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(54) **Heat exchange apparatus**

(57) A heat exchange apparatus comprising a body that includes an internal cavity for receiving a fluid, a fluid inlet and a fluid outlet. The internal cavity is provided with at least one formation that defines at least one fluid flow path within the internal cavity between the fluid inlet and

the fluid outlet, the or each formation comprising a first surface exposed to fluid within the internal cavity, and a second surface exposed to air surrounding the heat exchanger. Heat can be transferred from fluid flowing within the internal cavity to the air surrounding the heat exchanger via the at least one formation.

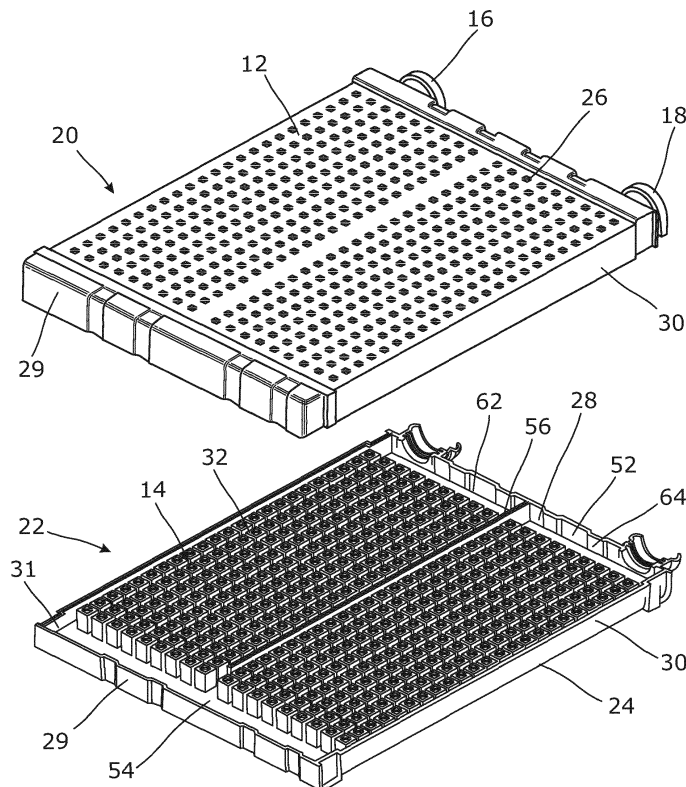


Figure 2

EP 2 647 939 A2

Description

Field of the invention

[0001] The invention relates to a heat exchange apparatus. In particular, but not exclusively, the invention relates a heat exchange apparatus for use in an automotive cabin to heat the air within the cabin.

Background to the invention

[0002] In heat exchangers of the type commonly used in automotive cabins, a fluid in the form of engine coolant is circulated through a series of radiator coils arranged to have a high surface area. Heat is transferred from the engine coolant, through the surfaces of the radiator coils, to the air surrounding the heat exchanger. This heated air can then be pumped into the automotive cabin.

[0003] Presently, heat exchangers for such applications are made from metals of high thermal conductivity, such as aluminium. The standard form is a 'fin and tube' construction, in which the engine coolant flows through a winding aluminium tube provided with fins. The fins are layers of corrugated aluminium that increase the surface area of the aluminium tubes, thereby increasing the rate of heat transfer.

[0004] However, such fin and tube constructions are labour intensive to construct, requiring many stages of material manipulation and hence large amounts of robotic and/or manual processing. The aluminium tubes must be extruded, bent and cut, and the aluminium fins must be stamped, assembled and brazed. The fins are particularly labour intensive to construct, as layers of the corrugated aluminium must be soldered or brazed together, and then soldered to the aluminium tubes.

[0005] Thus, a large number of costly, high- energy processes are required in the fabrication of traditional heat exchangers. Additionally, metals of high thermal conductivity such as aluminium tend to be expensive, adding further to the overall cost of the heat exchanger.

[0006] It is one object of the invention to provide a heat exchanger suitable for use in a automotive cabin which addresses the aforementioned problems.

Summary of the Invention

[0007] According to a first aspect of the present invention, there is provided a heat exchange apparatus, or heat exchanger, comprising a body that includes an internal cavity for receiving a fluid, a fluid inlet and a fluid outlet. The internal cavity is provided with at least one formation that defines at least one fluid flow path within the internal cavity between the fluid inlet and the fluid outlet, said formation comprising an inner surface in contact with the internal cavity, and an outer surface in contact with air surrounding the heat exchanger, such that heat can be transferred from the fluid flowing within the internal cavity to the air surrounding the heat exchanger

via the at least one formation.

[0008] Such a heat exchange apparatus is of simple construction and can be fabricated from simple manufacturing processes. The formations increase the internal and external surface areas of the body, and only the formation itself separates the fluid in the internal cavity from the air surrounding the heat exchanger, allowing for efficient heat transfer. The heat exchanger is particularly suitable for use in automotive vehicles due to its simple and lightweight construction.

[0009] So as to increase heat transfer, preferably the or each formation is hollow to define a channel to allow air to flow therethrough from one side of the body to the other.

[0010] Preferably, the second surface of the formation is provided with at least one feature which increases the surface area of the formation that is exposed to air. The feature may be a fin, and may comprise a wall that extends across the channel.

