(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 722 721 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
14.10.2020 Bulletin 2020/42

(51) Int Cl.:
F28D 7/00 *(2006.01)* ***F28D 7/16*** *(2006.01)*
F28F 7/02 *(2006.01)*

(21) Application number: **19213142.3**

(22) Date of filing: **03.12.2019**

(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

(30) Priority: **08.04.2019 US 201916377803**

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

(72) Inventors:
- **RUIZ, Gabriel**
  Granby, CT Connecticut 06035 (US)
- **FENG, Feng**
  South Windsor, CT Connecticut 06076 (US)
- **BECENE, Ahmet**
  West Simsbury, CT Connecticut 06092 (US)
- **HU, Michele**
  West Hartford, Connecticut 06119 (US)
- **MAYNARD, Michael**
  Springfield, MA Massachusetts 01118 (US)
- **DOE, Michael**
  Southwick, MA Massachusetts 01077 (US)

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

(54) VARIABLE GEOMETRY HEAT EXCHANGER

(57) A heat exchanger (10) includes a core (15) having a nonrectangular cross-sectional area, a plurality of cold flow layers (18) centered about a centerline with each of the plurality of cold flow layers (34) separated by corresponding walls. The heat exchanger (10) also includes a plurality of hot flow tubes (34) corresponding to each of the plurality of cold flow layers.

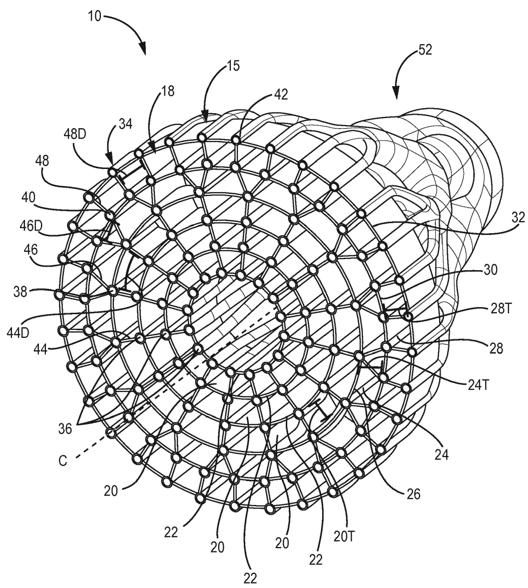

FIG. 1C

Printed by Jouve, 75001 PARIS (FR)

Description

BACKGROUND

[0001] The present disclosure relates to a heat exchanger and, more particularly, to a heat exchanger having a nonrectangular cross-sectional area.

[0002] Heat exchangers are well known in many industries for a variety of applications. When used in mobile applications, particularly for aerospace applications, it is desirable to use heat exchangers that provide a compact, low-weight, and highly-effective means of exchanging heat from a hot fluid to a cold fluid. Configurations of heat exchanger cores are generally arranged in a rectangular cross section (e.g., a square) that allows tube geometry and spacing to be kept constant across the core. While such geometries are well known, it may be desirable to find other geometries that permit even more compact, low-weight, and efficient heat transfer.

SUMMARY

[0003] A heat exchanger includes a core having nonrectangular cross-sectional area, a plurality of cold flow layers centered about a centerline with each of the plurality of cold flow layers separated by corresponding walls. The heat exchanger also includes a plurality of hot flow tubes corresponding to each of the plurality of cold flow layers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004]

FIG. 1A is a first partially perspective view of a heat exchanger.
FIG. 1B is a second partially perspective view of the heat exchanger of FIG 1A.
FIG. 1C is a cross-sectional perspective view of the heat exchanger of FIG. 1A.
FIG. 2 is a cross-sectional view of a second embodiment of the heat exchanger.
FIG. 3 is a cross-sectional view of a third embodiment of the heat exchanger.
FIGS. 4A-4D are cross-sectional views of various tube shapes of hot flow tubes within the heat exchanger.

DETAILED DESCRIPTION

[0005] A heat exchanger includes a core arranged in a nonrectangular cross-sectional shape with a plurality of cold flow layers and a plurality of hot flow tubes. The cross-sectional shape of the heat exchanger can be varied, such as a circular, hexagonal, octagonal, or oval cross-sectioanl shape. The geometries of the cold flow layers and the hot flow tubes can be varied, including differing shapes of the tubes, differing circumferential distances between the tubes, differing numbers of tubes per layer, differing heights of the layers, differing thicknesses of tube walls, and other geometries. Such configurations reduce the thermal stresses and also provide an equal flow resistance (i.e., even mass flow distribution) and pressure drop across the entire cross-sectional area of the heat exchanger, thereby ensuring the heat exchanger performs similarly across the entire cross-sectional area. Additionally, because the heat exchanger tube arrangement is substantially circular, it can accommodate high pressures of fluids flowing through the heat exchanger.

[0006] FIG. 1A is a first partially perspective view of heat exchanger 10 with outer shells 51A and 53A shown as transparent (solely for convenience of depicting the heat exchanger of FIG. 1A; a person skilled in the art will recognize that transparency is not an essential feature of the outer shell such that the outer shell need not be transparent), FIG. 1B is a second partially perspective view of heat exchanger 10 of FIG 1A with outer shells 51A and 53A shown as transparent, and FIG. 1C is a cross-sectional perspective view of heat exchanger 10 of FIG. 1A. Heat exchanger 10 extends axially along centerline C and is configured to allow thermal energy transfer between first fluid 12 and second fluid 14. Heat exchanger 10 includes core 15 having first end 16A (to which first header 50 with first outer shell 51A and first hot flow route 51B is attached) and second end 16B (to which second header 52 with second outer shell 53A and second hot flow route 53B is attached). Heat exchanger 10 also includes plurality of cold flow layers 18 and plurality of hot flow tubes 34. Plurality of cold flow layers 18 includes first cold flow layer 20 (shown in FIG. 1C as three similarly configured layers 20) having first radial height 20T, first annular wall 22, second cold flow layer 24 having second radial height 24T, second annular wall 26, third cold flow layer 28 having third radial height 28T, third annular wall 30, and fourth annular wall 32. Plurality of hot flow tubes 34 includes first set of hot flow tubes 36, second set of hot flow tubes 38, third set of hot flow tubes 40, and fourth set of hot flow tubes 42. Heat exchanger 10 also includes first plurality of radial walls 44 having first circumferential distance 44D, second plurality of radial walls 46 having second circumferential distance 46D, and third plurality of radial walls 48 having third circumferential distance 48D. First header 50 is connected to first duct 54, and second header 52 is connected to second duct 56. While heat exchanger 10 is shown having core 15 that is circular, other configurations of heat exchanger 10 can include other cross-sectional shapes, such as a hexagonal shape, an octagonal shape, and/or an oval shape (e.g., an ellipse).

[0007] Heat exchanger 10 is configured to allow the transfer of thermal energy between first fluid 12 and second fluid 14 as is necessary if first fluid 12 and/or second fluid 14 are used for cooling and/or lubrication of components in a larger system, such as a gas turbine engine or aerospace system. First fluid 12 and second fluid 14 can be any type of fluid, including air, water, lubricant, fuel, or another fluid. Heat exchanger 10 is described herein as providing thermal energy transfer from first fluid 12 to second fluid 14; thus, first fluid 12 is at a greater temperature than second fluid 14 at the point where both fluids enter heat exchanger 10 (i.e., first fluid 12 is a "hot" fluid and second fluid is a "cold" fluid). However, other configurations of heat exchanger 10 can have second fluid 14 being at a greater temperature than first fluid 12 (and thus second fluid 14 would be the "hot" fluid and first fluid 12 would be the "cold" fluid). Thus, when describing heat exchanger 10 has having "hot" flow tubes and "cold" flow layers, first fluid 12 flows through any flow space designated as a "hot" flow space and second fluid 14 flows through any flow space designated as a "cold" flow space even if first fluid 12 is at a lesser temperature than second fluid 14.

[0008] As seen most easily in FIG. 1C, core 15 of heat exchanger 10 has a substantially circular cross-sectional area (with first header 50 and second header 52 connected to the substantially circular cross-sectional core 15). While shown as having fourth annular wall 32 with a curved/arced profile, fourth annular wall 32 can also extend straight between each flow tube of the fourth set of hot flow tubes 42 such that the fourth annular wall 32 (and the outer profile of heat exchanger 10) is polygonal in shape but still substantially circular. Additionally, heat exchanger 10 can have other shapes and configurations not expressly disclosed but still within the scope of this disclosure. Core 15 of heat exchanger 10 is shown in FIG. 1A as extending laterally a distance that is less than a length of first header 50 and second header 52, but core 15 can extend laterally any length/distance necessary to allow for sufficient thermal energy transfer between first fluid 12 and second fluid 14. Core 15 is shown as having a center that does not include plurality of cold flow layers 18 or plurality of hot flow tubes 34 (although heat exchanger 10 can be configured such that second fluid 14 flows through the center), but core 15 can have other configurations in which the center includes one or multiple layers and/or tubes.

