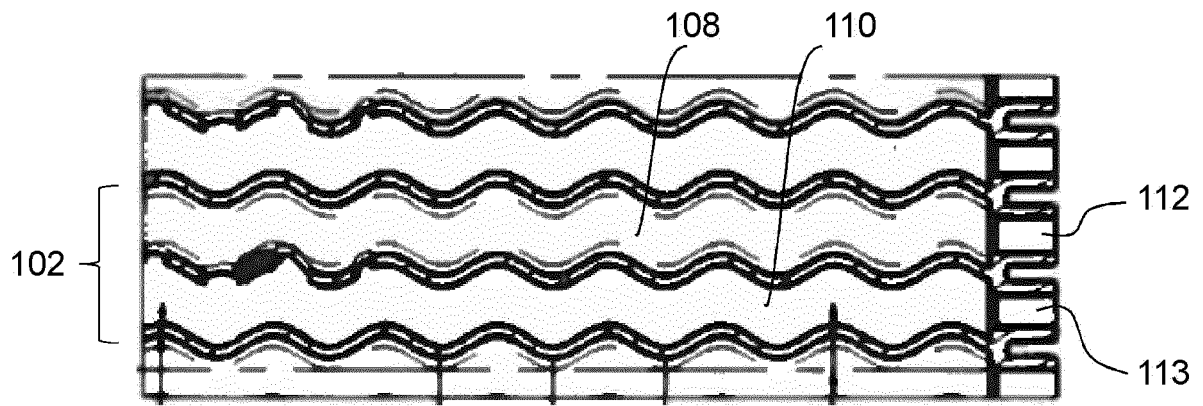


Figure 8

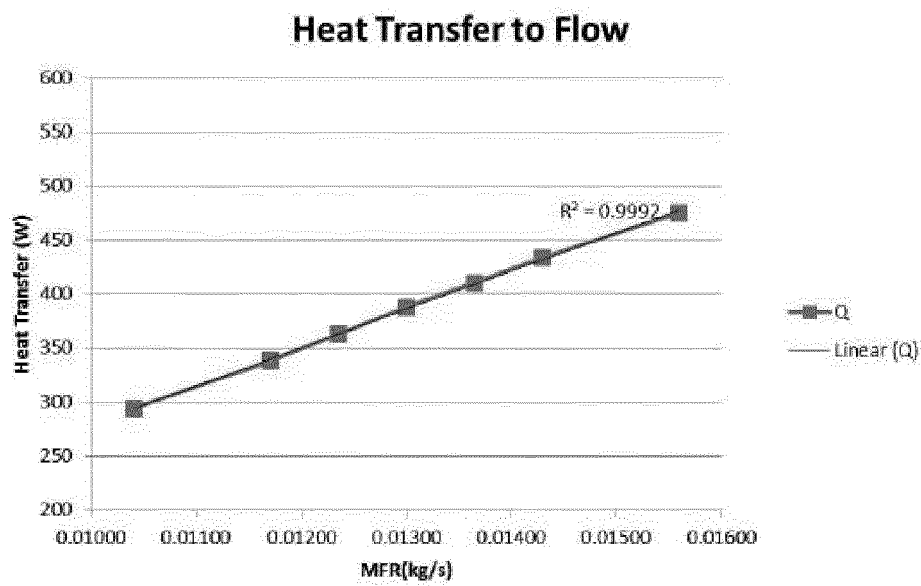


Figure 9



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CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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