[0011] Advantageously, the internal cavity may be provided with an array of formations that defines a tortuous fluid flow path within the internal cavity. The array may be a regular array of identical formations. Alternatively, formations of different shapes and/or sizes may be provided in different areas of the internal cavity, so as to control the flow of fluid within the cavity.

[0012] For ease of manufacture, the body and the at least one formation may be integrally formed.

[0013] Preferably the inlet and outlet are provided in the form of pipes formed integrally with the body, and may be provided on the same side of the body. In this case the internal cavity may be provided with a vacant channel, proximal to the side on which the inlet and outlet are provided, that is free from formations.

[0014] Advantageously, the internal cavity may be provided with at least one flow controlling structure, which may be arranged to divert the flow within the internal cavity between the inlet and the outlet. The flow controlling structure may be a baffle.

[0015] To ease manufacture, the body, the at least one formation and the flow controlling structure may all be integrally formed. Alternatively, only the body and the at least one formation may be integrally formed.

[0016] The heat exchange apparatus may be formed from a metal, or from a plastic. Advantageously, the heat exchange apparatus may be formed from a plastic having a high thermal conductivity.

[0017] Advantageously, the heat exchange apparatus may be formed by injection moulding.

[0018] For ease of manufacture, the heat exchange apparatus may comprise two tray portions that are joined together so that the base of one tray portion defines a floor of the internal cavity, and the base of the other tray portion defines a ceiling wall of the internal cavity.

[0019] The invention also extends, in a second aspect, to a method of manufacturing a heat exchange apparatus, the method including forming a first portion of the body of the heat exchange apparatus and a second por-

tion of the body of the heat exchange apparatus by injection moulding, and joining the first portion of the body to the second portion of the body at joining surfaces thereof.

[0020] Such a method is cheap, quick and requires little machining or manual labour.

[0021] The method may also include joining the first portion of the body to the second portion of the body by any one of the following means: ultrasonic welding, friction welding, hotplate welding, fluid adhesive, or adhesive gasket.

[0022] The method may also include joining the first portion of the body to the second portion of the body by placing a wire mesh heating element on the joining surface of the first portion of the body, placing the joining surface of the second portion of the body over the first portion of the body, such that the wire mesh is sandwiched between the first and second portions, and heating the wire mesh by passing a current therethrough, so as to melt at least a portion of the joining surfaces such that the first and second portions are joined together.

[0023] Optional or preferred features of the first aspect of the invention may be incorporated within the second aspect of the invention also, alone or in appropriate combination.

Brief description of the drawings

[0024] In order that the invention may be more readily understood, reference will now be made, by way of example, to the accompanying drawings, in which:

Figure 1 is a perspective view of a heat exchanger according to one embodiment of the present invention;

Figure 2 is a close-up perspective view of a cross-section through the heat exchanger of Figure 1;

Figure 3 is a perspective view of two tray portions of the heat exchanger of Figure 1, and prior to welding of the two tray portions together;

Figure 4 is a plan view from the side of the heat exchanger of Figure 1;

Figure 5 is a plan view from above the heat exchanger of Figure 1;

Figure 6 is a perspective view of two examples of a surface area increasing feature of the heat exchanger of Figure 1; and

Figure 7 is a plan view from the side of a heat exchanger according to another embodiment of the present invention.

Detailed description of embodiments of the invention

[0025] Referring to Figures 1 to 4, a heat exchanger 10 includes a body 12 which defines an internal cavity, generally indicated at 14, for receiving a fluid, a fluid inlet 16, which is constituted by an inlet pipe, and a fluid outlet 18, which is constituted by an outlet pipe.

[0026] To ease manufacture of the heat exchanger 10, and as best shown in Figures 2 and 4, the body 12 is formed from two parts: an upper tray portion 20 and a lower tray portion 24 that are welded together to form the body 12. The inlet 16 and outlet 18 pipes are also formed of two portions, with upper and lower portions of the inlet 16 and outlet 18 pipes being formed as one piece or integrally with the respective upper and lower tray portions 20, 22 of the body 12.

[0027] Each of the upper and lower tray portions 20, 22 of the body 12 is formed by a rectangular tray, which therefore defines a respective upper or lower portion of the internal cavity 14. The internal cavity 14 is therefore bounded by a base 24 of the lower tray 22 forming a floor of the cavity 14, by a base 26 of the upper tray 20 forming a ceiling of the cavity 14, and by transverse 28, 29 and longitudinal 30, 31 sidewalls of the upper and lower tray portions 20, 22 around its perimeter. The internal structure of the lower tray, generally indicated at 32, is arranged so as to be a direct mirror-reflection of the internal structure 32 of the upper tray 20, with the 'mirror-plane' being the plane parallel to the base of the tray 24. The upper tray 20 therefore defines the upper portion of the sidewalls 28, 30 of the cavity, whilst the lower tray 22 defines the lower portion of the sidewalls 28, 30 of the cavity. In one embodiment of the invention, the two trays 20, 22 are identical, such that the upper and lower portions 20, 22 of the heat exchanger 10 are interchangeable.

[0028] The bases 24, 26 of the upper and lower portions 20, 22 present upper and lower walls of the body, that define the length and width of the body 12. The longitudinal sidewalls 30, 31 together define the length and height of the body 12, and the transverse sidewalls 28, 29 together define the width and height of the body 12. It will be appreciated that the height of the body 12 is defined by the height of both the upper and lower tray portions 20, 22 together. The body 12 has a height substantially less than its length or width so that the surface area of the body 12, and in particular of the upper and lower walls 24, 26, is maximised.