[0009] Attached to first end 16A of core 15 is first header 50, which includes first outer shell 51A configured to contain the flow of second fluid 14 exiting plurality of cold flow layers 18 and first hot flow route 51B configured to transition the flow of first fluid 12 from first duct 54 to plurality of hot flow tubes 34. Similar in configuration to first header 50 is second header 52, which is attached to second end 16B of core 15 and includes second outer shell 53A configured to guide second fluid 14 into plurality of cold flow layers 18 and second hot flow routes 53B configured to transition the flow of first fluid 12 from plurality of hot flow tubes 34 to second duct 56. As shown, first header 50 and second header 52 have similar configurations except that first fluid 12 flows into heat exchanger 10 from first header 50 and out of heat exchanger 10 into second header 52, and second fluid 14 flows into heat exchanger 10 from second header 52 and out of heat exchanger 10 into first header 50. First header 50 and second header 52 can have any configuration that transitions flow of first fluid 12 and second fluid 14 into and out of heat exchanger 10.

[0010] As shown in FIGS. 1A and 1B, first outer shell 51A and second outer shell 53A are cylindrical in shape and have a cross-sectional shape that is similar to the cross-sectional shape of core 15. First outer shell 51A and second outer shell 53A provide an outer boundary to a cold flow path through first header 50 and second header 52, respectively, and guide second fluid 14 into and out of plurality of cold flow layers 18. Second fluid 14 flows around the subflows of hot flow routes 51B and 53B to enter and exit plurality of cold flow layers 18, and the cold flow paths of second fluid 14 through first header 50 and second header 52 can be guided by other features in addition to first outer shell 51A and second outer shell 53A, such as walls, fins, or other features. While not shown, first outer shell 51A and second outer shell 53A can be connected to cold flow ducts, respectively.

[0011] First hot flow route 51B (which is radially inward from first outer shell 51A) splits the flow from first duct 54 into four subflows, which then each split the subflow into four sub-subflows. Then, the sub-subflows split to connect to individual tubes of plurality of hot flow tubes 34 (or, if the number of tubes in plurality of hot flow tubes 34 is extensive, the sub-subflows can split into sub-sub-subflows and so on). While first hot flow route 51B is shown as splitting into four subflows and then into four sub-subflows, the number of branches at each split can vary, including more or less than four. Secondhot flow route 53B of second header 52 can have a similar configuration (except in an opposite direction such that the sub-subflows converge to form subflows, which in turn converge to form the singular flow into second duct 56) or another configuration for transitioning the flow of first fluid 12 from plurality of hot flow tubes 34 into second duct 56. First header 50 and second header 52 can have other configurations for transitioning first flow 12 and second flow 14 into and out of heat exchanger 10.

[0012] Plurality of cold flow layers 18 of heat exchanger 10 form concentric/coaxial annular rings centered about centerline C and are flow paths for second fluid 14 to flow through heat exchanger 10. Plurality of cold flow layers 18 provide a cross-sectional area/path through which second fluid 14 can flow through core 15 and accept (or convey) thermal energy from first fluid 12 flowing through plurality of flow tubes 34 (which are adjacent to plurality of cold flow layers 18). While plurality of cold flow layers 18 are shown as having five different layers in FIGS. 1A-1C, plurality of cold low layers 18 can have less than or more than five layers depending on the thermal energy transfer needs and any size constraints/requirements of heat exchanger 10. Three configurations of layers are described below with regards to plurality of cold flow layers 18: first cold flow layer 20, which actually designates the radially inner three layers because each has a similar configuration as one another; second cold flow layer 24, which is radially outward from the radially outermost first cold flow layer 20; and third cold flow layer 28, which is the radially outermost layer of plurality of cold flow layers 18.

[0013] First cold flow layer 20 is annular in shape centered about centerline C and is bounded by first annular wall 22 on a radially inner side and second annular wall 26 on a radially outer side. First cold flow layer 20 provides a flow area/path through which a portion of second fluid 14 flows to accept (or convey) thermal energy from first fluid 12 flowing through a number of plurality of hot flow tubes 34 adjacent first cold flow layer 20. First cold flow layer 20 has first radial height 20T, which can be the same as second radial height 24T of second cold flow layer 24 and third radial height 28T of third cold flow layer 28 (as shown in FIGS. 1A-1C), or heights 20T-28T can be different. For example, to maintain an equal cross-sectional flow area for each cold flow layer, first radial height 20T can be greater than second radial height 24T, and second radial height 24T can be greater than third radial height 28T. First cold flow layer 20 can be continuous in a circumferential direction with no boundaries (i.e., first plurality of radial walls 44 are not present) or, as shown in FIGS. 1A-1C, can be separated into circumferential segments/zones by first plurality of radial walls 44.

[0014] First plurality of radial walls 44 extend radially across first cold flow layer 20 between first annular wall 22 and second annular wall 26. First plurality of radial walls 44 divide first cold flow layer 20 into circumferential segments extending for first circumferential distance 44D. Each wall of first plurality of radial walls 44 is equidistant from adjacent walls (i.e., first circumferential distance 44D between adjacent walls is the same). However, other configurations of heat exchanger 10 can includes first plurality of radial walls 44 that are varying distances from adjacent walls, or heat exchanger 10 can include a configuration in which first cold flow layer 20 does not include any radial walls. Additionally, first set of hot flow tubes 36 are partially incorporated into first plurality of radial walls 44 (with first set of hot flow tubes 36 being at an intersection between first annular wall 22 and first plurality of radial walls 44), and second set of hot flow tubes 38 are partially incorporated into first plurality of radial walls 44 (with second set of hot flow tubes 38 being at an intersection between second annular wall 26, first plurality of radial walls 44, and second plurality of radial walls 46).

[0015] Second cold flow layer 24 is annular in shape centered about centerline C and is bounded by second annular wall 26 on a radially inner side and third annular wall 30 on a radially outer side. Second cold flow layer 24 is radially outward from first cold flow layer 20. Second cold flow layer 24 provides a flow area/path through which a portion of second fluid 14 flows to accept (or convey) thermal energy from first fluid 12 flowing through a number of plurality of hot flow tubes 34 adjacent second cold flow layer 24. Second cold flow layer 24 has second radial height 24T, which can be the same as first radial height 20T of first cold flow layer 20 and third radial height 28T of third cold flow layer 28 (as shown in FIGS. 1A-1C), or heights 20T-28T can be different. For example, to maintain an equal cross-sectional flow area for each cold flow layer, second radial height 24T can be greater than third radial height 28T but less than first radial height 20T. Similar to first cold flow layer 20, second cold flow layer 24 can be continuous in a circumferential direction with no boundaries (i.e., second plurality of radial walls 46 are not present) or, as shown in FIGS. 1A-1C, can be separated into circumferential segments/zones by second plurality of radial walls 46.

[0016] Second plurality of radial walls 46 extend partially radially and partially circumferentially (i.e., angled) across second cold flow layer 24 between second annular wall 26 and third annular wall 30. Second plurality of radial walls 46 divide second cold flow layer 24 into circumferential segments extending for second circumferential distance 46D on a radial outermost end. The circumferential segments of second cold flow layer 24 can have any shape, including alternating triangular and rectangular shaped flow areas. Second circumferential distance 46D can be equal at the radially outermost end between each wall of second plurality of radial walls 46. Second plurality of radial walls 46 alternate in a direction of angle to form segments of second cold flow layer 24 that alternate between triangles and rectangles. Other configurations of heat exchanger 10 can includes second plurality of radial walls 46 that are varying distances from adjacent walls, or heat exchanger 10 can include a configuration in which second cold flow layer 24 does not include any radial walls. Additionally, second set of hot flow tubes 38 are partially incorporated into second plurality of radial walls 46 (with second set of hot flow tubes 38 being at an intersection between second annular wall 26, first plurality of radial walls 44, and second plurality of radial walls 46), and third set of hot flow tubes 40 are partially incorporated into second plurality of radial walls 46 (with third set of hot flow tubes 40 being at an intersection between third annular wall 30, second plurality of radial walls 46, and third plurality of radial walls 48). First plurality of radial walls 44, second plurality of radial walls 46, and third plurality of radial walls 48 can be radially aligned or have other configurations/orientations, such as second plurality of radial walls 46 being branched/angled outward.

[0017] Third cold flow layer 28 is annular in shape centered about centerline C and is bounded by third annular wall 30 on a radially inner side and fourth annular wall 32 on a radially outer side. The disclosed heat exchanger 10 is configured such that fourth annular wall 32 forms the outermost boundary of core 15. However, other configurations can include one or multiple additional layers radially outward from third cold flow layer 28 that are bounded by additional annular walls. These layers can have similar or different configurations to plurality of cold flow layers 18. Third cold flow layer 28 provides a flow area/path through which a portion of second fluid 14 flows to accept (or convey) thermal energy from first fluid 12 flowing through a number of plurality of hot flow tubes 34 adjacent third cold flow layer 28. Third cold flow layer 28 has third radial height 28T, which can be the same as first radial height 20T of first cold flow layer 20 and second radial height 24T of second cold flow layer 24 (as shown in FIGS. 1A-1C), or heights 20T-28T can be different. For example, to maintain an equal cross-sectional flow area for each cold flow layer, third radial height 28T can be less than second radial height 24T, which in turn can be less than first radial height 20T. Similar to first cold flow layer 20 and second cold flow layer 24, third cold flow layer 28 can be continuous in a circumferential direction with no boundaries (i.e., third plurality of radial walls 48 are not present) or, as shown in FIGS. 1A-1C, can be separated into circumferential segments/zones by third plurality of radial walls 48.

