



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
03.06.2020 Bulletin 2020/23

(51) Int Cl.:
F28D 7/00 (2006.01)
F28F 7/02 (2006.01)
F28D 9/00 (2006.01)

(21) Application number: **19207464.9**

(22) Date of filing: **06.11.2019**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(72) Inventors:
• **TURNEY, Joseph**
Amston, CT Connecticut 06321 (US)
• **DOLD, Robert H.**
Monson, MA Massachusetts 01057 (US)
• **GREENE, Christopher Britton**
East Hartford, CT Connecticut 06118 (US)

(30) Priority: **27.11.2018 US 201816201321**

(74) Representative: **Dehns**
St. Bride's House
10 Salisbury Square
London EC4Y 8JD (GB)

(71) Applicant: **Hamilton Sundstrand Corporation**
Charlotte, NC 28217-4578 (US)

(54) **WEAVED CROSS-FLOW HEAT EXCHANGER AND METHOD OF FORMING A HEAT EXCHANGER**

(57) A heat exchanger is disclosed herein that includes three walls (12,14,16) that are each shaped in a wave pattern with the waves that extend in both a first lateral direction and a second lateral direction. A second wall is adjacent to and in contact with a first wall with the waves of the second wall being offset from the waves of the first wall by one-half wavelength in the first direction. The third wall is adjacent to and in contact with the second wall with the waves of the third wall being offset from the waves of the second wall by one-half wavelength in the second direction. The first wall and second wall form a first plurality of flow paths (30B) extending in the second direction, and the second wall and the third wall form a second plurality of flow paths (32B) extending in the first direction.

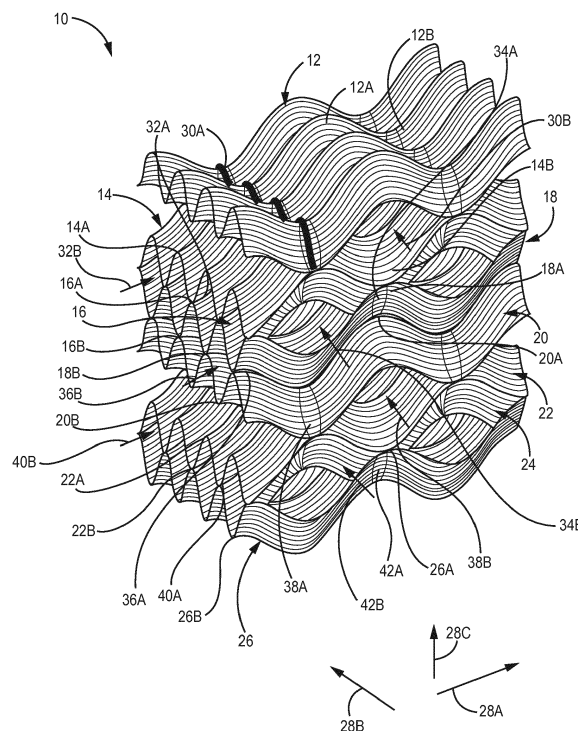


FIG. 1A

Description

FIELD OF THE INVENTION

[0001] The present invention relates to heat exchangers and, in particular, to a method for forming a heat exchanger and to a heat exchanger that utilizes a weaved cross-flow configuration to increase the thermal energy transfer primary surface area of the heat exchanger.

BACKGROUND

[0002] Heat exchangers aim to transfer heat between a hot fluid and a cool fluid. To increase the efficiency of heat exchangers, walls (primary surfaces) and fins (secondary surfaces) are utilized to increase the surface area through which thermal energy can transfer. The heat transfer through primary surface is very good because the walls are thin and the distance the thermal energy needs to travel is relatively small. The heat transfer through secondary surfaces is less efficient than primary surfaces because the thermal energy must travel a longer distance along the length of the fins. However, with conventional manufacturing techniques, the most compact heat exchangers (i.e., high surface area per unit volume) are achieved through increasing secondary surface area by adding fins rather than through the addition of primary surface area.

SUMMARY

[0003] A heat exchanger is disclosed herein that extends laterally in a first direction and a second direction. The heat exchanger includes three walls. A first wall is shaped in a wave pattern with waves that extend in both the first direction and the second direction. These waves can have a variety of configurations, including waves based on a sinusoidal curve in both the first direction and the second direction. The second wall is adjacent to and in contact with the first wall. The second wall is also shaped in a wave pattern with waves that extend in both the first direction and the second direction. The waves of the second wall are offset in the first direction from the first wall by one-half wavelength. The third wall is adjacent to and in contact with the second wall. The third wall is also shaped in a wave pattern with waves that extend in both the first direction and the second direction. The waves of the third wall are offset in the second direction from the second wall by one-half wavelength. The first wall and second wall form a first plurality of flow paths extending in the second direction, and the second wall and third wall form a second plurality of flow paths extending in the first direction.

[0004] A method of forming a heat exchanger includes forming a first wall with waves that extend laterally in both a first direction and in a second direction. The method also includes forming a second wall adjacent to and in contact with the first wall with waves that are based on

a sinusoidal curve and extend laterally in both the first direction and in the second direction. The waves of the second wall are offset in the first direction from the waves of the first wall by one-half wavelength. The method also includes forming a third wall adjacent to and in contact with the second wall with waves that extend laterally in both the first direction and in the second direction. The waves of the third wall are offset in the second direction from the waves of the second wall by one-half wavelength. The first wall and the second wall bound a first plurality of flow paths that extend in the second direction, and the second wall and the third wall bound a second plurality of flow paths that extend in the first direction. The waves of the first, second, and third walls can be based on a sinusoidal curve.

[0005] A method of transferring thermal energy through the use of a heat exchanger includes flowing a first fluid through a first plurality of flow paths bounded by a first wall and a second wall. The first wall having a wave pattern with waves that are based on a sinusoidal curve and extend laterally in both a first direction and a second direction. The second wall is adjacent to and in contact with the first wall and having a wave pattern with waves that are based on a sinusoidal curve and extend laterally in both the first direction and the second direction. The waves of the second wall are offset in the first direction from the waves of the first wall by one-half wavelength. The method also includes flowing a second fluid through a second plurality of flow paths bounded by the second wall and a third wall. The third wall is adjacent to and in contact with the second wall. The third wall has a wave pattern with waves that are based on a sinusoidal curve and extend laterally in both the first direction and the second direction. The waves of the third wall are offset in the second direction from the waves of the second wall by one-half wavelength.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006]

FIG. 1A is a perspective view of a portion of a heat exchanger.

FIG. 1B is a second perspective view of the heat exchanger in FIG. 1A.

FIG. 1C is a perspective view of a plurality of flow paths through the heat exchanger in FIG. 1A.

FIG. 2 is a second embodiment of a heat exchanger.

DETAILED DESCRIPTION

[0007] A heat exchanger is disclosed herein that utilizes a weaved cross-flow configuration to transfer thermal energy between a first fluid and a second fluid. The weaved configuration is constructed primarily from stacked sheets/walls that include waves in a first lateral direction and a second lateral direction. The waves can have a variety of configurations, including waves that are

based on a sinusoidal (i.e., cosine or sine) curve. The walls are primary surfaces that have improved thermal energy transfer capabilities. The waves of one wall are offset from waves of adjacent walls by one-half wavelength to form a plurality of flow paths between adjacent walls through which the first or second fluid flows. Utilizing walls with waves provides an increase in primary surface area of the walls which in turn increases the thermal energy transfer between fluids flowing adjacent those walls. The increase in surface area of the walls eliminates the need for fins (i.e., additional secondary surface), thereby improving efficiency of the heat exchanger by maximizing the energy transfer-to-volume ratio.

[0008] Additive manufacturing can be utilized to create the disclosed heat exchanger so that all components of the heat exchanger are formed during one manufacturing process to form a continuous and monolithic structure. Further, additive manufacturing can easily and reliably form the heat exchanger with complex walls/shapes and small tolerances. In the context of this application, continuous and monolithic means formed as a single unit without seams, weld lines, adhesive lines, or any other discontinuities. The waves of the walls (which, for example, are based on sinusoidal curves) can have alternate amplitudes, wavelengths, and other characteristics as required for optimal thermal energy transfer and to accommodate a designed flow of the first fluid and/or second fluid. Further, the waves can have a variety of shapes, such as triangular waves with pointed peaks and troughs, rectangular waves with flat tops and bottoms, and/or other configurations.

[0009] FIG. 1A is a perspective cross-sectional view of a portion of a heat exchanger, FIG. 1B is a second perspective view of the heat exchanger in FIG. 1A, and FIG. 1C is a perspective view of a plurality of flow paths through the heat exchanger in FIG. 1A. Heat exchanger 10 includes first wall 12, second wall 14, third wall 16, fourth wall 18, fifth wall 20, sixth wall 22, seventh wall 24, and eighth wall 26. Walls 12-26 are primary surfaces, extend laterally in first lateral direction 28A and second lateral direction 28B, and are vertically adjacent one another in vertical direction 28C. The terms "lateral" and "vertical" in the context of FIG. 1A and the rest of this application are merely relative terms and not intend to suggest any limitation into the orientation of the disclosed heat exchanger relative to any particular reference point. While the waves of walls 12-26 are described as being based on sinusoidal curves, the waves can have other configurations and/or orientations. Walls 12-26 with waves based on sinusoidal curves is just an exemplary embodiment of heat exchanger 10.