[0029] The inlet and outlet pipes 16, 18 are arranged at opposite ends of the first transverse side wall 28. For example, as shown in Figure 1, the inlet pipe 16 is arranged at one end of the first transverse sidewall 28, and the outlet pipe 18 is arranged at the other end of the first transverse sidewall 28. In this way, fluid enters and exits the heat exchanger 10 at the same end, allowing for easy connection of the heat exchanger 10 to a flow system for the fluid.

[0030] Figures 2 and 3 reveal the internal structure 32 of the body 12. The upper wall 26, the lower wall 24 and the sidewalls 28, 29, 30, 31 of the body 12 are relatively thin, so that the body 12 is substantially hollow, with the walls defining the internal cavity 14. The internal cavity 14 is in communication with the inlet and outlet pipes 16, 18, so that fluid can flow through the inlet pipe 16, into the internal cavity 14 of the body 12, and back out through the outlet pipe 18.

[0031] As best shown in Figure 2, the internal surface 38 of the lower wall 24 of the body 12 is provided with a plurality of formations 40 that extend upwardly into the internal cavity 14. It should be appreciated that, although not visible in the figures, the formations 40 extend as far as an internal surface 42 of the upper wall 26 of the body 12.

[0032] Each formation 40 is of cuboidal configuration, and is formed of four sidewalls 44 that extend upwardly from the internal surface 38 of the lower wall 24 into the internal cavity 14. The four sidewalls 44 are of the same width, and are arranged so as to provide a square cross section in a plane parallel to the bases 24, 26 of the trays 20, 22. The formations 40 extend upwards so that the height of each formation 40 extending in a direction transverse to this plane is greater than its width. The sidewalls 44 form a hollow structure, so as to define a void 34 of square-cross section that runs upwardly from the internal surface 38 of the lower wall 24 to the internal surface 42 of the upper wall 26.

[0033] As best seen from Figures 1 and 5, the lower and upper walls 24, 26 of the body 12 are provided with holes that align with the voids 34 defined by the formations 40. The voids 34 therefore extend through the body 12 opening at the upper wall 26 of the upper tray 20 and the lower wall 24 of the lower tray 22, so that air can pass from an upper surface to a lower surface of the heat exchanger 10, through the voids 34.

[0034] The voids 34 serve to increase the external surface area of the body 12 that is exposed to the surrounding air. Although not shown, the other tray of the body 12 is also provided with the same formations 30 and voids 34. To further increase this surface area, the upper wall 24 of the body is provided with voids 34 that include surface area increasing formations 36 (exemplified here as fins), to be further described. Although not shown, the lower wall of the body is also provided with the same voids 34 and fins 36.

[0035] In this way, the formations 40 have a first or internal surface 46 that is exposed to the internal cavity 14 of the body 12, and a second or external surface 48 that is exposed to the air surrounding the heat exchanger 10.

[0036] As most clearly seen in Figure 2, the formations 40 are arranged to form an evenly-spaced square array within the internal cavity 14. Adjacent rows and columns of the array of formations 40 define narrow passages 50 for fluid within the internal cavity 14. The spacing between adjacent formations 40 is less than the width of each

formation 40 so that a large number of formations 40 may be arranged within the tray 20, 22, providing a large internal surface area that is in contact with the fluid flowing through the cavity 14, and a large external surface area that is in contact with the air surrounding the heat exchanger 12.

[0037] The large number of formations 40 and the narrow passages 50 defined between them means that the formations 40 define one tortuous fluid flow path within the internal cavity 14 between the inlet pipe 16 and the outlet pipe 18.

[0038] To further increase the external surface area of the heat exchanger 12, a fin 36, constituted by a thin wall, extends diagonally between opposed corners of each void 34 between opposed external surfaces 48 of the formation. In this way, each void 34 is divided into two triangular sections by the fin 36. Air moving through the voids 34 is therefore in contact with a large number of external surfaces, so as to allow efficient transfer of heat from the body 12 to the air.

[0039] As best shown in Figure 3, the formations 40 are absent from first and second vacant channels 52, 54 of the internal cavity 14 that are proximal and parallel to the first and second transverse sidewalls 28, 29 of the body 12 respectively. The first and second vacant channels 52, 54 define first and second unobstructed flow paths for fluid flowing within the cavity 14.

[0040] The internal cavity 14 is also provided with a flow controlling structure 56 exemplified as a baffle, to control flow of the fluid within the internal cavity 14. In the embodiment shown in Figure 3, the baffle 56 is arranged centrally within the array of formations 40 and takes the form of a thin, elongate wall. The wall extends from the centre of the first transverse sidewall 28 of the body into the internal cavity 14. The wall is parallel to the longitudinal sidewalls 30, 31 and does not extend as far as the second transverse sidewall 29 of the body. In this example, the wall therefore stops short of the second vacant channel 54.