[0018] Third plurality of radial walls 48 extend radially across third cold flow layer 28 between third annular wall 30 and fourth annular wall 32. Third plurality of radial walls 48 divide third cold flow layer 28 into circumferential segments extending for third circumferential distance 48D. Each wall of third plurality of radial walls 48 is equidistant from adjacent walls (i.e., third circumferential distance 48D between adjacent walls is the same). However, other configurations of heat exchanger 10 can includes third plurality of radial walls 48 that are varying distances from adjacent walls, or heat exchanger 10 can include a configuration in which third cold flow layer 28 does not include any radial walls. Additionally, third set of hot flow tubes 40 are partially incorporated into third plurality of radial walls 48 (with third set of hot flow tubes 40 being at an intersection between third annular wall 30, second plurality of radial walls 46, and third plurality of radial walls 48), and fourth set of hot flow tubes 42 are partially incorporated into third plurality of radial walls 48 (with fourth set of hot flow tubes 42 being at an intersection between fourth annular wall 32 and third plurality of radial walls 48).

[0019] Plurality of hot flow tubes 34 of heat exchanger 10 extend parallel to centerline C. Plurality of hot flow tubes 34 are located so as to extend adjacent to and/or through plurality of cold flow layers 18, and plurality of hot flow tubes 34 are flow paths for first fluid 12 to flow through core 15. Plurality of hot flow tubes 34 provide a cross-sectional area/path through which first fluid 12 can flow through heat exchanger 10 and convey (or accept) thermal energy from second fluid 14 flowing through plurality of cold flow layers 18 (which are adjacent to and in contact with plurality of hot flow tubes 34). Plurality of hot flow tubes 34 are shown in FIGS. 1A- 1C as each having a circular cross-sectional areas/shapes that are equal to other hot flow tubes, but plurality of hot flow tubes 34 can have a variety of different shapes and/or cross-sectional areas.

[0020] Differently shaped exemplary tubes 34A-34D are shown in FIGS. 4A-4D. Tube 34A of FIG. 4A has a circular cross-sectional shape, which is also shown as the cross-sectional shape of each tube of plurality of tubes 34 in heat exchanger 10. Tube 34B of FIG. 4B has an elliptical cross-sectional shape that has a greater cross-sectional area (i.e., flow area) than tube 34A. Tube 34C of FIG. 4C has a polygonal cross-sectional shape that has a greater cross-sectional area (i.e., flow area) than tube 34A. While shown as a hexagon, tube 34C can be a polygon with any number of sides and/or configurations, including less than six sides (such as a triangle or rectangle) or more than six sides. Tube 34D of FIG. 4D has a tear-drop cross-sectional shape that has smaller cross-sectional area (i.e., flow area) than tube 34A. While tube 34D is approximately pear shaped with a smaller cross-sectional portion above a larger cross-sectional portion, tube 34D can have other configurations and/or orientations. Tubes 34A-34D of FIGS. 4A-4D are provided for exemplary purposes only, and each tube of plurality of tubes 34 can have other shapes, configurations, and orientations not expressly disclosed.

[0021] Plurality of hot tubes 34 are arranged in circumferentially extending sets (as described below) with tubes in each set being equidistant from centerline C. However, other configurations of heat exchanger 10 can have tubes within a set that are different distances from centerline C (e.g., some tubes are incorporated into corresponding annular walls and some tubes extend through corresponding cold flow layers without being in contact with annular walls). Further, plurality of tubes 34 can be arranged in radial rows so that, for example, tubes in first set of hot flow tubes 36 are radially inward from tubes in second set of hot flow tubes 38 (and thus first set of hot flow tubes 36 are equal in number to second set of hot flow tubes 38). However, tubes in some or all sets of plurality of tubes 34 can be circumferentially offset from adjacent sets of plurality of hot flow tubes 34 so that, for example, tubes in third set of hot flow tubes 40 are circumferentially offset from tubes in second set of hot flow tubes 38. The sets of hot flow tubes that include tubes that are circumferentially offset from tubes in an adjacent set of hot flow tubes can have a greater number of tubes, an equal number of tubes, or a smaller number of tubes. As shown in FIGS. 1A-1C, the tubes in third set of hot flow tubes 40 have a greater number than the tubes in second set of hot flow tubes 38. Plurality of tubes 34 can be arranged to each be at an intersection of annular walls 22-32 and radial walls 44-48 or have another configuration and/or location.

[0022] Heat exchanger 10 can have any number of tubes of plurality of hot flow tubes 34 (and each set can have any number of tubes) as is necessary to provide sufficient thermal energy transfer between first fluid 12 and second fluid 14 while also reducing thermal stresses and providing for an equal flow resistance (i.e., even mass flow distribution) and pressure drop across the entire cross-sectional area of core 15. While plurality of hot flow tubes 34 are shown as having six different circumferentially extending sets in FIGS. 1A-1C, plurality of hot flow tubes 34 can have less than or more than six sets depending on the thermal energy transfer needs and any size and/or flow constraints/requirements of heat exchanger 10. Four sets of hot flow tubes are described below with regards to plurality of hot flow tubes 34: first set of hot flow tubes 36, which actually designates the radially inner three sets because each has a similar configuration as one another; second set of hot flow tubes 38, which is radially outward from the radially outermost first set of hot flow tubes 36; third set of hot flow tubes 40, which is radially outward from second set of hot flow tubes 38; and fourth set of hot flow tubes 42, which is the radially outermost set of plurality of hot flow tubes 34.

[0023] First set of hot flow tubes 36 is radially inward from first cold flow layer 20 and provides a number of flow areas/paths through which a portion of first fluid 12 flows to convey (or accept) thermal energy from second fluid 14 flowing through adjacent plurality of cold flow layers 18. As shown in heat exchanger 10, each hot flow tube of first set of hot flow tubes 36 is incorporated into first annular wall 22. First set of hot flow tubes 36 designates the three radially innermost circumferential rings of hot flow tubes because those three are similar in configuration and number to one another except that first circumferential distance 44D is different from one another. Adjacent tubes in first set of hot flow tubes 36 are circumferentially equally spaced from one another, and first set of hot flow tubes 36 includes sixteen individual flow tubes. However, other configurations of heat exchanger 10 can include tubes in first set of hot flow tubes 36 that are not circumferentially equally spaced from adjacent tubes and/or include more or less individual flow tubes within first set of hot flow tubes 36. While first set of hot flow tubes 36 are shown as being incorporated into first annular wall 22 and first plurality of radial walls 44, first set of hot flow tubes 36 can be at other locations, such as a location that is within one plurality of cold flow layers 18 (as is shown in the embodiment in FIG. 2) or only incorporated into first annular wall 22 or first plurality of radial walls 44. Additionally, hot flow tubes of first set of hot flow tubes 36 can have different circumferential and/or radial locations than adjacent hot flow tubes.

[0024] Second set of hot flow tubes 38 is radially outward from first set of hot flow tubes 36 and are between first cold flow layer 20 and second cold flow layer 24. In heat exchanger 10, second set of hot flow tubes 38 are incorporated into second annular wall 26. Second set of hot flow tubes 38 provide a number of flow areas/paths through which a portion of first fluid 12 flows to convey (or accept) thermal energy from second fluid 14 flowing through first cold flow layer 20 and second cold flow layer 24. Second set of hot flow tubes 38 can have the same number of hot flow tubes as first set of hot flow tubes 36 with those tubes being equidistant from adjacent tubes, but if second set of hot flow tubes 38 does have the same number of hot flow tubes as first set of hot flow tubes 36, second circumferential distance 46D is greater than first circumferential distance 44D. Adjacent tubes in second set of hot flow tubes 38 in heat exchanger 10 are circumferentially equally spaced from one another, and second set of hot flow tubes 38 includes sixteen individual flow tubes. However, other configurations of heat exchanger 10 can include tubes of second set of hot flow tubes 38 that are not circumferentially equally spaced from adjacent tubes, and/or second set of hot flow tubes 38 can include more or less individual flow tubes. While second set of hot flow tubes 38 are shown as being incorporated into second annular wall 26 and second plurality of radial walls 46, second set of hot flow tubes 38 can be at other locations, such as a location that is within one plurality of cold flow layers 18 (as is shown in the embodiment in FIG. 2) or only incorporated into second annular wall 26 or second plurality of radial walls 46. Additionally, hot flow tubes of second set of hot flow tubes 38 can have different circumferential and/or radial locations than adjacent hot flow tubes.

[0025] Third set of hot flow tubes 40 is radially outward from second set of hot flow tubes 38 and is between second cold flow layer 24 and third cold flow layer 28. In heat exchanger 10, third set of hot flow tubes 40 are incorporated into third annular wall 30. Third set of hot flow tubes 40 provide a number of flow areas/paths through which a portion of first fluid 12 flows to convey (or accept) thermal energy from second fluid 14 flowing through second cold flow layer 24 and third cold flow layer 28. Third set of hot flow tubes 40 can have the same number of hot flow tubes as second set of hot flow tubes 38 with those tubes being equidistant from adjacent tubes or, as shown in heat exchanger 10, can have a greater number of hot flow tubes than second set of hot flow tubes 38. In heat exchanger 10, third set of hot flow tubes 40 has thirty-two hot flow tubes. With third set of hot flow tubes 40 having a greater number of tubes than second set of hot flow tubes 38, third circumferential distance 48D is less than second circumferential distance 46D. Additionally, because third plurality of radial walls 48 extend between radially adjacent hot flow tubes, third plurality of radial walls 48 do not extend entirely in a radial direction and extend partially in the circumferential direction as well. Third set of hot flow tubes 40 can include other configurations that include an equal number of hot flow tubes as second set of hot flow tubes 38 (as is shown in FIGS. 2 and 3). Adjacent tubes in third set of hot flow tubes 40 are circumferentially equally spaced from one another. However, other configurations of heat exchanger 10 can include third set of hot flow tubes 40 that are not circumferentially equally spaced from one another, and/or third set of hot flow tubes 40 can include more or less individual flow tubes. While third set of hot flow tubes 40 are shown as being incorporated into third annular wall 30 and third plurality of radial walls 48, third set of hot flow tubes 40 can be at other locations, such as a location that is within one plurality of cold flow layers 18 (as is shown in the embodiment in FIG. 2) or only incorporated into third annular wall 30 or third plurality of radial walls 48. Additionally, hot flow tubes of third set of hot flow tubes 40 can have different circumferential and/or radial locations than adjacent hot flow tubes.