[0010] First wall 12 and second wall 14 contact one another at first contact lines 30A to form first plurality of flow paths 30B, second wall 14 and third wall 16 contact one another at second contact lines 32A to form second plurality of flow paths 32B, third wall 16 and fourth wall 18 contact one another at third contact lines 34A to form third plurality of flow paths 34B, fourth wall 18 and fifth

wall 20 contact one another at fourth contact lines 36A to form fourth plurality of flow paths 36B, fifth wall 20 and sixth wall 22 contact one another at fifth contact lines 38A to form fifth plurality of flow paths 38B, sixth wall 22 and seventh wall 24 contact one another at sixth contact lines 40A to form sixth plurality of flow paths 40B, and seventh wall 24 and eighth wall 26 contact one another at seventh contact line 42A to form seventh plurality of flow paths 42B.

[0011] First wall 12 includes waves having first wall crests 12A and first wall troughs 12B, second wall 14 includes waves having second wall crests 14A and second wall troughs 14B, third wall 16 includes waves having third wall crests 16A and third wall troughs 16B, fourth wall 18 includes waves having fourth wall crests 18A and fourth wall troughs 18B, fifth wall 20 includes waves having fifth wall crests 20A and fifth wall troughs 20B, sixth wall 22 includes waves having sixth wall crests 22A and sixth wall troughs 22B, seventh wall 24 includes waves having seventh wall crests 24A and seventh wall troughs 24B, and eighth wall 26 includes waves having eighth wall crests 26A and eighth wall troughs 26B.

[0012] Heat exchanger 10 is formed by stacking walls 12-26 vertically to form a plurality of flow paths 30B-42B (seen most easily in FIG. 1C) through which hot fluid and cold fluid can flow (in a cross-flow configuration) to transfer thermal energy to cool the hot fluid through primary surface walls 12-26. While shown as having eight walls 12-26, heat exchanger 10 can have any number of walls that form the plurality of flow paths 30B-42B, including only three walls 12-16 that form two pluralities of flow paths 30B and 32B or more than eighth walls forming more than seven pluralities of flow paths (as shown in FIG. 1B (unlabeled)). Additionally, heat exchanger 10 can extend in a lateral direction any distance, including in first lateral direction 28A a distance that is equal to a distance that heat exchanger 10 extends in second lateral direction 28B. Alternately, heat exchanger 10 can extend in first lateral direction 28A a different distance than that in second lateral direction 28B to form heat exchanger 10 that has a rectangular footprint or another shape. In such configurations, the waves of walls 12-26 would repeat so as to have multiple wavelengths in first lateral direction 28A and second lateral direction 28B to provide sufficient thermal energy transfer surface area to meet thermal energy transfer requirements.

[0013] As shown in FIGS. 1A and 1B, walls 12-26 each include waves in both first lateral direction 28A and second lateral direction 28B that are based on a sinusoidal curve. However, adjacent walls are offset from one another either in first lateral direction 28A or second lateral direction 28B by one-half wavelength, resulting in crests 12A-26A contacting troughs 12B-26B of adjacent walls 12-26 to form a plurality of discrete flow paths 30B-42B. Adjacent walls 12-26 being offset by one-half wavelength in either first lateral direction 28A or second lateral direction 28B forms contact lines 30A-42A that, along with adjacent walls 12-26, bound the plurality of discrete flow

paths 30B-42B. Such a configuration provides a weaved, cross-flow heat exchanger 10 with increased primary surface area. Nearly the entire surface area of each flow path of the plurality of flow paths 30B-42B is primary heat transfer area resulting in increased heat transfer and reduced volume of heat exchanger 10. Each wall 12-26 will be described below and its relation to adjacent walls. However, other configurations of heat exchanger 10 can have different orientations such that "lateral" and "vertical" are used herein only to describe component in relation to one another with regards to FIG.S 1A-1C and do not require heat exchanger 10 be oriented such that walls 12-26 extend in a horizontal direction or any particular special direction.

[0014] First wall 12 is shaped in a wave pattern with waves extending both in first lateral direction 28A and second lateral direction 28B. The waves of first wall 12 are based on a sinusoidal curve that repeat in both directions 28A and 28B. Additionally, a person of ordinary skill in the art will recognize that the waves can be based on either cosine or sine curves, which are essentially the same and are only different as to the starting point of each type of wave. For convenience, this application will describe the disclosed heat exchanger 10 using cosine terminology. As shown in FIG. 1A, the waves of first wall 12 show two complete wavelengths in first lateral direction 28A and four complete wavelengths in second lateral direction 28B. In FIG. 1B, walls 12-26 are shown to have at least five waves in both directions 28A and 28B. Multiple first wall crests 12A (the peaks of the waves) and multiple first wall troughs 12B (the valleys of the waves) are in each direction 28A and 28B. However, since the waves extend both in first lateral direction 28A and second lateral direction 28B, first wall crests 12A and first wall troughs 12B are lines that extend in either first lateral direction 28A or second lateral direction 28B. For example, as shown by thick line 30A (first contact lines 30A), first wall 12 contacts second wall 14 along first wall troughs 12B that extend in second lateral direction 28B. However, first contact lines 30A do include multiple first wall crests 12A extending along lines in first lateral direction 28A. Thus, first wall crests 12A and first wall troughs 12B form a checkered pattern with a lowest point of first wall 12 being at a point where first wall troughs 12B in first lateral direction 28A intersect first wall troughs 12B in second lateral direction 28B.

[0015] First wall 12 can have any thickness, including a constant thickness in one or both directions 28A and 28B or a varying thickness depending on structural and/or thermal energy transfer needs. The thickness of first wall 12 (and other walls 14-26) can be configured to alter the cross-sectional flow area of the plurality of flow paths 30B-42B. For example, the cross-sectional flow area can be substantially circular (as shown in FIG. 2) or another shape. Additionally, the amplitude and/or wavelength of first wall 12 can be anything suitable for thermal energy transfer, can be the same or different than the amplitude and/or wavelength of the other walls 14-26,

and/or can be different in first lateral direction 28A as compared to second lateral direction 28B. For example, the waves of first wall 12 in first lateral direction 28A can be at least 1.5 times greater in amplitude than the waves of first wall 12 in second lateral direction 28B. However, for walls 12-26 to line up, first wall 12, third wall 16, fifth wall 20, and seventh wall 24 may need to have the same amplitude and wavelength (and similarly, second wall 14, fourth wall 18, sixth wall 20, and eighth wall 26).

[0016] Second wall 14 is similar to first wall 12 in that second wall 14 is shaped in a wave pattern with waves extending both in first lateral direction 28A and second lateral direction 28B. Second wall 14 is adjacent to and in contact with first wall 14 (on a top side) and third wall 18 (on a bottom side). The waves of second wall 14 are based on a cosine curve (or sine curve) that repeat in both directions 28A and 28B. The waves of second wall 14 are offset from first wall 12 in first lateral direction 28A by one-half wavelength. Because second wall 14 is offset from first wall 12 in first lateral direction 28A, second wall crests 14A (in first lateral direction 28A) contact first wall troughs 12B (in first lateral direction 28A) to form first contact lines 30A, which extend in second lateral direction 28B. First contact lines 30A are where first wall 12 and second wall 14 connect to one another to bound first plurality of flow paths 30B. As with first wall 12, second wall 14 has multiple second wall crests 14A and troughs 14B in both first lateral direction 28A and second lateral direction 28B. The waves of second wall 14 can have the same or differing amplitudes and/or wavelengths as the waves of first wall 12 in one or both directions 28A and 28B. Additionally, similar to first wall 12, the thickness of second wall 12 can be constant or varying in any direction 28A and 28B.

[0017] First plurality of flow paths 30B are formed and bounded by first wall 12 and second wall 14 (and first contact lines 30A) and extend in second lateral direction 28B. As seen most easily in FIG. 1C, which shows plurality of flow paths 30B-42B without the presence of walls 12-26, first plurality of flow paths 30B have undulating cross-sectional flow areas due to the waves of first wall 12 and second wall 14, which enhances heat transfer by limiting boundary layer growth through first plurality of flow paths 30B. In FIGS. 1A-1C, each of the first plurality of flow paths 30B are fluidically isolated from adjacent flow paths of first plurality of flow paths 30B. However, as shown in FIG. 2, first plurality of flow paths 30B can be laterally or vertically interconnected such that flow through one flow path of first plurality of flow paths 30B can transition and flow through an adjacent flow path of first plurality of flow paths 30B or adjacent pluralities of flow paths 32B-42B. With such a configuration, first contact lines 30A are not continuous along an entire distance of first wall 12 and second wall 14 in second lateral direction 28B and rather there are transition openings between adjacent flow paths of first plurality of flow paths 30B. The cross-sectional flow area of each of the first plurality of flow paths 30B can be similar to adjacent flow

paths or can be differing, such as flow paths of the first plurality of flow paths 30B alternating between a flow path that has a circular cross-sectional flow area and a flow path that has an eyelet-type shape. Fluid flowing through each of first plurality of flow paths 30B can be hot or cold gas or liquid, and the fluid can flow in alternating directions (i.e., fluid in one flow path flows in the opposite direction to fluid in another/adjacent flow path).