[0041] In both trays 20, 22 of the heat exchanger 10, the formations 40, the fins 36 and the baffle 56 are all equal in height to the sidewalls of the tray 20, 22. In this way, the uppermost surfaces 58 of the walls of the internal structure 32 are flush with the uppermost surfaces 60 of their respective trays 20, 22. Together, the uppermost surfaces 58, 60 of the tray 20, 22, the baffles 56, the formations 40 and the fins 36 define a joining surface. Thus, when the two trays 20, 22 are arranged with the upper tray 20 on top of the lower tray 22, the joining surfaces of the upper and lower trays 20, 22 align. In this way, the formations 40, the fins 36 and the baffles 56 are continuous from the lower surface to the upper surface of the body 12. To assemble the heat exchanger 10, the joining surface of the upper tray 20 is placed on the joining surface of the lower tray 22, and the two trays 20, 22 are joined together, for example by welding.

[0042] The baffle 56 divides the first vacant channel 52 into two sections. The left section 62, shown in Figure

3, is in communication with the inlet pipe 16, and the right section 64 shown in Figure 3 is in communication with the outlet pipe 18. Thus fluid cannot flow directly from the inlet pipe 16 to the outlet pipe 18 via the first vacant channel, but must instead follow a convoluted flow path through the array of formations 40. The absence of formations from the first vacant channel 52 prevents blockages of the flow path.

[0043] In one preferred embodiment of the invention, shown in Figure 6, the external surface area of the heat exchanger may be still further increased by adding surface features 66 to the fins 36. These surface features 66 increase the surface area of the fins 36, thereby increasing the rate of heat exchange. For example, hemispherical surface features 66 may be provided, as shown in Figure 6, or alternatively tetrahedral or cubic surface features 66 may be provided.

[0044] In use, and with reference to Figure 3, the heat exchanger 10 is connected to a system that supplies heated fluid which is to be cooled. Heated fluid flows into the heat exchanger 10 through the inlet pipe 16, where it is received in the left side 62 of the first vacant channel 52. The baffle 56 prevents the fluid from moving directly to the outlet pipe 18 on the right side 64 of the first vacant channel 52, and instead ensures the fluid flows into the tortuous fluid flow path defined by the array of formations 40.

[0045] The fluid flows through the fluid flow path, and as it does so, heat is transferred from the fluid to the internal surfaces 46 of the walls 44 of the formations 40 and then, by conduction, to the outer surfaces 48 of those walls 44 and to the fins 36, and then by convection to the air that has penetrated the voids 34. Air can flow freely within the voids 34 and circulate between the upper and lower walls 24, 26 of the heat exchanger 10, allowing efficient heating of the air.

[0046] The fluid continues to flow through the fluid flow path around the array of formations 40 until it reaches the second vacant channel 54, where it may freely flow to the right side of the heat exchanger 10, crossing the baffle 56. The fluid then continues on the tortuous fluid flow path around the array of formations 40, transferring further heat to the air surrounding the heat exchanger 10. Eventually the fluid reaches the right side 64 of the first vacant channel 52, where it may exit the heat exchanger 10 through the outlet pipe 18, now in a cooler state.

[0047] Thus, the heat exchanger 10 provides an efficient means of transferring heat from the fluid to the surrounding air, thereby cooling the fluid.

[0048] In an alternative embodiment of the invention, shown in Figure 7, the two portions of the heat exchanger are asymmetrical, and include a first portion provided as a cassette 68, and a second portion provided as a casing 70. The cassette 68 includes a base 72 provided with formations 40 as previously described and having a height that is substantially the same as the height of the body 12. The casing 70 is a hollow container that defines

the internal cavity 14. The cassette 68 is smaller in length than the casing 70, so that when the cassette 68 is received into the casing 70, the casing 70 extends beyond the cassette 68 to provide the first and second vacant channels 52, 54 at either end of the body 12.

[0049] In this embodiment, the two portions 70, 72 may be joined by substantially the same methods as already described.

[0050] A particular advantage of both embodiments of the present invention is the simple method of manufacture. The portions 20, 22, 70, 72 formations 40, fins 36, and baffles 56 of each portion are all formed from a single piece, so that each portion 20, 22, 70, 72 can be integrally formed, for example by injection moulding a single material. This is a quick and simple process that requires little energy and/or labour. The two portions 20, 22, 70, 72 are injection moulded, then are welded together, for example by ultrasonic welding, friction welding, hot plate joining, or adhesion. The manufacturing process is hence significantly more cost efficient than the manufacturing processes of heat exchangers of the prior art. Alternatively the two portions 20, 22, 70, 72 may be formed by die-casting, or by machining from a block.

[0051] An additional advantage is that the heat exchanger 10 of the present invention can be made from any material that can be injected, and is not restricted only to materials that are suitable for forming by methods such as extrusion, stamping and other forms of plastic deformation. For example, the heat exchanger 10 of the present invention could be made from metals such as aluminium or copper, but could also be made from plastics, which are significantly less dense than metals. In one particularly advantageous embodiment, the heat exchanger 10 is made from a lightweight plastic having a high thermal conductivity.

[0052] One particularly preferred method of forming the heat exchanger 10 when formed from a plastic includes joining the two portions 20, 22, 70, 72 of the heat exchanger together using a mesh heater grid. A metallic mesh is placed upon the joining surface of one of the portions, and the joining surface of the other portion is placed on top of the mesh, so that it is sandwiched between the two portions 20, 22, 70, 72. An electric current is applied to the mesh heater grid so as to heat it, which melts the plastic of the joining surfaces, and they are thereby joined together as they cool. The mesh heater grid then remains within the heat exchanger 10 after manufacturing.