[0026] Fourth set of hot flow tubes 42 is radially outward from third set of hot flow tubes 40, radially outward from third cold flow layer 28, and is the radially outermost set of hot flow tubes. In heat exchanger 10, fourth set of hot flow tubes 42 are incorporated into fourth annular wall 32. Fourth set of hot flow tubes 42 provide a number of flow areas/paths through which a portion of first fluid 12 flows to convey (or accept) thermal energy from second fluid 14 flowing through third cold flow layer 28. Fourth set of hot flow tubes 42 can have the same number of hot flow tubes as second set of hot flow tubes 38 and/or third set of hot flow tubes 40. As shown in heat exchanger 10, fourth set of hot flow tubes 42 has an equal number of hot flow tubes as third set of hot flow tubes 40, which has thirty-two hot flow tubes. A distance between each tube of fourth set of hot flow tubes 42 is greater than third circumferential distance 48D. Fourth set of hot flow tubes 42 can include other configurations that include an equal number of hot flow tubes as second set of hot flow tubes 38 (as is shown in FIGS. 2 and 3). Adjacent tubes in fourth set of hot flow tubes 42 are circumferentially equally spaced from one another. However, other configurations of heat exchanger 10 can include adjacent tubes of fourth set of hot flow tubes 42 that are not circumferentially equally spaced from one another, and/or fourth set of hot flow tubes 42 can include more or less individual flow tubes. While fourth set of hot flow tubes 42 are shown as being incorporated into fourth annular wall 30 and third plurality of radial walls 48, fourth set of hot flow tubes 42 can be at other locations or, as shown in FIG. 2, heat exchanger 10 can be configured such that it does not include a fourth set of hot flow tubes 42. Additionally, hot flow tubes of fourth set of hot flow tubes 42 can have different circumferential and/or radial locations than adjacent hot flow tubes.

[0027] Heat exchanger 10 in FIGS. 1A-1C provides core 15 with multiple cold flow paths through plurality of cold flow layers 18 and multiple hot flow paths through plurality of hot flow tubes 34. The configuration of plurality of cold flow layers 18 and plurality of hot flow tubes 34 reduces thermal stresses and provides an equal flow resistance (and pressure drop) across the entire circular cross-sectional area of heat exchanger 10, which ensures heat exchanger 10 performs similarly across the entire cross-sectional area. With many of the components of heat exchanger 10 being formed from circles, heat exchanger 10 can accommodate high pressure of first fluid 12 and second fluid 14. The configuration of heat exchanger 10 provides a checkerboard-type core 15 that efficiently transfers thermal energy between first fluid 12 and second fluid 14 while also accommodating a circular cross-sectional shape that is able to be located in areas that conventional rectangular heat exchangers cannot fit.

[0028] FIG. 2 is a cross-sectional view of a second embodiment of the heat exchanger. Heat exchanger 110 is centered about and extends along centerline C (extending into and out of the page in FIG. 2). Heat exchanger 110 can include all of the components of heat exchanger 10 in FIGS. 1A-1C (including a first header, second header, first duct, and second duct) and is different than heat exchanger 10 in that core 115 of heat exchanger 110 includes a different configuration of plurality of cold flow layers 118 and plurality of hot flow layers 134. These differences will be described below. If a component of heat exchanger 110 is not described, then that component is similar to the component in heat exchanger 10.

[0029] Core 115 has a substantially circular cross-sectional area within which plurality of annular flow layers 118 and plurality of hot flow tubes 134 extend to convey and allow thermal energy transfer between first fluid 12 and second fluid 14 (shown in FIGS. 1A-1C) flowing in opposite directions through plurality of hot flow tubes 134 and plurality of annular flow layers 118, respectively. Similar to core 15, core 115 is shown as having a center that does not include plurality of cold flow layers 118 or plurality of hot flow tubes 134 (although heat exchanger 110 can be configured such that second fluid 14 flows through the center), but core 115 can have other configurations in which the center includes one or multiple layers and/or tubes.

[0030] Plurality of cold flow layers 118 are similar to plurality of cold flow layers 18 in heat exchanger 10. Plurality of cold flow layers 118 form concentric/coaxial annular rings centered about centerline C and are flow paths for second fluid 14 to flow through heat exchanger 110. Plurality of cold flow layers 118 provide a cross-sectional area/path through which second fluid 14 can flow through core 115 and accept (or convey) thermal energy from first fluid 12 flowing through plurality of flow tubes 134. While plurality of cold flow layers 118 are shown as having three different layers in FIG. 2, plurality of cold low layers 118 can have less than or more than three layers depending on the thermal energy transfer needs and any size constraints/requirements of heat exchanger 110. Three configurations of layers are described below with regards to plurality of cold flow layers 118: first cold flow layer 120, which is on a radially inner side of core 115; second cold flow layer 124, which is radially outward from first cold flow layer 120; and third cold flow layer 128, which is the radially outermost layer of plurality of cold flow layers 118.

[0031] Plurality of cold flow layers 118 can have the same configurations and functionality as plurality of cold flow layers 18 of heat exchanger 10. However, as shown in FIG. 2, plurality of cold flow layers 118 have varying heights such that each segment of each cold flow layer has an approximately equal cross-sectional area (with each cold flow layer being divided into segments by plurality of radial walls 144-148 similar to the configuration in heat exchanger 10). First cold flow layer 120 includes first radial height 120T that is greater than second radial height 124T of second cold flow layer 124, which in turn is greater than third radial height 128T of third cold flow layer 128. First cold flow layer 120 is divided into segments by first plurality of radial walls 144, second cold flow layer 124 is divided into segments by second plurality or radial walls 146, and third cold flow layer 128 is divided into segments by third plurality of radial walls 148. Radial walls 144-148 can be radially aligned so that each segment of plurality of cold flow layers 118 extend an equal circumferential angle as measured in degrees or radians. However, because second cold flow layer 124 is radially outward from first cold flow layer 120, and third cold flow layer 128 is radially outward from second cold flow layer 124, the circumferential distance (third circumferential distance 48D) as measured in units of length (e.g., centimeters) of each segment of third cold flow layer 128 is greater than second circumferential distance 46D of second cold flow layer 124, which in turn is greater than first circumferential distance 44D of first cold flow layer 120. Thus, for each segment of plurality of cold flow layers 118 to have approximately equal cross-sectional flow areas, first radial height 120T is greater than second radial height 124T which is greater than third radial height 128T. Heights 120T, 124T, and 128T depend on circumferential distances 144D, 146D, and 148D, respectively. Other configurations of plurality of cold flow layers 118 can have layers with different heights, different circumferential distances between radial walls, different numbers of layers, and/or different shapes of layers.

[0032] Plurality of hot flow tubes 134 have the same functionality as plurality of hot flow tubes 34 of heat exchanger 10. However, plurality of hot flow tubes 134 are not located at the intersection of the annular walls and the radial walls as is the case in heat exchanger 10. Rather, plurality of hot flow tubes 134 are located within and extend through plurality of cold flow layers 118. Plurality of hot flow tubes 134 are shown in FIG. 2 as being equidistant from centerline C, but other configurations of heat exchanger 110 can have tubes within a set (i.e., first set of hot flow tubes 136, second set of hot flow tubes 138, and third set of hot flow tubes 140) that are different distances from centerline C. Plurality of hot flow tubes 134 are arranged in radial rows with each set of hot flow tubes having an equal number of tubes as other sets of hot flow tubes 136-140, but other configurations can include tubes that are circumferentially offset from radially adjacent tubes (i.e., tubes in other sets) and/or include sets of hot flow tubes 136-140 that have a different number of tubes than adjacent sets. While each tube of plurality of hot flow tubes 134 are shown as having a circular cross-sectional shape that is equal in size to other hot flow tubes, hot flow tubes can have a variety of sizes, shapes, and/or configurations.

[0033] First set of hot flow tubes 136 are located within first cold flow layer 120 with each hot flow tube being equally spaced from adjacent hot flow tubes. As shown in FIG. 2, first set of hot flow tubes 136 are radially centered between first annular wall 122 and second annular wall 126 (i.e., are half a distance of first radial height 120T). Additionally, first set of hot flow tubes 136 are circumferentially centered between adjacent walls of first plurality of radial walls 144 (i.e., are half a distance of first circumferential distance 144T from adjacent first plurality of radial walls 144). However, first set of hot flow tubes 136 can have other locations within first cold flow layer 120, such as being closer to first annular wall 122 and/or closer to one wall of first plurality of radial walls 144.