[0018] Third wall 16 is similar to second wall 14 in that third wall 16 is shaped in a wave pattern with waves extending both in first lateral direction 28A and second lateral direction 28B. Third wall 16 is adjacent to and in contact with second wall 14 (on a top side) and fourth wall 18 (on a bottom side). The waves of third wall 16 are based on a cosine curve (or sine curve) that repeat in both directions 28A and 28B. The waves of third wall 16 are offset from second wall 14 in second lateral direction 28B by one-half wavelength. Because third wall 16 is offset from second wall 14 in second lateral direction 28B, third wall crests 16A (in second lateral direction 28B) contact second wall troughs 14B (in second lateral direction 28B) to form second contact lines 32A, which extend in first lateral direction 28A. Second contact lines 32A are where second wall 14 and third wall 16 connect to one another to bound second plurality of flow paths 32B. As with second wall 14, third wall 16 has multiple third wall crests 16A and third wall troughs 16B in both first lateral direction 28A and second lateral direction 28B. The waves of third wall 16 can have the same or differing amplitudes and/or wavelengths as the waves of first wall 12 and/or second wall 14 in one or both directions 28A and 28B. In one embodiment, the waves in first lateral direction 28A of first wall 12, second wall 14, and third wall 16 have an amplitude and/or wavelength that is greater than an amplitude and/or wavelength of the waves in second lateral direction 28B of first wall 12, second wall 14, and third wall 16. Additionally, similar to first wall 12 and second wall 14, a thickness of third wall 16 can be constant or varying in any direction 28A and 28B.

[0019] Second plurality of flow paths 32B are formed and bounded by second wall 14 and third wall 16 (and second contact lines 32A) and extend in first lateral direction 28A. Second plurality of flow paths 32B form a weaved, cross-flow pattern with first plurality of flow paths 30B and third plurality of flow paths 34B. For example, hot fluid can flow through second plurality of flow paths 32B while cold fluid flows through first plurality of flow paths 30B and third plurality of flow paths 34B such that thermal energy transfers across second wall 14 and third wall 16. Second plurality of flow paths 32B can be similar in configuration and functionality to first plurality of flow paths 30B (except that second plurality of flow paths 32B extend in first lateral direction 28A). In FIGS. 1A-1C, each flow path of second plurality of flow paths 32B are fluidically isolated from adjacent flow paths of second plurality of flow paths 32B. However, as shown in FIG. 2, second plurality of flow paths 32B can be laterally or vertically interconnected such that flow through one flow path of

second plurality of flow paths 32B can transition and flow through an adjacent flow path of second plurality of flow paths 32B. With such a configuration, second contact lines 32A are not continuous along an entire distance of second wall 14 and third wall 16 in first lateral direction 28A and rather there are transition openings between adjacent flow paths of second plurality of flow paths 32B. The cross-sectional flow area of each of the second plurality of flow paths 32B can be similar to adjacent flow paths or can be differing, such as flow paths of the second plurality of flow paths 32B alternating between a flow path that has a circular cross-sectional flow area and a flow path that has an eyelet-type shape. Fluid flowing through each of second plurality of flow paths 32B can be hot or cold gas or liquid, and the fluid can flow in alternating directions (i.e., fluid in one flow path flows in the opposite direction to fluid in another/adjacent flow path).

[0020] Fourth wall 18 is similar to third wall 16 in that fourth wall 18 is shaped in a wave pattern with waves extending both in first lateral direction 28A and second lateral direction 28B. Fourth wall 18 is adjacent to and in contact with third wall 16 (on a top side) and fifth wall 20 (on a bottom side). The waves of fourth wall 18 are based on a cosine curve (or sine curve) that repeat in both directions 28A and 28B. The waves of fourth wall 18 are offset from third wall 16 in first lateral direction 28A by one-half wavelength. Because fourth wall 18 is offset from third wall 16 in first lateral direction 28A, fourth wall crests 18A (in second lateral direction 28B) contact third wall troughs 16B (in second lateral direction 28B) to form third contact lines 34A, which extend in second lateral direction 28B. Third contact lines 34A are where third wall 16 and fourth wall 18 connect to one another to bound third plurality of flow paths 34B. As with third wall 16, fourth wall 18 has multiple fourth wall crests 18A and fourth wall troughs 18B in both first lateral direction 28A and second lateral direction 28B. The waves of fourth wall 18 can have the same or differing amplitudes and/or wavelengths as the waves of first wall 12, second wall 14, and/or third wall 16 in one or both directions 28A and 28B. Additionally, similar to first wall 12, second wall 14, and third wall 16, the thickness of fourth wall 18 can be constant or varying in any direction 28A and 28B.

[0021] Third plurality of flow paths 34B are formed and bounded by third wall 16 and fourth wall 18 (and third contact lines 34A) and extend in second lateral direction 28B. Third plurality of flow paths 34B form a weaved, cross-flow pattern with second plurality of flow paths 32B and fourth plurality of flow paths 36B. For example, hot fluid can flow through first plurality of flow paths 30B and third plurality of flow paths 34B while cold fluid flows through second plurality of flow paths 32B and fourth plurality of flow paths 36B such that thermal energy transfers through second wall 14, third wall 16, and fourth wall 18. Third plurality of flow paths 34B can be similar in configuration and functionality to first plurality of flow paths 30B and second plurality of flow paths 32B (except that third plurality of flow paths 34B extend in second

lateral direction 28B and are offset from first plurality of flow paths 30B by one-half wavelength in first lateral direction 28A). In FIGS. 1A-1C, each flow path of third plurality of flow paths 34B are fluidically isolated from adjacent flow paths of third plurality of flow paths 34B. However, as shown in FIG. 2, third plurality of flow paths 34B can be laterally or vertically interconnected such that flow through one flow path of third plurality of flow paths 34B can transition and flow through an adjacent flow path of third plurality of flow paths 34B. With such a configuration, third contact lines 34A are not continuous along an entire distance of third wall 16 and fourth wall 18 in second lateral direction 28B and rather there are transition openings between adjacent flow paths of third plurality of flow paths 34B. The cross-sectional flow area of each of the third plurality of flow paths 34B can be similar to adjacent flow paths or can be differing, such as flow paths of the third plurality of flow paths 34B alternating between a flow path that has a circular cross-sectional flow area and a flow path that has an eyelet-type shape. Fluid flowing through each of third plurality of flow paths 34B can be hot or cold gas or liquid, and the fluid can flow in alternating directions (i.e., fluid in one flow path flows in the opposite direction to fluid in another/adjacent flow path).

[0022] Fifth wall 20 is similar to fourth wall 18 in that fifth wall 20 is shaped in a wave pattern with waves extending both in first lateral direction 28A and second lateral direction 28B. Fifth wall 20 is adjacent to and in contact with fourth wall 18 (on a top side) and sixth wall 22 (on a bottom side). Fifth wall 20 has the same orientation as first wall 12 with the waves of fifth wall 20 being offset from fourth wall 18 in second lateral direction 28B by one-half wavelength. The configuration of heat exchanger 10 downward from fifth wall 20 repeats so as to have the same configuration of heat exchanger 10 between first wall 12 and fifth wall 20. Because fifth wall 20 is offset from fourth wall 18 in second lateral direction 28B, fifth wall crests 20A (in first lateral direction 28A) contact fourth wall troughs 18B (in first lateral direction 28A) to form fourth contact lines 36A, which extend in first lateral direction 28A. Fourth contact lines 36A are where fourth wall 18 and fifth wall 20 connect to one another to bound fourth plurality of flow paths 36B. As with fourth wall 18, fifth wall 20 has multiple fifth wall crests 20A and fifth wall troughs 20B in both first lateral direction 28A and second lateral direction 28B. The waves of fifth wall 20 can have the same or differing amplitudes and/or wavelengths as the waves of walls 12-18 in one or both directions 28A and 28B. Additionally, similar to walls 12-18, the thickness of fifth wall 20 can be constant or varying in any direction 28A and 28B.

[0023] Fourth plurality of flow paths 36B are formed and bounded by fourth wall 18 and fifth wall 20 (and fourth contact lines 36A) and extend in first lateral direction 28A. Fourth plurality of flow paths 36B form a weaved, cross-flow pattern with third plurality of flow paths 34B and fifth plurality of flow paths 38B. For example, hot fluid can flow through first plurality of flow paths 30B and third plu-

rality of flow paths 34B while cold fluid flows through second plurality of flow paths 32B and fourth plurality of flow paths 36B such that thermal energy transfers through second wall 14, third wall 16, fourth wall 18, and fifth wall 20. Fourth plurality of flow paths 36B can be similar in configuration and functionality to other pluralities of flow paths 30B-42B. In FIGS. 1A-1C, each flow path of fourth plurality of flow paths 36B are fluidically isolated from adjacent flow paths of fourth plurality of flow paths 36B. However, as shown in FIG. 2, fourth plurality of flow paths 36B can be laterally or vertically interconnected such that flow through one flow path of fourth plurality of flow paths 36B can transition and flow through an adjacent flow path of fourth plurality of flow paths 36B. With such a configuration, fourth contact lines 36A are not continuous along an entire distance of fourth wall 18 and fifth wall 20 in first lateral direction 28A and rather there are transition openings between adjacent flow paths of fourth plurality of flow paths 36B. The cross-sectional flow area of each of the fourth plurality of flow paths 36B can be similar to adjacent flow paths or can be differing, such as flow paths of the fourth plurality of flow paths 36B alternating between a flow path that has a circular cross-sectional flow area and a flow path that has an eyelet-type shape. Fluid flowing through each of fourth plurality of flow paths 36B can be hot or cold gas or liquid, and the fluid can flow in alternating directions (i.e., fluid in one flow path flows in the opposite direction to fluid in another/adjacent flow path).