[0053] It should be appreciated that a heat exchanger 10 according to the present invention may provide a lower surface area than known heat exchangers, and might therefore produce a lower rate of heat transfer per unit volume. However, this is compensated, at least in part, by the fact that in the present invention the fluid is in contact with the walls 44 of the formations 40 and is hence separated from the air surrounding the heat exchanger 10 only by a single wall.

[0054] Additionally, the fins 36 have a large area of

contact with the formations 40. Each fin 36 extends from one external surface 48 of the formation 40 to another so that it is joined to the formation 40 throughout the entirety of its height. Hence, heat is efficiently transferred from the body 12 to the fins 36.

[0055] Furthermore, the significantly lower manufacturing cost of the heat exchanger 10 means that the heat transfer per unit cost is significantly better than that of known heat exchangers. When formed from a lightweight material such as a plastic, the heat transfer per unit weight is also significantly improved.

[0056] A further advantage of the present invention is that a variety of complicated flow paths can be produced by varying the internal structure 32 of the heat exchanger. For example, further baffles 56 may be provided to guide the flow of the fluid within the internal cavity 14. Additionally, the formations 40 need not be uniformly sized or spaced, but instead the array of formations 40 may be arranged so as to form flow paths of different widths. In this way, the heat transfer rate can be varied at different areas within the heat exchanger 10, so as to tailor the design for specific applications. With a conventional fin and tube design this would require even more complicated forming methods during fabrication of every heat exchanger. By contrast, when manufacturing the heat exchanger of the present invention, a single mould having the complex structure would be produced, and each heat exchanger could be easily produced from this mould by injection moulding.

[0057] It should be appreciated that various modifications and improvements can be made without departing from the scope of the invention as defined in the claims. For example, the heat exchanger may be of any shape. The formations need not be of cuboidal configuration, but may be cylindrical or of any other suitable shape. The internal cavity may be provided with any number of formations and flow controlling structures. The heat exchanger need not be manufactured from two portions, but may instead be formed as a single portion.

Claims

1. A heat exchange apparatus comprising a body that includes an internal cavity for receiving a fluid, a fluid inlet and a fluid outlet, the internal cavity being provided with at least one formation that defines at least one fluid flow path within the internal cavity between the fluid inlet and the fluid outlet, the or each formation comprising a first surface exposed to fluid within the internal cavity, and a second surface exposed to air surrounding the heat exchanger, such that heat can be transferred from fluid flowing within the internal cavity to the air surrounding the heat exchanger via the at least one formation.
2. The heat exchange apparatus of claim 1, wherein the or each formation is hollow to define a channel

to allow air to flow therethrough from one side of the body to the other.

3. The heat exchange apparatus of claim 2, wherein the second surface of the formation is provided with at least one feature which increases the surface area of the formation that is exposed to air.
4. The heat exchange apparatus of claim 3, wherein the feature is a fin.
5. The heat exchange apparatus of claim 4, wherein the fin comprises a wall that extends across the channel.
6. The heat exchange apparatus of any preceding claim, wherein the internal cavity is provided with an array of formations that defines a tortuous flow path for fluid within the internal cavity.
7. The heat exchange apparatus of claim 6, wherein the array is a regular array of identical formations.
8. The heat exchange apparatus of any preceding claim, wherein the body and the at least one formation are integrally formed.
9. The heat exchange apparatus of any preceding claim, wherein the fluid inlet and the fluid outlet are provided in the form of pipes formed integrally with the body.
10. The heat exchange apparatus of claim 9, wherein the fluid inlet and fluid outlet are provided on the same side of the body.
11. The heat exchange apparatus of claim 10, wherein the internal cavity is provided with a vacant channel, proximal to the side on which the fluid inlet and fluid outlet are provided, that is free from formations.
12. The heat exchange apparatus of any preceding claim, wherein the internal cavity is provided with at least one flow controlling structure.
13. The heat exchange apparatus of claim 12, wherein the flow controlling structure is arranged to divert the flow within the internal cavity between the fluid inlet and the fluid outlet.
14. The heat exchange apparatus of claim 12 or claim 13, wherein the flow controlling structure is a baffle.
15. The heat exchange apparatus of any of claims 12 to 14, wherein the body, the at least one formation and the flow controlling structure are integrally formed.
16. The heat exchange apparatus of any preceding

claim, wherein the body and the at least one formation are integrally formed.

ence to the accompanying drawings.

17. The heat exchange apparatus of any preceding claim, wherein the heat exchanger is formed from a metal. 5
18. The heat exchange apparatus of any one of claims 1 to 17, wherein the heat exchanger is formed from a plastic. 10
19. The heat exchange apparatus of any preceding claim, wherein the heat exchanger is formed by injection moulding. 15
20. The heat exchange apparatus of any preceding claim, wherein the heat exchanger comprises two tray portions that are joined together so that the base of one tray portion defines a floor of the internal cavity, and the base of the other tray portion defines a ceiling wall of the internal cavity. 20
21. A method of manufacturing a heat exchange apparatus, the method including: 25
 - forming a first portion of a body of a heat exchanger and a second portion of a body of a heat exchanger by injection moulding; and
 - joining the first portion of the body to the second portion of the body at joining surfaces thereof. 30
22. The method of claim 21, further including joining the first portion of the body to the second portion of the body by any one of the following means: ultrasonic welding, friction welding, hotplate welding, fluid adhesive, or adhesive gasket. 35
23. The method of claim 22, further including joining the first portion of the body to the second portion of the body by: 40
 - placing a wire mesh heating element on the joining surface of the first portion of the body;
 - placing the joining surface of the second portion of the body over the first portion of the body, such that the wire mesh is sandwiched between the first and second portions; and 45
 - heating a wire mesh by passing a current there-through, so as to melt at least a portion of the joining surfaces such that the first and second portions are joined together. 50
24. A heat exchange apparatus substantially as herein described with reference to the accompanying drawings. 55
25. A method of manufacturing a heat exchange apparatus substantially as herein described with refer-