[0034] Second set of hot flow tubes 138 has the same configuration as first set of hot flow tubes 136 with regards to second cold flow layer 124, second annular wall 126, third annular wall 130, and second plurality of radial walls 146. While shown as being radially centered between second annular wall 126 and third annular wall 130 and circumferentially centered between adjacent walls of second plurality of radial walls 146, second set of hot flow tubes 138 can have other locations within second cold flow layer 124, such as being closer to second annular wall 126 and/or closer to one wall of second plurality of radial walls 146.

[0035] Third set of hot flow tubes 140 has the same configuration as first set of hot flow tubes 136 with regards to third cold flow layer 128, third annular wall 130, fourth annular wall 132, and third plurality of radial walls 148. While shown as being radially centered between third annular wall 130 and fourth annular wally 132 and circumferentially centered between adjacent walls of third plurality of radial walls 148, third set of hot flow tubes 140 can have other locations within third cold flow layer 128, such as being closer to third annular wall 130 and/or closer to one wall of third plurality of radial walls 148.

[0036] With segments of plurality of cold flow layers 118 having approximately equal cross-sectional flow areas/paths and plurality of hot flow tubes 134 being located within and extending through each segment of plurality of cold flow layers 118, heat exchanger 110 provides increased thermal energy transfer capabilities while reducing thermal stresses and providing an equal flow resistance (and pressure drop) across the entire circular cross-sectional area of core 115. With the components of heat exchanger 110 having circular shapes, heat exchanger 110 can accommodate high pressures of first fluid 12 and second fluid 14.

[0037] FIG. 3 is a cross-sectional view of a third embodiment of the heat exchanger. Heat exchanger 210 is centered about and extends along centerline C (extending into and out of the page in FIG. 3). Heat exchanger 210 can include all of the components of heat exchanger 10 in FIGS. 1A-1C (including a first header, second header, first duct, and second duct) and is different than heat exchanger 10 in that plurality of hot flow tubes 234 increase in size from first set of hot flow tubes 236 through fourth set of hot flow tubes 242.

[0038] Core 215 has a substantially circular cross-sectional area within which plurality of annular flow layers 218 and plurality of hot flow tubes 234 extend to convey and allow thermal energy transfer between first fluid 12 and second fluid 14 (shown in FIGS. 1A-1C), respectively. First fluid 12 and second fluid 14 can flow in opposite directions through plurality of hot flow tubes 234 and plurality of annular flow layers 218, respectively. Similar to core 15, core 215 is shown as having a center that does not include plurality of cold flow layers 218 or plurality of hot flow tubes 234 (although heat exchanger 210 can be configured such that second fluid 14 flows through the center), but core 215 can have other configurations in which the center includes one or multiple layers and/or tubes.

[0039] Plurality of cold flow layers 218 are similar in configuration and functionality to plurality of cold flow layers 18 in heat exchanger 10. First radial height 220T of first cold flow layer 220 is equal to second radial height 224T of second cold flow layer 224, which is also equal to third radial height 228T of third cold flow layer 228. With radial walls 244-248 being radially aligned, each segment of third cold flow layer 228 has a greater cross-sectional area than each segment of second cold flow layer 224, and each segment of second cold flow layer 224 has a greater cross-sectional area than each segment of first cold flow layer 220. To provide a more even distribution of thermal energy transfer across the entire cross-sectional area of core 215, each hot flow tube of plurality of hot flow tubes 234 increases in cross-sectional area as each segment of plurality of cold flow layers 218 increases in cross-sectional area.

[0040] First set of hot flow tubes 236 is radially inward from first cold flow layer 220, and each hot flow tube is incorporated into first annular wall 222 and a radially inner end of first plurality of radial walls 244. First set of hot flow tubes 236 is similar in configuration and functionality as first set of hot flow tubes 36 in heat exchanger 10. However, each tube of first set of hot flow tubes 236 has a smaller cross-sectional area than each tube of second set of hot flow tubes 238 (which in turn has a smaller cross-sectional area than each tube of third set of hot flow tubes 240 and each tube of fourth set of hot flow tubes 242). First set of hot flow tubes 236 can have other locations and configurations than that which is shown in FIG. 3, such as being located within and extending through first cold flow layer 220.

[0041] Second set of hot flow tubes 238 is radially inward from second cold flow layer 224 and radially outward from first cold flow layer 220, and each hot flow tube is incorporated into second annular wall 226 at an intersection between first plurality of radial walls 244 and second plurality of radial walls 246. Second set of hot flow tubes 238 is similar in configuration and functionality as second set of hot flow tubes 38 in heat exchanger 10. However, each tube of second set of hot flow tubes 238 has a smaller cross-sectional area than each tube of third set of hot flow tubes 240 (which in turn has a smaller cross-sectional area than each tube of fourth set of hot flow tubes 242) but has a greater cross-sectional area than each tube of first set of hot flow tubes 236. Second set of hot flow tubes 238 can have other locations and configurations than that which is shown in FIG. 3, such as being located within and extending through second cold flow layer 224.

[0042] Third set of hot flow tubes 240 is radially inward from third cold flow layer 228 and radially outward from second cold flow layer 224, and each hot flow tube is incorporated into third annular wall 230 at an intersection between second plurality of radial walls 246 and third plurality of radial walls 248. Third set of hot flow tubes 240 is similar in configuration and functionality as third set of hot flow tubes 40 in heat exchanger 10. However, each tube of third set of hot flow tubes 240 has a smaller cross-sectional area than each tube of fourth set of hot flow tubes 242 but has a greater cross-sectional area than each tube of second set of hot flow tubes 238 (which in turn has a greater cross-sectional area than each tube of first set of hot flow tubes 236). Third set of hot flow tubes 240 can have other locations and configurations than that which is shown in FIG. 3, such as being located within and extending through third cold flow layer 228.

[0043] Fourth set of hot flow tubes 242 is radially outward from third cold flow layer 228, and each hot flow tube is incorporated into fourth annular wall 232 at an intersection between fourth annular wall 232 and third plurality of radial walls 248. Fourth set of hot flow tubes 242 is similar in configuration and functionality as fourth set of hot flow tubes 42 in heat exchanger 10. However, each tube of fourth set of hot flow tubes 242 has a greater cross-sectional area than each tube of third set of hot flow tubes 240 (which in turn has a greater cross-sectional area than each tube of second set of hot flow tubes 238). Fourth set of hot flow tubes 242 can have other locations and configurations than that which is shown in FIG. 3.

[0044] Heat exchanger 10/110/210 includes core 15/115/215 arranged in a nonrectangular cross-sectional shape with plurality of cold flow layers 18/118/218 and plurality of hot flow tubes 34/134/234 extending therethrough. The geometries of cold flow layers 18/118/218 and hot flow tubes 34/134/234 can be varied, including differing shapes of the tubes, differing circumferential distances between the tubes, differing numbers of tubes per layer, differing heights of the layers, and other geometries. Such configurations reduce the thermal stresses and also provide an equal flow resistance/even mass flow distribution (and pressure drop) across the entire cross-sectional area of heat exchanger 10/110/210, thereby ensuring heat exchanger 10/110/210 performs similarly across the entire cross-sectional area. Additionally, because the arrangement of the components of heat exchanger 10/110/210 are substantially circular, heat exchanger 10/110/210 can accommodate high pressures of first fluid 12 and second fluid 14 flowing through the heat exchanger. Heat exchanger 10/110/210 and core 15/115/215 may be made using any technique or combination of techniques that a person of ordinary skill would deem appropriate, including additive manufacturing, casting, rolling, forging, or any other manufacturing technique.

Discussion of Possible Embodiments

[0045] The following are non-exclusive descriptions of possible embodiments of the present invention.

[0046] A heat exchanger includes a core having a non-rectangular cross-sectional area, a plurality of cold flow layers centered about a centerline with each of the plurality of cold flow layers separated by corresponding walls. The heat exchanger also includes a plurality of hot flow tubes corresponding to each of the plurality of cold flow layers.

[0047] 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:

[0048] The core has a circular cross-sectional area and the plurality of cold flow layers are annular in shape, coaxial about the centerline, and are separated by corresponding annular walls.

[0049] The plurality of cold flow layers includes a first cold flow layer having a first annular wall on a radially inner boundary, a second cold flow layer radially outward from the first cold flow layer and having a second annular wall between the first cold flow layer and the second cold flow layer, and a third cold flow layer radially outward from the second cold flow layer and having a third annular wall between the second cold flow layer and the third cold flow layer and a fourth annular wall radially outward from the third cold flow layer.

[0050] The plurality of hot flow tubes includes a first set of hot flow tubes radially inward from the first cold flow layer with each hot flow tube being incorporated into the first annular wall, a second set of hot flow tubes radially between the first cold flow layer and the second cold flow layer with each hot flow tube being incorporated into the second annular wall, a third set of hot flow tubes radially between the second cold flow layer and the third cold flow layer with each hot flow tube being incorporated into the third annular wall, and a fourth set of hot flow tubes radially outward from the third cold flow layer with each hot flow tube being incorporated into the fourth annular wall.

[0051] The first set of hot flow tubes has an equal number of hot flow tubes as the second set of hot flow tubes, the third set of hot flow tubes has a greater number of hot flow tubes than the number of hot flow tubes of the second set of hot flow tubes, and the fourth set of hot flow tubes has an equal number of hot flow tubes as the number of hot flow tubes of the third set of hot flow tubes.