[0024] Sixth wall 22 has the same orientation, configuration, and functionality as second wall 14. Sixth wall 22 is adjacent to and in contact with fifth wall 20 (along fifth contact lines 38A) to form fifth plurality of flow paths 38B. Fifth plurality of flow paths 38B has the same orientation, configuration, and functionality as first plurality of flow paths 30B. Seventh wall 24 has the same orientation, configuration, and functionality as third wall 16. Seventh wall 24 is adjacent to and in contact with sixth wall 22 (along sixth contact lines 40A) to form sixth plurality of flow paths 40B. Sixth plurality of flow paths 40B has the same orientation, configuration, and functionality as second plurality of flow paths 32B. Eighth wall 26 has the same orientation, configuration, and functionality as fourth wall 18. Eighth wall 26 is adjacent to and in contact with seventh wall 24 (along seventh contact lines 42A) to form seventh plurality of flow paths 42B. Seventh plurality of flow paths 42B has the same orientation, configuration, and functionality as third plurality of flow paths 34B.

[0025] Heat exchanger 10 can extend in vertical direction 28C by including additional walls having the same orientation as walls 12-26 (as shown in FIG. 1B) and/or by increasing the amplitude of the waves of walls 12-26. Heat exchanger 10 can be constructed from a variety of materials, including conventional materials and materials that have lower thermal conductivity properties than materials conventionally used to construct heat exchangers. Because the primary thermal energy transfer surface ar-

ea of each flow path of the plurality of flow paths 30B-42B is increased due to the wave pattern of walls 12-26 of heat exchanger 10, the amount of thermal energy transfer of heat exchanger 10 is increased as compared to prior art heat exchangers. With an increase in primary surface area, heat exchanger 10 can be constructed from materials that have low thermal conductivity properties, such as plastics or composites. For example, heat exchanger 10 may be constructed from reinforced nylon, acrylonitrile butadiene styrene, epoxy, or urethane methacrylate. If desired, heat exchanger 10 can be located within a machine that requires increased thermal energy transfer capabilities and a small volume, such as a gas turbine engine.

[0026] While heat exchanger 10 can be constructed from multiple components such that each of walls 12-26 is constructed independently and then fastened together along contact lines 30A-42A, heat exchanger 10 can be formed as one continuous and monolithic piece through additive manufacturing or other methods such that heat exchanger 10 is formed as a single unit without seams, weld lines, adhesive lines, or any other discontinuities. To construct heat exchanger 10, first wall 12 is formed with waves based on a cosine curve extending in both first lateral direction 28A and second lateral direction 28B.

[0027] Next, second wall 14 is formed with waves based on a cosine curve extending in both directions 28A and 28B with the waves being offset in first lateral direction 28A from first wall 12 by one-half wavelength to form first plurality of flow paths 30B. Second wall 14 is adjacent to first wall 12 and can be either fastened to first wall 12 along first contact lines 30A, or second wall 14 can be formed simultaneously with first wall 12 such that first wall 12 and second wall 14 are one continuous and monolithic piece.

[0028] Then, third wall 16 is formed with waves based on a cosine curve extending in both directions 28A and 28B with the waves being offset in second lateral direction 28A from second wall 14 by one-half wavelength to form second plurality of flow paths 32B. Third wall 16 is adjacent to second wall 14 and can be either fastened to second wall 14 along second contact lines 32A, or third wall 16 can be formed simultaneously with second wall 14 (and possibly first wall 12) such that second wall 14 and third wall 16 are one continuous and monolithic piece. Subsequent walls 18-26 (or more) can be formed utilizing similar steps. Additionally, a method of forming heat exchanger 10 can start at a bottom wall (a wall that is on a bottom side of heat exchanger 10) and build up walls from there, or the method can form heat exchanger 10 building the walls in first lateral direction 28A or second lateral direction 28B.

[0029] While the disclosed heat exchanger 10 will be described as transferring thermal energy between two fluids, a first fluid and a second fluid, a person skilled in the art will recognize that the disclosed heat exchanger 10 may be used with more than two fluids provided it is

constructed with sufficient pluralities of flow paths to accommodate more than two heat exchange fluids. First, the first fluid (which can be a hot fluid or cold fluid) is conveyed/flowed in second lateral direction 28B through first plurality of flow paths 30B and, if necessary, third plurality of flow paths 34B, fifth plurality of flow paths 38B, and seventh plurality of flow paths 42B. Then, the second fluid (which can be a hot fluid or a cold fluid but should be a fluid that has a different temperature than the first fluid) is conveyed/flowed in first lateral direction 28A through second plurality of flow paths 32B and, if necessary, fourth plurality of flow paths 36B and sixth plurality of flow paths 40B. Because of the weaved, cross-flow configuration of heat exchanger 10 having walls 12-26 with a wave pattern, thermal energy transfer between the first fluid and second fluid is rapid because the thermal energy transfer surface areas of each flow path of the pluralities of flow paths 30B-42B is large and direct from the hot fluid to the cold fluid (i.e., no conduction along a fin) and the undulating nature of each flow path creates enhances heat transfer.

[0030] FIG. 2 is a second embodiment of a heat exchanger. Heat exchanger 110 is similar to heat exchanger 10 in FIGS. 1A-1C except that heat exchanger 110 includes sub flow paths as part of a plurality of flow paths that are vertically connected by transition openings. In FIG. 2, a plurality of flow paths includes multiple subflow paths that are connected to adjacent subflow paths vertically to allow for a fluid flowing through the plurality of flow paths to transition and flow through an adjacent subflow path while still providing an increase in primary surface area for optimal heat transfer. While FIG. 2 shows subflow paths connected to adjacent subflow paths vertically, the orientation and configuration of heat exchanger 110 can be such that subflow paths can be connected to adjacent subflow paths horizontally (i.e., the pluralities of flow paths 30B-42B in heat exchanger 10 are connected to one another by transition openings between adjacent flow paths). While the pluralities of flow paths of heat exchanger 110 can be described with regards to walls in a similar fashion to that of heat exchanger 10, it may be easier to understand the configuration of heat exchanger 110 by describing the pluralities of flow paths through heat exchanger 110 rather than the walls that bound the pluralities of flow paths.

[0031] Heat exchanger 110 includes walls 112 bounding cold fluid flow path 150 (which encompasses all cold fluid flow paths, including the pluralities of cold flow paths as well as subflow paths) extending in first lateral direction 128A and hot fluid flow path 170 (which encompasses all hot fluid flow paths, including the pluralities of hot flow paths as well as subflow paths) extending in second lateral direction 128B. While this disclosure describes the flow paths as being for "hot" fluid and "cold" fluid, this is done for simplicity such that the temperature and/or type of fluid is exemplary and any type of fluid and even more than two fluids can be utilized in heat exchanger 110. Cold fluid flow path 150 includes first plurality of cold

flow paths 152, second plurality of cold flow paths 154, third plurality of cold flow paths 156, fourth plurality of cold flow paths 158, fifth plurality of cold flow paths 160, sixth plurality of cold flow paths 162, and seventh plurality of cold flow paths 164. Each cold plurality of cold flow paths 152-164 includes six cold subflow paths, with first plurality of cold flow paths 152 having first cold subflow paths 152A-152F (while not labeled in FIG. 2 for simplicity, the other pluralities of flow paths 154-164 also include six cold subflow paths of similar configuration and functionality). Between cold subflow paths 152A-152F are transition openings 166, which provide a path through which cold fluid can flow between adjacent cold subflow paths 152A-152F. Similarly, hot fluid flow path 170 includes first plurality of hot flow paths 172, second plurality of hot flow paths 174, third plurality of hot flow paths 176, fourth plurality of hot flow paths 178, fifth plurality of hot flow paths 180, sixth plurality of hot flow paths 182, and seventh plurality of hot flow paths 184. Each plurality of hot flow paths 172-184 includes six hot subflow paths, with first plurality of hot flow paths 172 having first hot subflow paths 172A-172F (while not labeled in FIG. 2 for simplicity, the other pluralities of hot flow paths 174-184 also include six hot subflow paths of similar configuration and functionality). Between hot subflow paths 172A-172F are transition openings 186, which provide a path through which hot fluid can flow between adjacent hot subflow paths 172A-172F. The below disclosure will focus on first plurality of cold flow paths 152 of cold fluid flow path 150 and first plurality of hot flow paths 172 of hot fluid flow path 170. However, the other pluralities of cold flow paths 154-164 and hot flow paths 174-184 have similar configurations and functionalities.