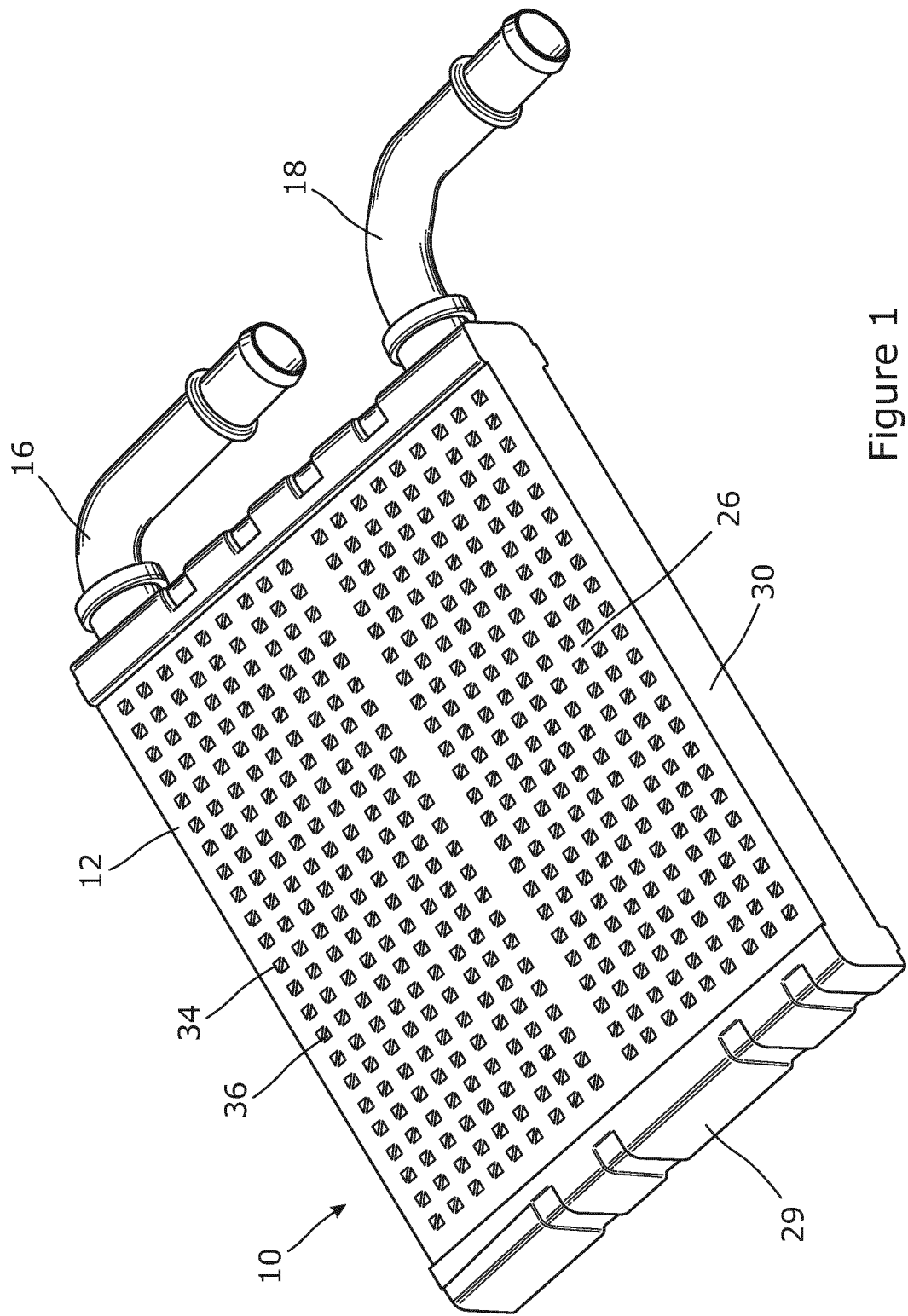


Figure 1

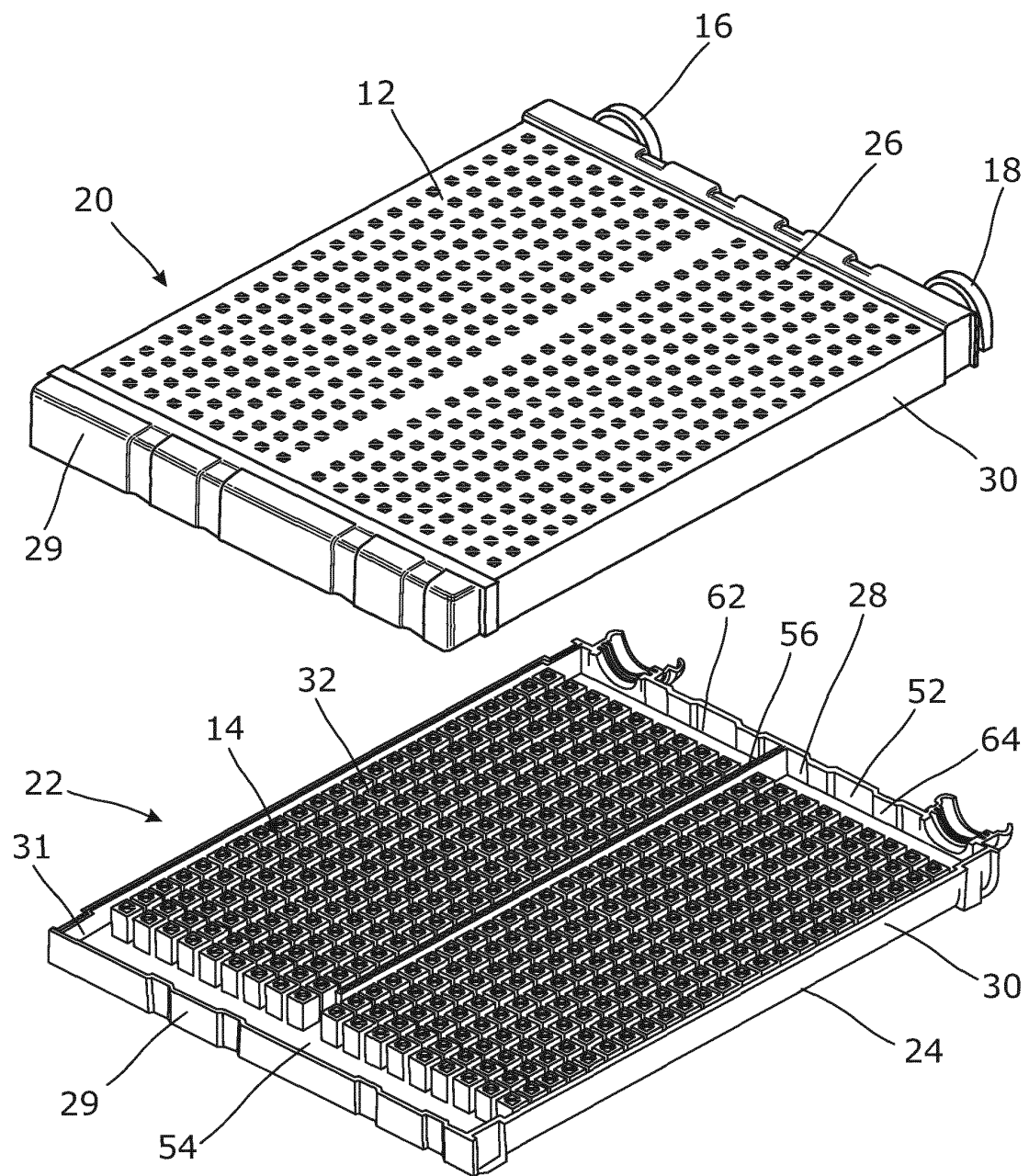


Figure 2