[0052] A first plurality of radial walls extending between radially adjacent hot flow tubes of the first set of hot flow tubes and the second set of hot flow tubes, a second plurality of radial walls extending between radially adjacent hot flow tubes of the second set of hot flow tubes and the third set of hot flow tubes, and a third plurality of radial walls extending between radially adjacent hot flow tubes of the third set of hot flow tubes and the fourth set of hot flow tubes.

[0053] A circumferential distance between adjacent radial walls of the first plurality of radial walls is less than a circumferential distance between adjacent radial walls of the second plurality of radial walls, and the circumferential distance between adjacent radial walls of the second plurality of radial walls is less than a circumferential distance between adjacent radial walls of the third plurality of radial walls.

[0054] Each hot flow tube of the second set of hot flow tubes has a greater cross-sectional area than each hot flow tube of the first set of hot flow tubes.

[0055] Each hot flow tube of the third set of hot flow tubes has a greater cross-sectional area than each hot flow tube of the second set of hot flow tubes.

[0056] A first set of hot flow tubes extending through the first cold flow layer, a second set of hot flow tubes extending through the second cold flow layer, and a third set of hot flow tubes extending through the third cold flow layer.

[0057] A radial height of the first cold flow layer, the second cold flow layer, and the third cold flow layer are equal to one another.

[0058] A radial height of the first cold flow layer is greater than a radial height of the second cold flow layer and the radial height of the second cold flow layer is greater than a radial height of the third cold flow layer.

[0059] Each hot flow tube of the plurality of hot flow tubes has a circular cross-sectional shape.

[0060] Each hot flow tube of the plurality of hot flow tubes has an elliptical cross-sectional shape.

[0061] Each hot flow tube of the plurality of hot flow tubes has a polygonal cross-sectional shape.

[0062] Each hot flow tube of the plurality of hot flow tubes has a tear-drop cross-sectional shape.

[0063] A first fluid configured to flow through the plurality of hot flow tubes and second fluid configured to flow through the plurality of annular cold flow layers in an opposite direction from a flow of the first fluid.

[0064] A first header having a first hot flow route connected to a first end of the plurality of hot flow tubes, the first hot flow route configured to transition the flow of the first fluid from a first duct into the plurality of hot flow tubes and a second header having a second hot flow route connected to a second end of the plurality of hot flow tubes with the second hot flow route configured to transition the flow of the first fluid from the plurality of hot flow tubes into a second duct.

[0065] The first header includes a first outer shell configured to contain the second fluid exiting the plurality of cold flow layers and the second header includes a second outer shell configured to guide the second fluid into the plurality of cold flow layers.

[0066] The plurality of hot flow tubes are arranged in circumferential sets and include at least six circumferential sets of hot flow tubes.

[0067] The core has an oval cross-sectional shape and the plurality of cold flow layers are oval in shape and are separated by corresponding oval-shaped walls.

[0068] A method including constructing the above heat exchanger utilizing an additive manufacturing process.

[0069] 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. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. 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 (10) comprising:

a core (15) having a nonrectangular cross-sectional area;
a plurality of cold flow layers (18) centered about a centerline, each of the plurality of cold flow layers separated by corresponding walls; and
a plurality of hot flow tubes (34) corresponding to each of the plurality of cold flow layers.

2. The heat exchanger of claim 1, wherein the core has a circular cross-sectional area and the plurality of cold flow layers are annular in shape, coaxial about the centerline, and are separated by corresponding annular walls.

3. The heat exchanger of claim 2, wherein the plurality of cold flow layers comprises:

a first cold flow layer having a first annular wall on a radially inner boundary;
a second cold flow layer radially outward from the first cold flow layer and having a second annular wall between the first cold flow layer and the second cold flow layer; and
a third cold flow layer radially outward from the second cold flow layer and having a third annular wall between the second cold flow layer and the third cold flow layer and a fourth annular wall radially outward from the third cold flow layer.

4. The heat exchanger of claim 3, wherein the plurality of hot flow tubes comprises:

a first set of hot flow tubes radially inward from the first cold flow layer with each hot flow tube being incorporated into the first annular wall;
a second set of hot flow tubes radially between the first cold flow layer and the second cold flow layer with each hot flow tube being incorporated into the second annular wall;
a third set of hot flow tubes radially between the second cold flow layer and the third cold flow layer with each hot flow tube being incorporated into the third annular wall; and
a fourth set of hot flow tubes radially outward from the third cold flow layer with each hot flow tube being incorporated into the fourth annular wall.

5. The heat exchanger of claim 4, wherein the first set of hot flow tubes has an equal number of hot flow tubes as the second set of hot flow tubes, the third set of hot flow tubes has a greater number of hot flow tubes than the number of hot flow tubes of the second set of hot flow tubes, and the fourth set of hot flow tubes has an equal number of hot flow tubes as the number of hot flow tubes of the third set of hot flow tubes.

6. The heat exchanger of claim 4, further comprising:

a first plurality of radial walls extending between radially adjacent hot flow tubes of the first set of hot flow tubes and the second set of hot flow tubes;
a second plurality of radial walls extending between radially adjacent hot flow tubes of the second set of hot flow tubes and the third set of hot flow tubes; and
a third plurality of radial walls extending between radially adjacent hot flow tubes of the third set of hot flow tubes and the fourth set of hot flow tubes; and preferably
wherein a circumferential distance between adjacent radial walls of the first plurality of radial walls is less than a circumferential distance between adjacent radial walls of the second plurality of radial walls, and the circumferential distance between adjacent radial walls of the second plurality of radial walls is less than a circumferential distance between adjacent radial walls of the third plurality of radial walls.

7. The heat exchanger of claim 4, wherein each hot flow tube of the second set of hot flow tubes has a greater cross-sectional area than each hot flow tube of the first set of hot flow tubes, and wherein each hot flow tube of the third set of hot flow tubes has a greater cross-sectional area than each hot flow tube of the second set of hot flow tubes.

8. The heat exchanger of claim 4, further comprising:

a first set of hot flow tubes extending through the first cold flow layer;
a second set of hot flow tubes extending through the second cold flow layer; and

a third set of hot flow tubes extending through the third cold flow layer.

9. The heat exchanger of claim 3, wherein a radial height of the first cold flow layer, the second cold flow layer, and the third cold flow layer are equal to one another.

10. The heat exchanger of claim 3, wherein a radial height of the first cold flow layer is greater than a radial height of the second cold flow layer and the radial height of the second cold flow layer is greater than a radial height of the third cold flow layer.

11. The heat exchanger of claim 1, wherein each hot flow tube of the plurality of hot flow tubes has a circular cross-sectional shape; or wherein each hot flow tube of the plurality of hot flow tubes has an elliptical cross-sectional shape; or wherein each hot flow tube of the plurality of hot flow tubes has a polygonal cross-sectional shape; or wherein each hot flow tube of the plurality of hot flow tubes has a tear-drop cross-sectional shape.

12. The heat exchanger of any preceding claim, further comprising:

a first fluid configured to flow through the plurality of hot flow tubes; and
a second fluid configured to flow through the plurality of annular cold flow layers in an opposite direction from a flow of the first fluid.

13. The heat exchanger of claim 12, further comprising:

a first header having a first hot flow route connected to a first end of the plurality of hot flow tubes, the first hot flow route configured to transition the flow of the first fluid from a first duct into the plurality of hot flow tubes; and
a second header having a second hot flow route connected to a second end of the plurality of hot flow tubes, the second hot flow route configured to transition the flow of the first fluid from the plurality of hot flow tubes into a second duct; and preferably

wherein the first header includes a first outer shell configured to contain the second fluid exiting the plurality of cold flow layers and the second header includes a second outer shell configured to guide the second fluid into the plurality of cold flow layers.

14. The heat exchanger of any preceding claim, wherein the core has an oval cross-sectional shape and the plurality of cold flow layers are oval in shape and are separated by corresponding oval-shaped walls.