[0032] Cold fluid flow path 150 includes pluralities of cold flow paths 152-164 that are columns of flow paths arranged so as to be laterally adjacent to at least one other plurality of cold flow paths 152-164. Each of the pluralities of cold flow paths 152-164 extend in first lateral direction 128A such that cold fluid flowing through the plurality of cold flow paths 152-164 flows substantially in first lateral direction 128A. As shown, there are seven pluralities of cold flow paths 152-164. However, for more or less thermal energy transfer capabilities, heat exchanger 110 can include a lesser or greater number of pluralities of cold flow paths 152-164 for accommodating cold fluid flow. Additionally, while each plurality of cold flow paths 152-164 is shown as having six cold subflow paths 152A-152F, heat exchanger 110 can include less than six or greater than six cold subflow paths as the design requires (and, for example, space within a gas turbine engine allows). In the embodiment of heat exchanger 110 shown in FIG. 2, adjacent pluralities of cold flow paths 152-164 do not provide for cold fluid flow therebetween and cold fluid is only able to flow between adjacent cold subflow paths 152A-152F within a single plurality of cold flow paths 152-164. However, other embodiments of heat exchanger 110 can include openings that allow cold fluid to transition between adjacent pluralities

of cold flow paths 152-164.

[0033] First plurality of cold flow paths 152 is shown in a cross-sectional representation so that cold subflow paths 152A-152F are more easily seen. First plurality of cold flow paths 152 (and other pluralities of cold flow paths 154-164 and 172-184) extend vertically and are bounded by walls 112. First plurality of cold flow paths 152 include cold subflow paths 152A-152F, which allow cold fluid to flow in first lateral direction 128A while also allowing cold fluid to transition between adjacent cold subflow paths 152A-152F. Cold fluid is able to flow between adjacent cold subflow paths 152A-152F by flowing at least partially vertically through transition openings 166 between adjacent cold subflow paths 152A-152F. Each of cold subflow paths 152A-152F have a wave pattern with waves that extend in first lateral direction 128A based on a cosine curve (or sine curve depending on the starting point of the wave). However, cold subflow paths 152A-152F are offset from adjacent cold subflow paths 152A-152F by one-half wavelength in first lateral direction 128A.

[0034] For example, as shown in FIG. 2, cold subflow path 152A (a topmost subflow path), cold subflow path 152C, and cold subflow path 152E have the same configuration as one another with waves that propagate in first lateral direction 128A in phase (i.e., crests and troughs of the waves line up vertically). Cold subflow path 152B, cold subflow path 152D, and cold subflow path 152F (a bottommost subflow path) also have the same configuration as one another with waves that propagate in first lateral direction 128A in phase. However, cold subflow paths 152B, 152D, and 152F are offset from cold subflow paths 152A, 152C, and 152E one-half wavelength such that the crests of cold subflow paths 152A, 152C, and 152E interconnect with the troughs of cold subflow paths 152B, 152D, and 152F (and vice-versa) to form transition openings 166 through which cold fluid can flow into adjacent cold subflow paths 152A-152F. While cold subflow paths 152A-152F are shown as having the same amplitude and wavelength, other embodiments can include cold subflow paths 152A-152F that have differing amplitudes and wavelengths. Further, other pluralities of cold flow paths 154-164 can have different configurations such that those cold subflow paths (which are part of each plurality of cold flow paths 154-164) have differing amplitudes, wavelengths, and/or orientations.

[0035] Transition openings 166 that interconnect cold subflow paths 152A-152F can have as large or small cross-sectional area as desired and, in other embodiments, heat exchanger 110 may not include transition openings 166 and instead cold subflow paths 152A-152F are discrete and fluidically isolated from one another.

[0036] Cold subflow paths 152A-152F are shown as having a substantially circular cross-sectional area due to walls 112 having a varying thickness to form the circular cross-sectional area. However, cold subflow paths 152A-152F can have other cross-sectional areas, such as any non-circular cross-section including eyelet-type

shape or another shape.

[0037] First plurality of hot flow paths 172 is shown in a cross-sectional representation so that hot subflow paths 172A-172F are more easily seen. First plurality of hot flow paths 172 has the same configuration as first plurality of cold flow paths 152 except that first plurality of hot flow paths 172 extends in second lateral direction 128B and provide flow paths for a different fluid (in this exemplary embodiment, the fluid is a hot fluid).

[0038] First plurality of hot flow paths 172 include hot subflow paths 172A-172F that allow hot fluid to flow in second lateral direction 128B while also allowing hot fluid to transition between adjacent subflow paths 172A-172F by flowing at least partially vertically through transition openings 186 between adjacent subflow paths 172A-172F. Each of hot subflow paths 172A-172F have a wave pattern with waves that extend in second lateral direction 128B based on a cosine curve (or sine curve depending on the starting point of the wave). However, hot subflow paths 172A-172F are offset from adjacent hot subflow paths 172A-172F by one-half wavelength in second lateral direction 128B.

[0039] For example, as shown in FIG. 2, hot subflow path 172A (a topmost subflow path), hot subflow path 172C, and hot subflow path 172E have the same configuration as one another with waves that propagate in second lateral direction 128B in phase (i.e., crests and troughs of the waves line up vertically). Hot subflow path 172B, hot subflow path 172D, and hot subflow path 172F (a bottommost subflow path) also have the same configuration as one another with waves that propagate in second lateral direction 128B in phase. However, hot subflow paths 172B, 172D, and 172F are offset from hot subflow paths 172A, 172C, and 172E one-half wavelength such that the crests of hot subflow paths 172A, 172C, and 172E interconnect with the troughs of hot subflow paths 172B, 172D, and 172F (and vice-versa) to form transition openings 186 through which hot fluid can flow into adjacent hot subflow paths 172A-172F. While hot subflow paths 172A-172F are shown as having the same amplitude and wavelength, other embodiments can include hot subflow paths 172A-172F that have differing amplitudes and wavelengths. Further, other pluralities of hot flow paths 174-184 can have different configurations such that those hot subflow paths (which are part of each plurality of hot flow paths 174-184) have differing amplitudes, wavelengths, and/or orientations.

[0040] Transition openings 186 that interconnect hot subflow paths 172A-172F can have as large or small cross-sectional areas as desired and, in other embodiments, heat exchanger 110 may not include transition openings 186 and instead hot subflow paths 172A-172F are discrete and fluidically isolated from one another.

[0041] Hot subflow paths 172A-172F are shown as having a substantially circular cross-sectional area due to walls 112 having a varying thickness to form the circular cross-sectional area. However, hot subflow paths 172A-172F can have other cross-sectional areas, such

as any non-circular cross-section including eyelet-type shape or another shape.

[0042] As shown in FIG. 2, the wave pattern of cold subflow paths 152A-152F and hot subflow paths 172A-172F create a weaved cross-flow configuration in which each subflow path of cold fluid flow path 150 is adjacent multiple subflow paths of hot fluid flow path 170 (and vice-versa). This configuration provides for increased thermal energy transfer while minimizing the volume needed for heat exchanger 110 (i.e., increasing the thermal energy-to-volume ratio of heat exchanger 110). Additionally, the wave pattern and transition openings 166 and 186 between subflow paths limits the growth of boundary layers of the cold fluid and hot fluid through cold fluid flow path 150 and hot fluid flow path 170, respectively, thereby increasing the thermal energy transfer capabilities.

[0043] As with heat exchanger 10 in FIGS. 1A-1C, heat exchanger 110 can be constructed from multiple components such that walls 112 are constructed independently and then fastened together to form heat exchanger 110. Heat exchanger 110 can also be formed as one continuous and monolithic piece through additive manufacturing or other methods.

[0044] Heat exchanger 10/110 utilizes a weaved cross-flow configuration to provide increased primary surface area to improve the thermal energy transfer capabilities between a first fluid and a second fluid. The weaved configuration is constructed primarily from stacked sheets/walls 12-26/112 (primary surfaces) that include waves in first lateral direction 28A/128A and second lateral direction 28B/128B. Waves 12-26/112 can have a variety of configurations, including waves that are based on a sinusoidal curve. Walls 12-26/112 are primary surfaces that have improved thermal energy transfer capabilities. The waves of one wall 12-26/112 are offset from waves of adjacent walls 12-26/112 by one-half wavelength to form plurality of flow paths 30B-42B/152-164 and 172-184 between adjacent walls 12-26/112 through which the hot or cool fluid flows. Utilizing walls 12-26/112 with waves provides an increase in primary surface area of walls 12-26/112 which in turn increases the thermal energy transfer between fluids flowing adjacent those walls 12-26/112. The increase in surface area of walls 12-26/112 eliminates the need for fins (i.e., additional secondary surfaces), thereby improving efficiency of heat exchanger 10/110 by minimizing the distance thermal energy must transfer to maximize the energy transfer-to-volume ratio.

[0045] Additive manufacturing can be utilized to create the disclosed heat exchanger 10/110 so that all components of heat exchanger 10/110 are formed during one manufacturing process to form a continuous and monolithic structure. Further, additive manufacturing can easily and reliably form heat exchanger 10/110 with complex walls 12-26/112 or shapes and small tolerances. While the waves of walls 12-26/112 are based on sinusoidal curves in the disclosed embodiments, the waves can have a variety of configurations with alternate ampli-

tudes, wavelengths, and other characteristics as required for optimal thermal energy transfer and to accommodate a designed flow of the first fluid and/or second fluid. Further, the waves of walls 12-26/112 can have other shapes, such as triangular waves with pointed peaks and troughs, rectangular waves with flat tops and bottoms, and/or other configurations.