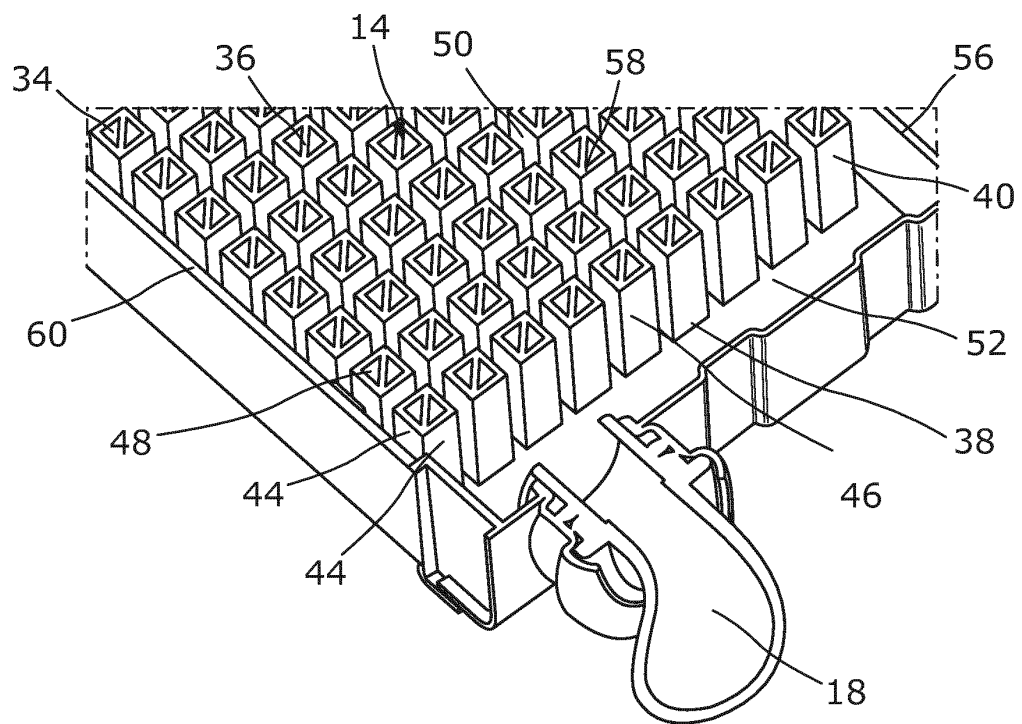


Figure 3

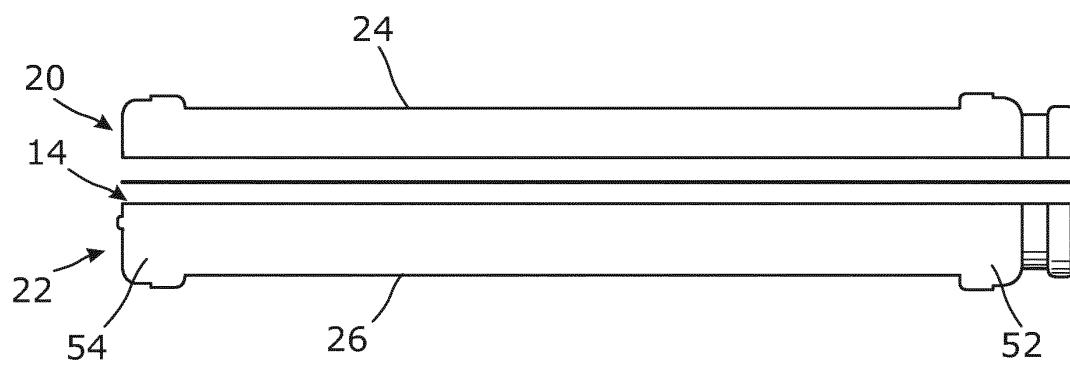


Figure 4

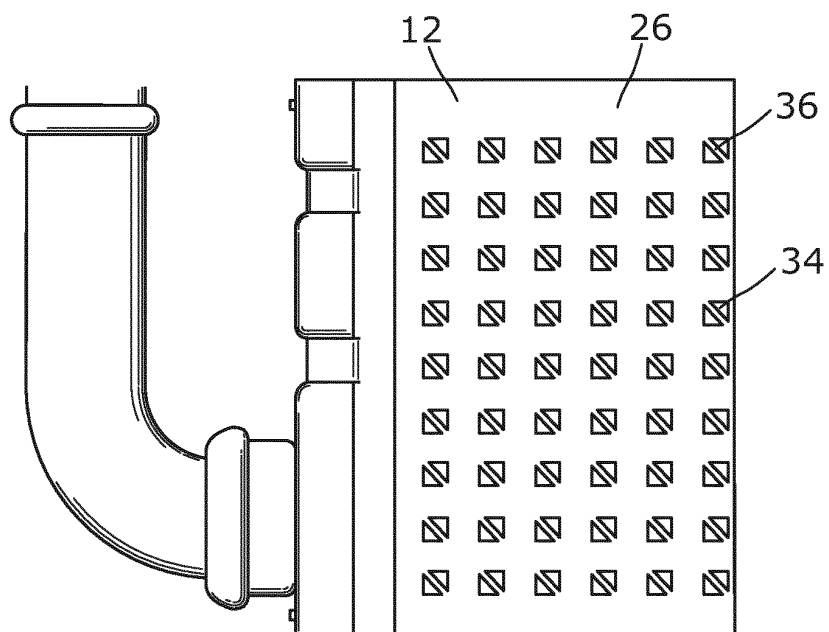