15. A method comprising:
constructing the heat exchanger of claim 1 utilizing an additive manufacturing process.

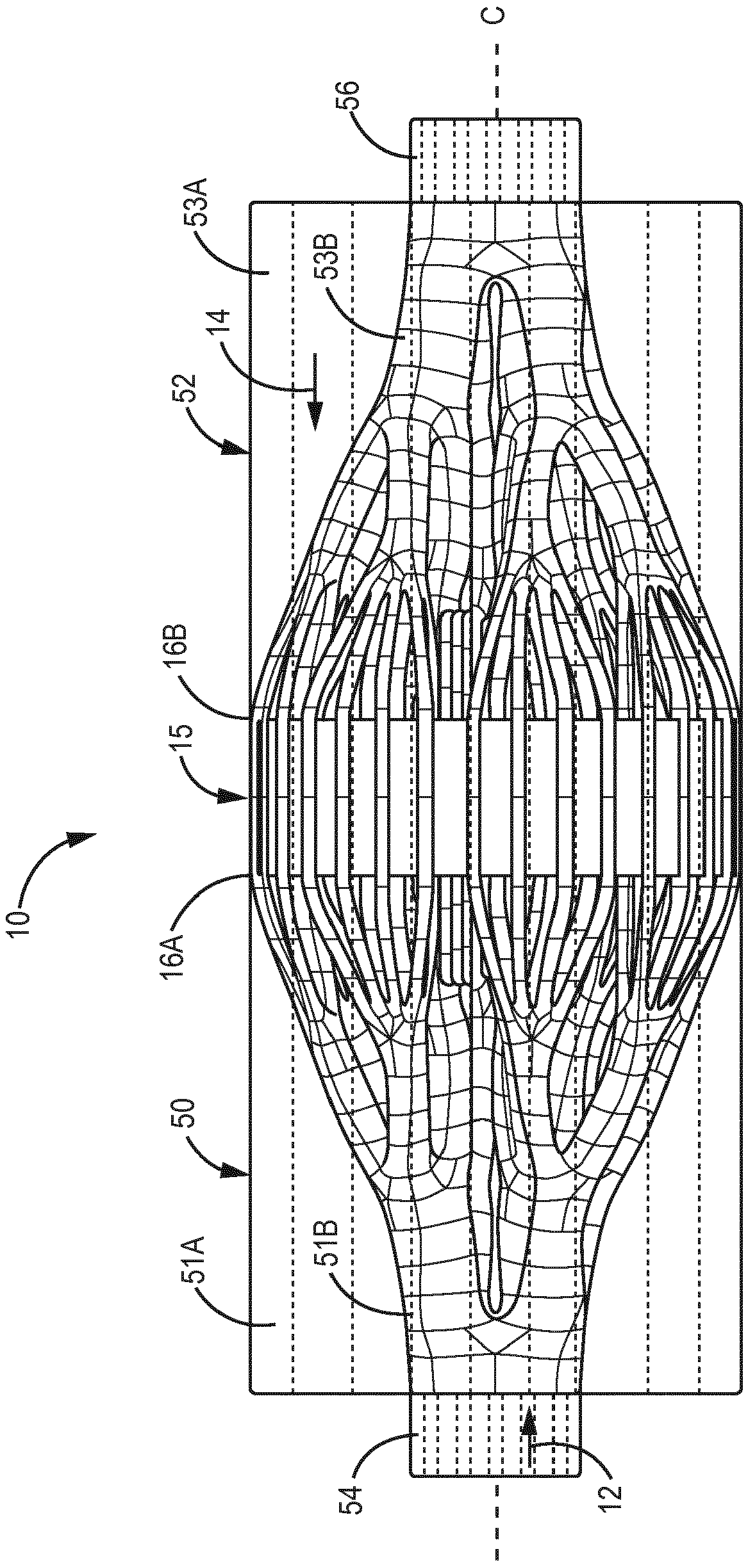

FIG. 1A

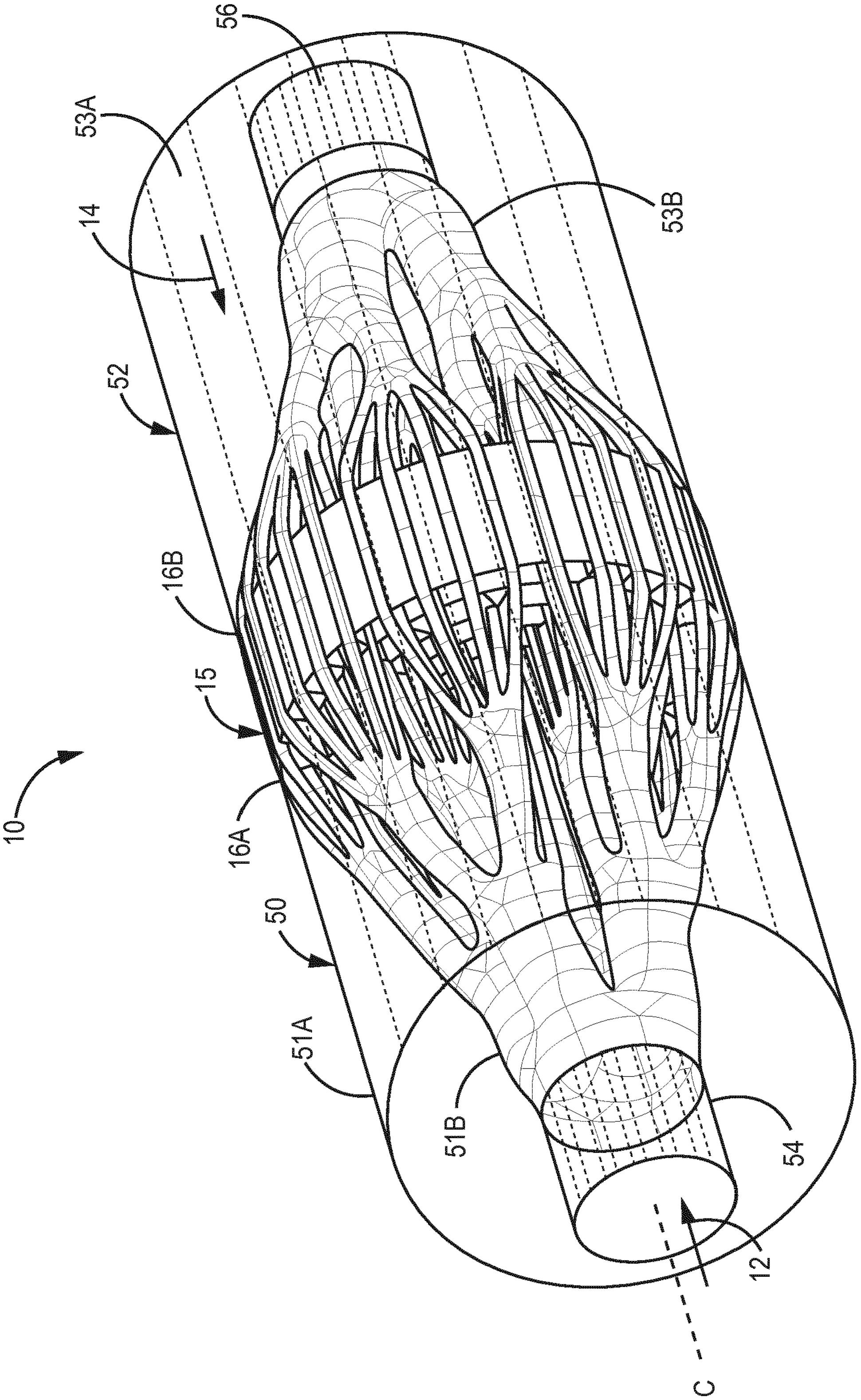

FIG. 1B

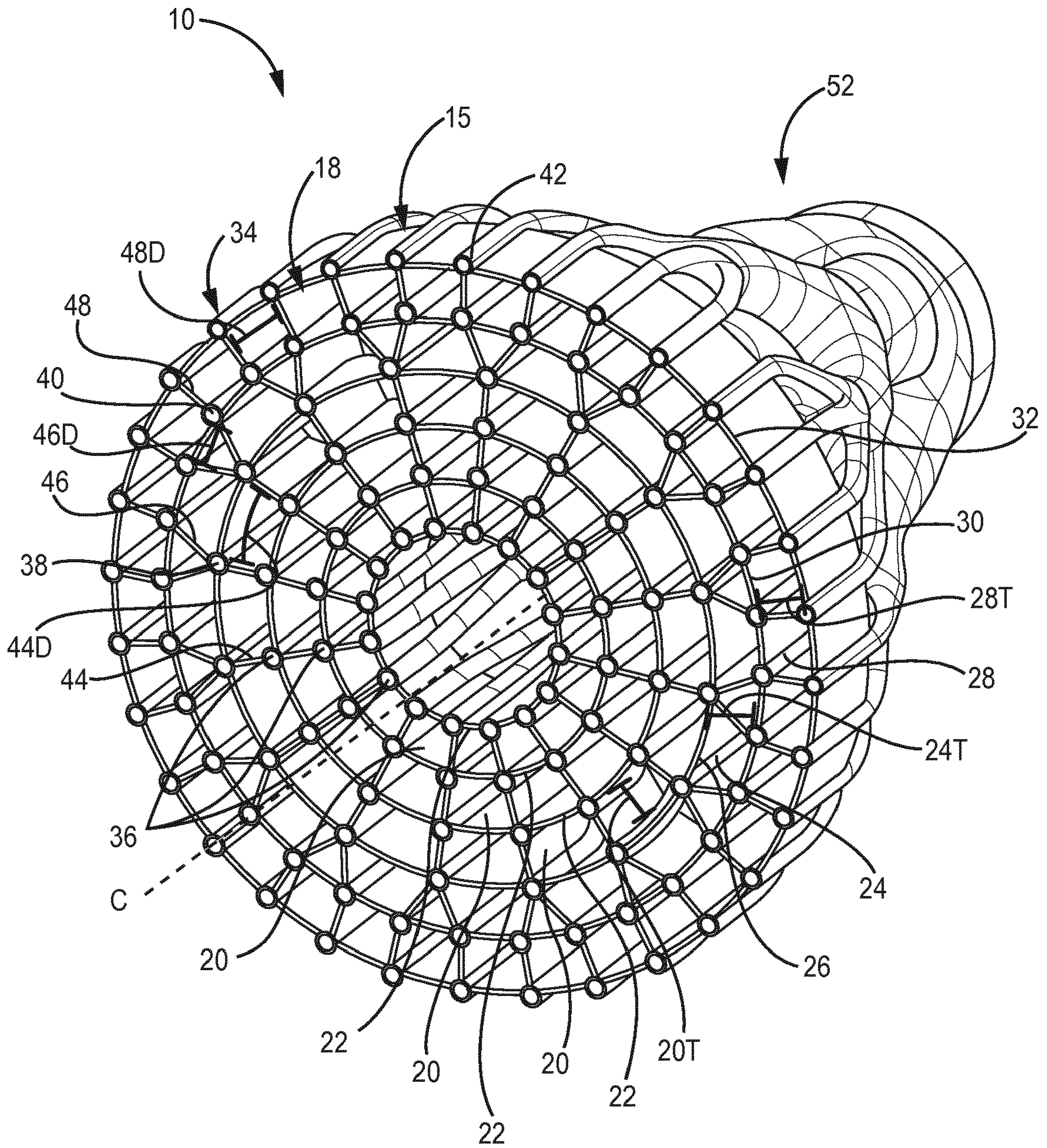
10
52
15
18
42
34
48D
48
40
46D
46
38
44D
44
36
C
20
22
20
22
20
22
20T
26
24
24T
28
28T
30
32