Discussion of Possible Embodiments

[0046] The following are non-exclusive descriptions of possible embodiments of the present invention.

[0047] A heat exchanger that extends laterally in a first direction and a second direction and has a first wall, a second wall, and a third wall. The first wall is shaped in a wave pattern with waves that extend in both the first direction and the second direction. The second wall is adjacent to and in contact with the first wall with the second wall being shaped in a wave pattern with waves that extend in both the first direction and the second direction. The waves of the second wall are offset in the first direction from the waves of the first wall by one-half wavelength. The third wall is adjacent to and in contact with the second wall with the third wall being shaped in a wave pattern with waves that extend in both the first direction and the second direction. The waves of the third wall are offset in the second direction from the second wall by one-half wavelength. The heat exchanger also includes a first plurality of flow paths extending in the second direction with the first plurality of flow paths each bounded by the first wall and the second wall and a second plurality of flow paths extending in the first direction with the second plurality of flow paths each bounded by the second wall and the third wall.

[0048] The heat exchanger of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations, and/or additional components:

A fourth wall adjacent to and in contact with the third wall with the fourth wall being shaped in a wave pattern with waves that extend in both the first direction and the second direction, the waves of the fourth wall being offset from the waves of the third wall in the first direction by one-half wavelength and a third plurality of flow paths extending in the second direction with the third plurality of flow paths each bounded by the third wall and the fourth wall.

[0049] The waves of the first wall are based on a sinusoidal curve in the first direction and a sinusoidal curve in the second direction, and the waves of the second wall are based on a sinusoidal curve in the first direction and a sinusoidal curve in the second direction.

[0050] Each flow path of the first plurality of flow paths and the second plurality of flow paths have a substantially circular cross-sectional area.

[0051] The first plurality of flow paths are laterally interconnected by first transition openings and the second plurality of flow paths are laterally interconnected by sec-

ond transition openings such that flow through one flow path of the first plurality of flow paths can transition and flow through an adjacent flow path of the first plurality of flow paths and flow through one flow path of the second plurality of flow paths can transition and flow through an adjacent flow path of the second plurality of flow paths.

[0052] Each flow path of the first plurality of flow paths are fluidically isolated from one another and each flow path of the second plurality of flow paths are fluidically isolated from one another.

[0053] The first wall contacts and connects to the second wall along a plurality of contact lines extending in the second direction to form the fluidically isolated first plurality of flow paths extending in the second direction.

[0054] The second wall contacts and connects to the third wall along a plurality of contact lines extending in the first direction to form the fluidically isolated second plurality of flow paths extending in the first direction.

[0055] The first wall, second wall, and third wall are constructed by additive manufacturing so that the heat exchanger is one continuous and monolithic component.

[0056] The waves in the first direction of the first wall, the waves in the first direction of the second wall, and the waves in the first direction of the third wall have an amplitude that is greater than an amplitude of the waves in the second direction of the first wall, the waves in the second direction of the second wall, and the waves in the second direction of the third wall.

[0057] The amplitude of the waves in the first direction of the first wall, second wall, and third wall is at least 1.5 times greater than the amplitude of the waves in the second direction of the first wall, second wall, and third wall.

[0058] The waves in the first direction of the first wall, the waves in the first direction of the second wall, and the waves in the first direction of the third wall have a wavelength that is greater than a wavelength of the waves in the second direction of the first wall, the waves in the second direction of the second wall, and the waves in the second direction of the third wall.

[0059] The first wall, second wall, and third wall are constructed from a material having low thermal conductivity.

[0060] A gas turbine engine comprising the heat exchanger disclosed above.

[0061] A first fluid flows through the first plurality of flow paths and a second fluid flows through the second plurality of flow paths.

[0062] A method of forming a heat exchanger includes forming a first wall with waves that extend laterally in both a first direction and in a second direction. The method also includes forming a second wall adjacent to and in contact with the first wall with waves that are based on a sinusoidal curve and extend laterally in both the first direction and in the second direction. The waves of the second wall are offset in the first direction from the waves of the first wall by one-half wavelength. The method also includes forming a third wall adjacent to and in contact with the second wall with waves that extend laterally in

both the first direction and in the second direction. The waves of the third wall are offset in the second direction from the waves of the second wall by one-half wavelength. The first wall and the second wall bound a first plurality of flow paths that extend in the second direction, and the second wall and the third wall bound a second plurality of flow paths that extend in the first direction. The waves of the first, second, and third walls can be based on a sinusoidal curve.

[0063] The method of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations, steps, and/or additional components:

Additively manufacturing the first wall, second wall, and third wall.

[0064] Forming a fourth wall adjacent to and in contact with the third wall with waves that extend laterally in both the first direction and in the second direction, the waves being offset in the first direction from the waves of the third wall by one-half wavelength, and wherein the third wall and fourth wall bound a third plurality of flow paths that extend in the second direction.

[0065] The waves of the first wall are based on a sinusoidal curve in the first direction and a sinusoidal curve in the second direction, and wherein the waves of the second wall are based on a sinusoidal curve in the first direction and a sinusoidal curve in the second direction.

[0066] A method of transferring thermal energy through the use of a heat exchanger includes flowing a first fluid through a first plurality of flow paths bounded by a first wall and a second wall. The first wall having a wave pattern with waves that are based on a sinusoidal curve and extend laterally in both a first direction and a second direction. The second wall is adjacent to and in contact with the first wall and having a wave pattern with waves that are based on a sinusoidal curve and extend laterally in both the first direction and the second direction. The waves of the second wall are offset in the first direction from the waves of the first wall by one-half wavelength. The method also includes flowing a second fluid through a second plurality of flow paths bounded by the second wall and a third wall. The third wall is adjacent to and in contact with the second wall. The third wall has a wave pattern with waves that are based on a sinusoidal curve and extend laterally in both the first direction and the second direction. The waves of the third wall are offset in the second direction from the waves of the second wall by one-half wavelength.

[0067] While the invention has been described with reference to an exemplary embodiment(s), it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention as defined by the claims. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the scope of the invention. Therefore, it is intended that the invention not be limited to the particular

embodiment(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

Claims

1. A heat exchanger extending laterally in a first direction and a second direction, the heat exchanger comprising:

a first wall (12) shaped in a wave pattern with waves that extend in both the first direction and the second direction;

a second wall (14) adjacent to and in contact with the first wall with the second wall being shaped in a wave pattern with waves that extend in both the first direction and the second direction, the waves of the second wall being offset in the first direction from the waves of the first wall by one-half wavelength;

a third wall (16) adjacent to and in contact with the second wall with the third wall being shaped in a wave pattern with waves that extend in both the first direction and the second direction, the waves of the third wall being offset in the second direction from the second wall by one-half wavelength;

a first plurality of flow paths (30B) extending in the second direction with the first plurality of flow paths each bounded by the first wall and the second wall; and

a second plurality of flow paths (32B) extending in the first direction with the second plurality of flow paths each bounded by the second wall and the third wall.

2. The heat exchanger of claim 1, further comprising:

a fourth wall (18) adjacent to and in contact with the third wall with the fourth wall being shaped in a wave pattern with waves that extend in both the first direction and the second direction, the waves of the fourth wall being offset from the waves of the third wall in the first direction by one-half wavelength; and

a third plurality of flow paths (34B) extending in the second direction with the third plurality of flow paths each bounded by the third wall and the fourth wall.

3. The heat exchanger of claim 1 or 2, wherein the waves of the first wall are based on a sinusoidal curve in the first direction and a sinusoidal curve in the second direction, and wherein the waves of the second wall are based on a sinusoidal curve in the first direction and a sinusoidal curve in the second direction.