Figure 5

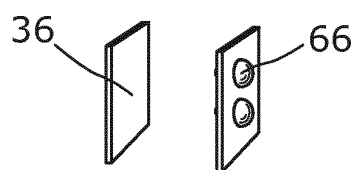


Figure 6

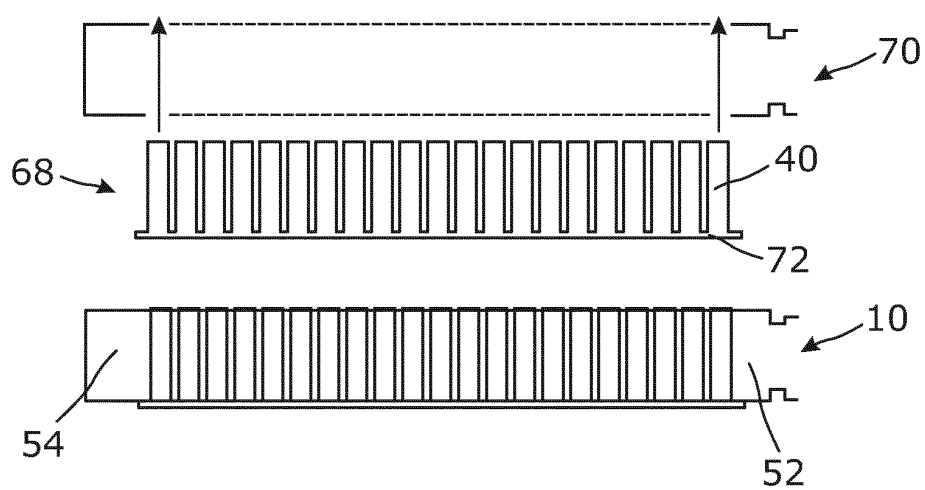


Figure 7