4. The heat exchanger of claim 1, 2 or 3, wherein each flow path of the first plurality of flow paths and the second plurality of flow paths have a substantially circular cross-sectional area.
5. The heat exchanger of claim 4, wherein the first plurality of flow paths are laterally interconnected by first transition openings and the second plurality of flow paths are laterally interconnected by second transition openings such that flow through one flow path of the first plurality of flow paths can transition and flow through an adjacent flow path of the first plurality of flow paths and flow through one flow path of the second plurality of flow paths can transition and flow through an adjacent flow path of the second plurality of flow paths.
6. The heat exchanger of any preceding claim, wherein each flow path of the first plurality of flow paths are fluidically isolated from one another and each flow path of the second plurality of flow paths are fluidically isolated from one another, and preferably wherein the first wall contacts and connects to the second wall along a plurality of contact lines extending in the second direction to form the fluidically isolated first plurality of flow paths extending in the second direction, and/or wherein the second wall contacts and connects to the third wall along a plurality of contact lines extending in the first direction to form the fluidically isolated second plurality of flow paths extending in the first direction.
7. The heat exchanger of any preceding claim, wherein the first wall, second wall, and third wall are constructed by additive manufacturing so that the heat exchanger is one continuous and monolithic component.
8. The heat exchanger of any preceding claim, wherein the waves in the first direction of the first wall, the waves in the first direction of the second wall, and the waves in the first direction of the third wall have an amplitude that is greater than an amplitude of the waves in the second direction of the first wall, the waves in the second direction of the second wall, and the waves in the second direction of the third wall.
9. The heat exchanger of claim 8, wherein the amplitude of the waves in the first direction of the first wall, second wall, and third wall is at least 1.5 times greater than the amplitude of the waves in the second direction of the first wall, second wall, and third wall, and/or wherein the waves in the first direction of the first wall, the waves in the first direction of the second wall, and the waves in the first direction of the third wall have a wavelength that is greater than a wavelength of the waves in the second direction of the first wall, the waves in the second direction of the second wall, and the waves in the second direction of the third wall.
10. A gas turbine engine comprising the heat exchanger of any preceding claim.
11. A method of forming a heat exchanger, the method comprising:
 - forming a first wall with waves that extend laterally in both a first direction and in a second direction;
 - forming a second wall adjacent to and in contact with the first wall with waves that extend laterally in both the first direction and in the second direction, the waves of the second wall being offset in the first direction from the waves of the first wall by one-half wavelength;
 - forming a third wall adjacent to and in contact with the second wall with waves that extend laterally in both the first direction and in the second direction, the waves of the third wall being offset in the second direction from the waves of the second wall by one-half wavelength, wherein the first wall and the second wall bound a first plurality of flow paths that extend in the second direction, and wherein the second wall and the third wall bound a second plurality of flow paths that extend in the first direction.
12. The method of claim 11, further comprising: additively manufacturing the first wall, second wall, and third wall.
13. The method of claim 11 or 12, further comprising:
 - forming a fourth wall adjacent to and in contact with the third wall with waves that extend laterally in both the first direction and in the second direction, the waves being offset in the first direction from the waves of the third wall by one-half wavelength, wherein the third wall and fourth wall bound a third plurality of flow paths that extend in the second direction.
14. The method of claim 11, 12 or 13, wherein the waves of the first wall are based on a sinusoidal curve in the first direction and a sinusoidal curve in the second direction, and wherein the waves of the second wall are based on a sinusoidal curve in the first direction and a sinusoidal curve in the second direction.
15. A method of transferring thermal energy through the use of a heat exchanger, the method comprising:
 - flowing a first fluid through a first plurality of flow

paths bounded by a first wall and a second wall,
the first wall having a wave pattern with waves
that are based on a sinusoidal curve and extend
laterally in both a first direction and a second
direction, the second wall being adjacent to and 5
in contact with the first wall and having a wave
pattern with waves that are based on a sinusoi-
dal curve and extend laterally in both the first
direction and the second direction, the waves of 10
the second wall being offset in the first direction
from the waves of the first wall by one-half wave-
length;
flowing a second fluid through a second plurality
of flow paths bounded by the second wall and a 15
third wall, the third wall being adjacent to and in
contact with the second wall, the third wall hav-
ing a wave pattern with waves that are based
on a sinusoidal curve and extend laterally in both
the first direction and the second direction, the 20
waves of the third wall being offset in the second
direction from the waves of the second wall by
one-half wavelength.

25

30

35

40

45

50

55

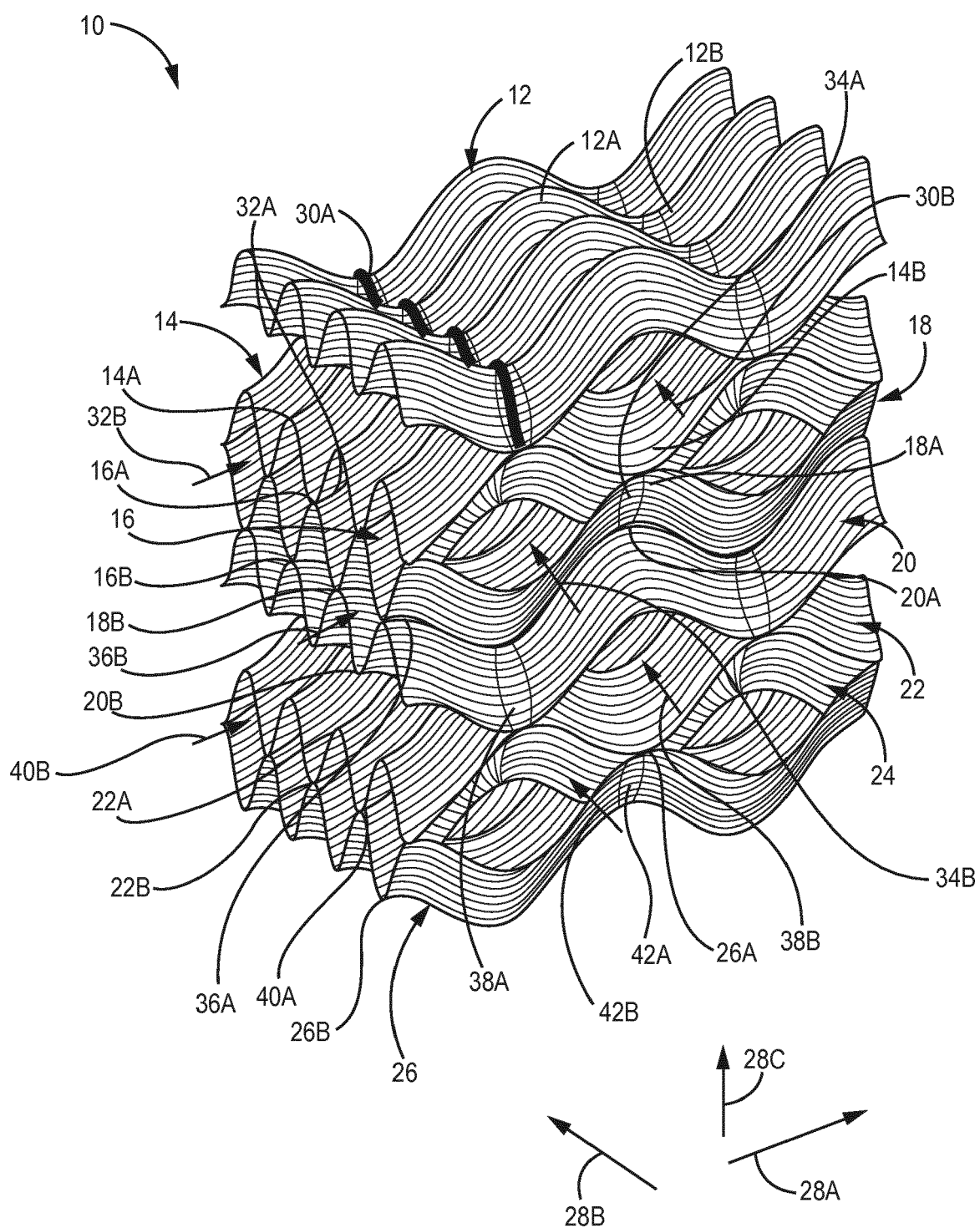


FIG. 1A

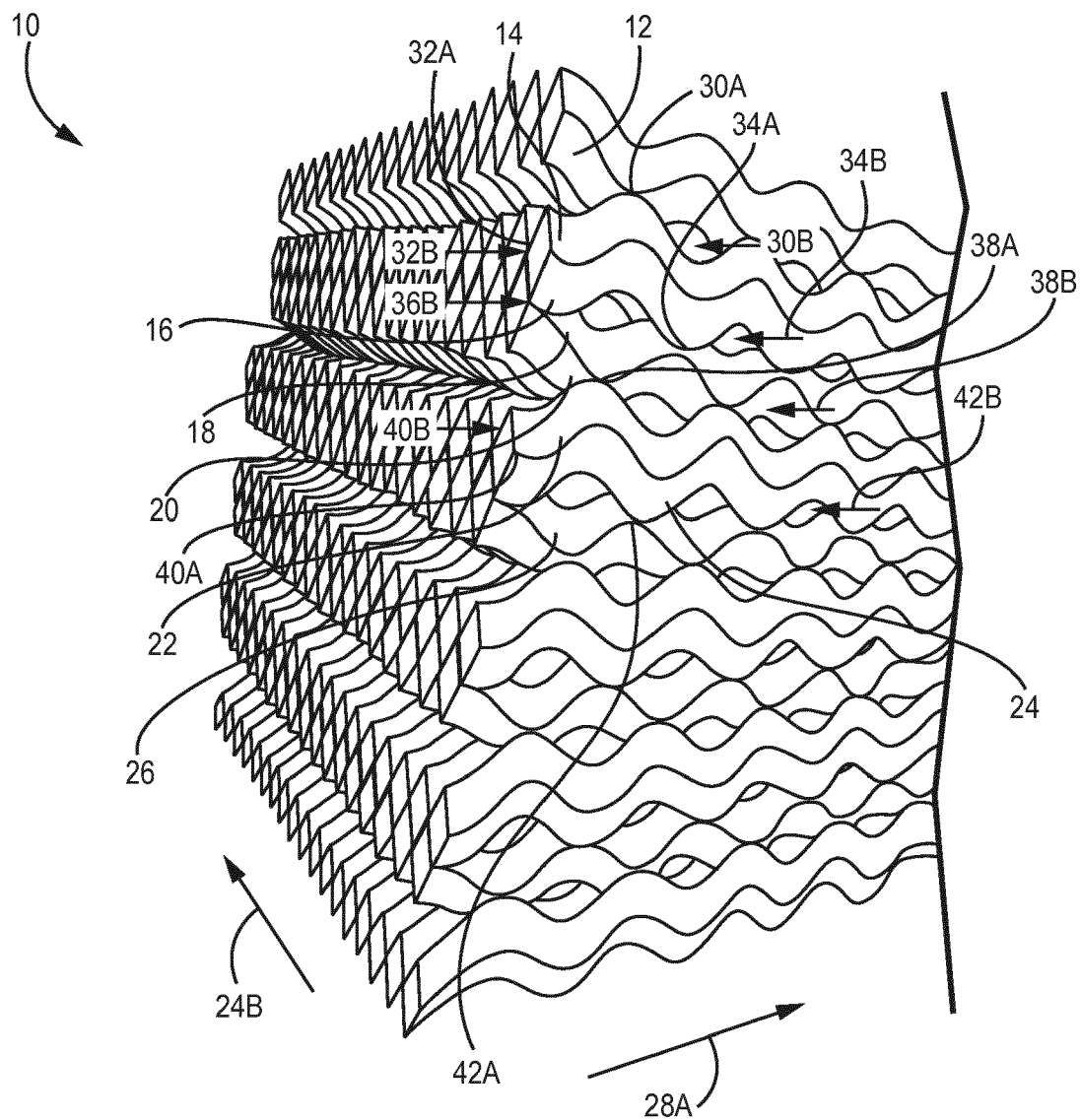


FIG. 1B

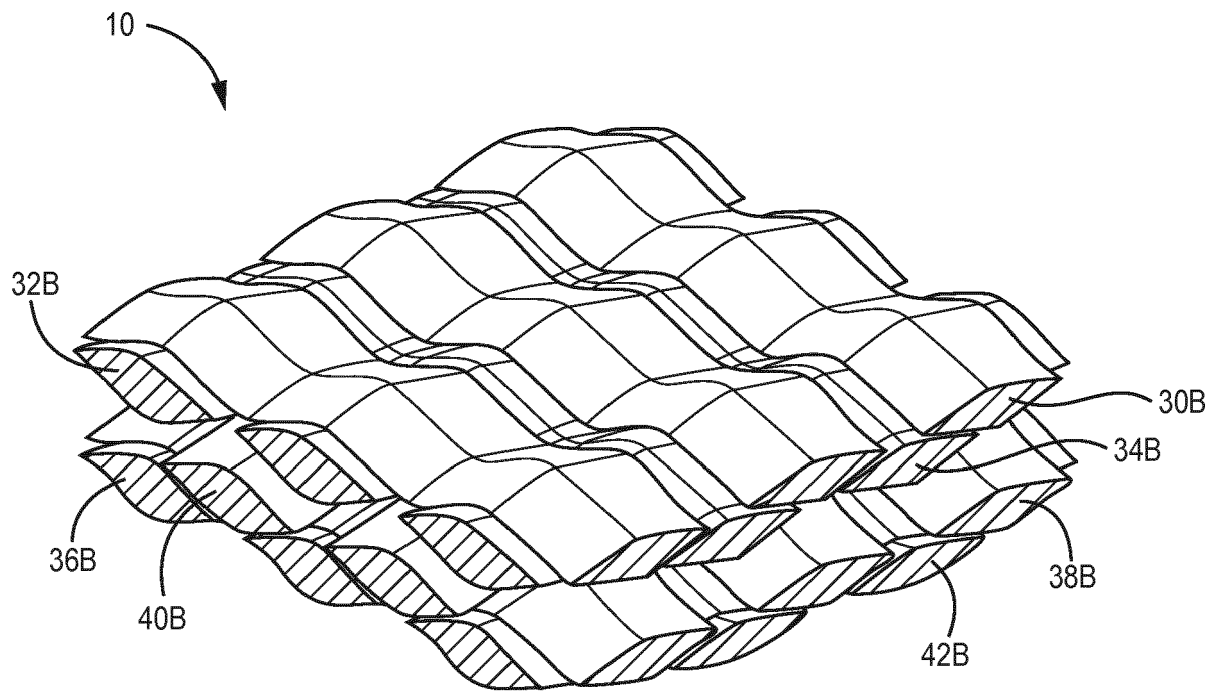


FIG. 1C

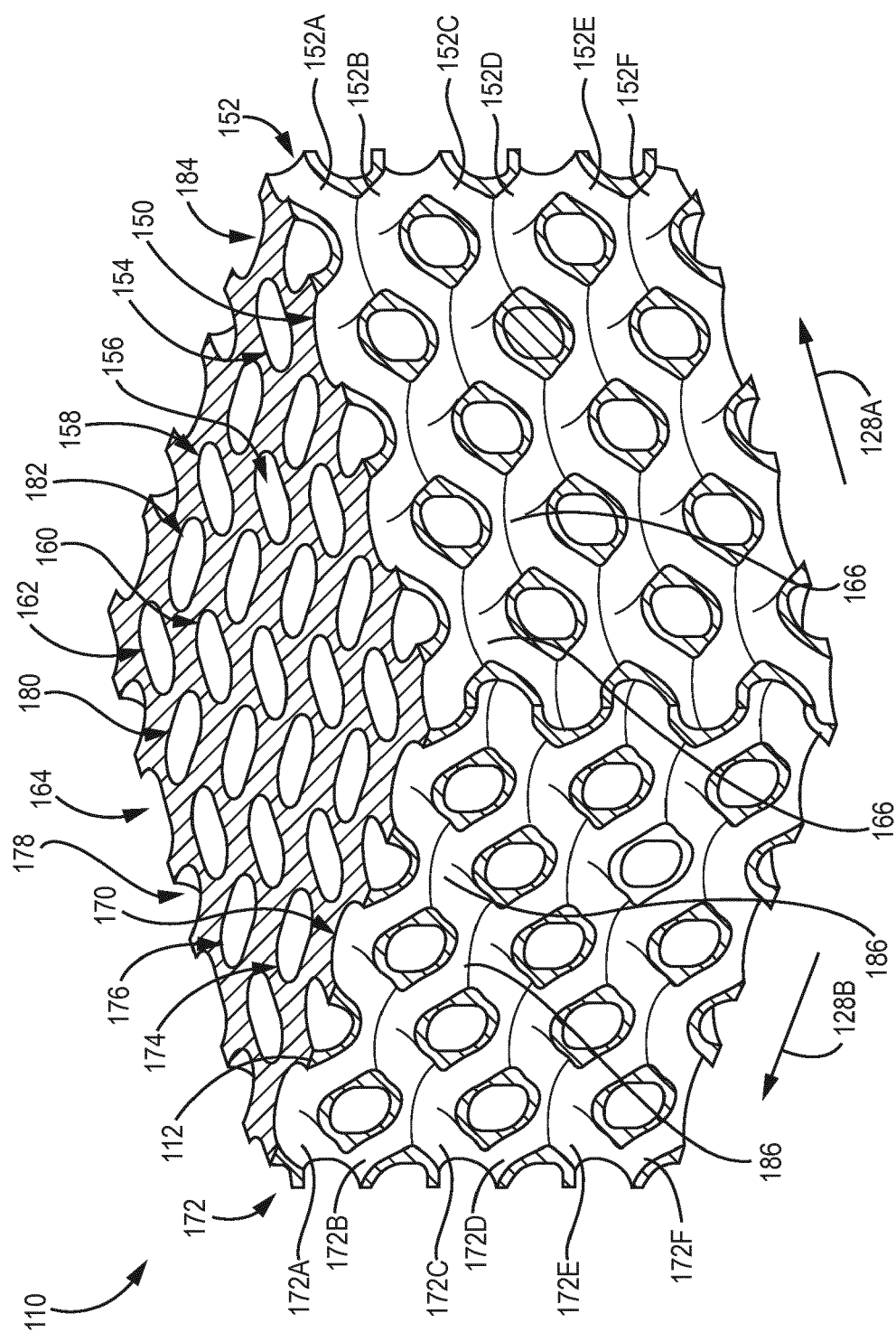


FIG. 2



EUROPEAN SEARCH REPORT

Application Number
EP 19 20 7464

5

10

15

20

25

30

35

40

45

50

55

2

EPO FORM 1503 03.82 (P04C01)

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	US 4 919 200 A (GLOMSKI STANISLAS [CA] ET AL) 24 April 1990 (1990-04-24) * figures 7-9 *	1-6,8,11,15	INV. F28D7/00 F28D9/00 F28F7/02
X	EP 2 607 831 A1 (ROLLS ROYCE PLC [GB]) 26 June 2013 (2013-06-26)	1-6,8-15	
Y	* paragraph [0029] * * paragraph [0031] * * paragraph [0036] * * paragraph [0038]; claims 2,6; figure 3a *	7	
Y	EP 3 193 125 A1 (HAMILTON SUNDSTRAND CORP [US]) 19 July 2017 (2017-07-19) * paragraph [0002] * * paragraph [0006] * * paragraph [0018] *	7	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC)
			F28D F28F
Place of search		Date of completion of the search	Examiner
Munich		6 April 2020	Bain, David
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			

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 19 20 7464

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

06-04-2020

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4919200 A	24-04-1990	EP 0423275 A1	24-04-1991
		JP H03506069 A	26-12-1991
		US 4919200 A	24-04-1990
		WO 9013783 A1	15-11-1990

EP 2607831 A1	26-06-2013	EP 2607831 A1	26-06-2013
		US 2013153184 A1	20-06-2013

EP 3193125 A1	19-07-2017	EP 3193125 A1	19-07-2017
		US 2017205146 A1	20-07-2017