FIG. 1C

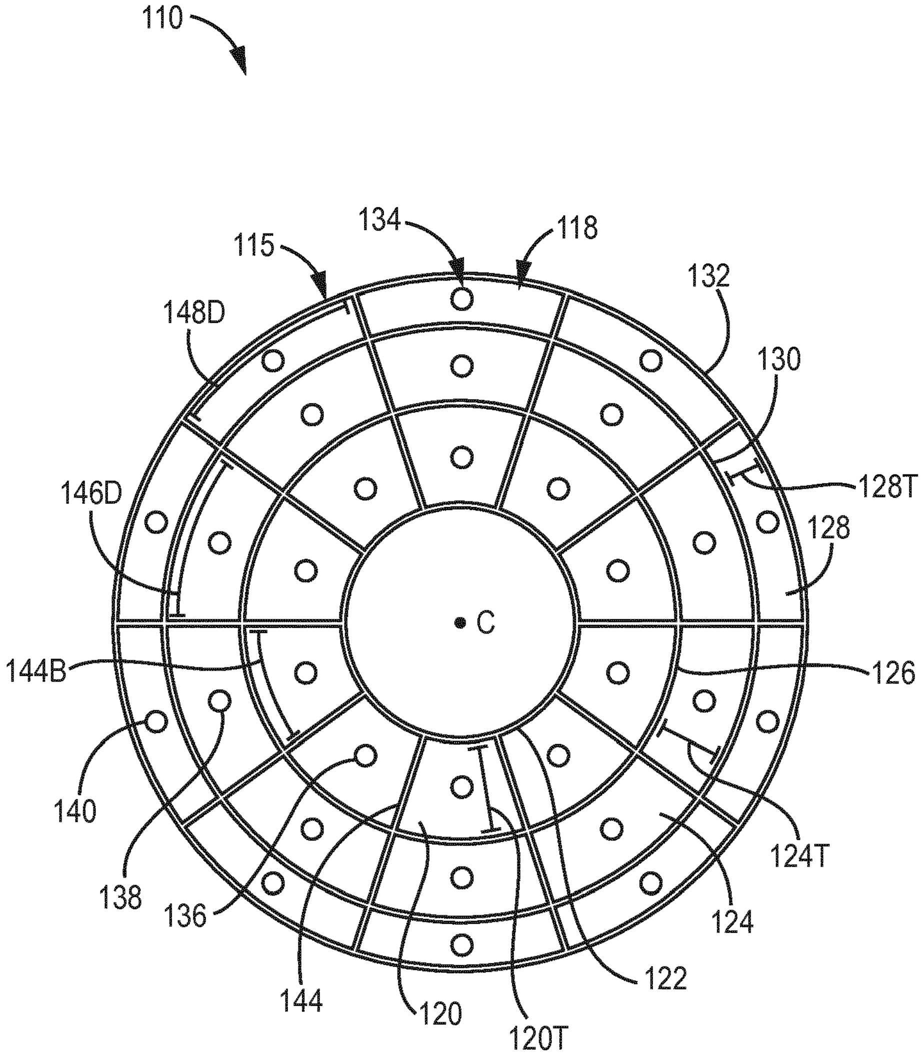
110
115
134
118
132
148D
130
128T
146D
128
C
144B
126
140
138
136
144
120
120T
122
124
124T

FIG. 2

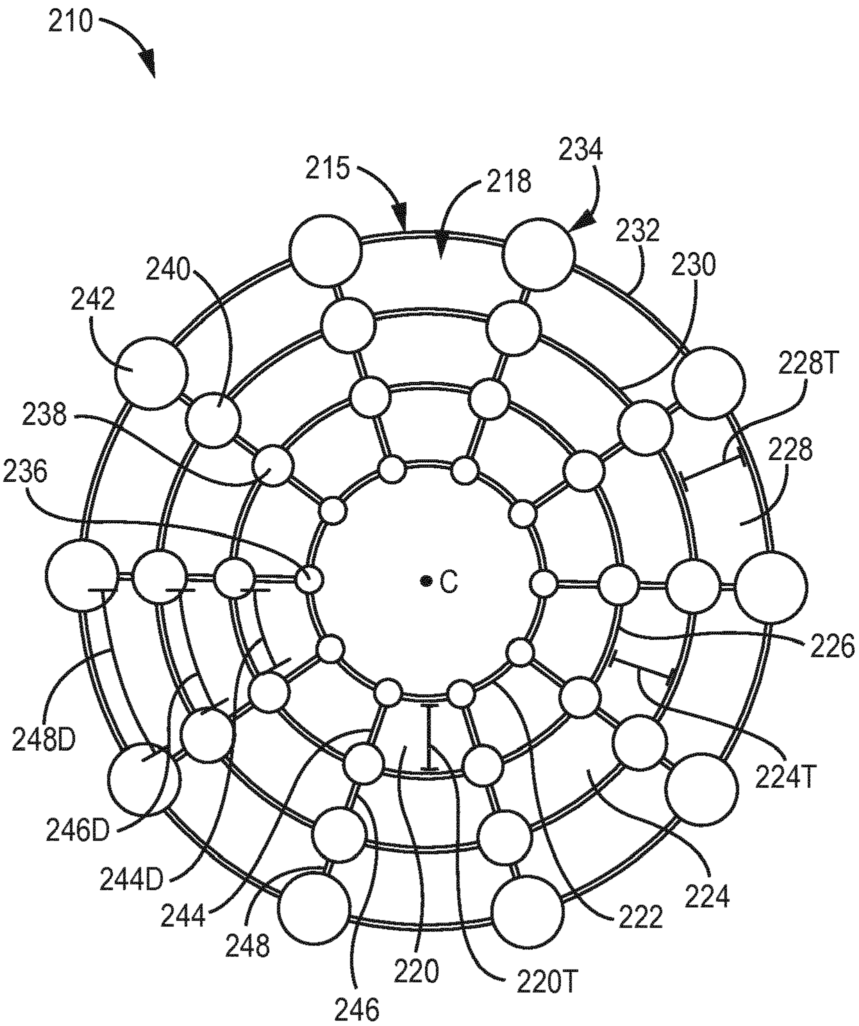
210
215
218
234
232
230
240
242
228T
238
228
236
C
226
248D
224T
246D
244D
244
248
246
220
220T
222
224

FIG. 3

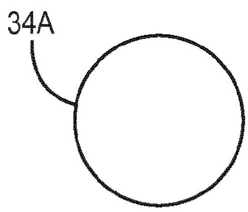

FIG. 4A

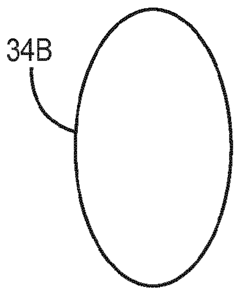

FIG. 4B

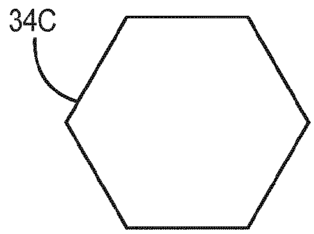

FIG. 4C

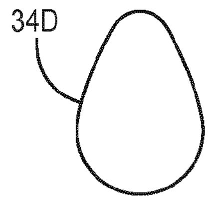

FIG. 4D

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 19 21 3142

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 A	WO 2017/008108 A1 (CONFLUX ENTPR PTY LTD [AU]) 19 January 2017 (2017-01-19) * figures 14,18 *	1-3,9-15 4-8	INV. F28D7/00 F28D7/16 F28F7/02
A	EP 3 339 792 A1 (ALFA LAVAL CORP AB [SE]) 27 June 2018 (2018-06-27) * paragraph [0059]; figure 11 *	1-15	
A	US 2017/205156 A1 (RANJAN RAM [US] ET AL) 20 July 2017 (2017-07-20) * figure 1c *	1-15	
A	EP 3 193 125 A1 (HAMILTON SUNDSTRAND CORP [US]) 19 July 2017 (2017-07-19) * figure 2 *	1-15	

TECHNICAL FIELDS SEARCHED (IPC)
F28D
F28F

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	3 February 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

EPO FORM 1503 03.82 (P04C01)

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

EP 19 21 3142

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.

03-02-2020

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2017008108 A1	19-01-2017	AU 2016293374 A1	18-01-2018
		CA 2991813 A1	19-01-2017
		CN 108351175 A	31-07-2018
		EP 3320288 A1	16-05-2018
		JP 2018519490 A	19-07-2018
		KR 20180066022 A	18-06-2018
		US 2019120562 A1	25-04-2019
		WO 2017008108 A1	19-01-2017
EP 3339792 A1	27-06-2018	CA 3043665 A1	28-06-2018
		CN 110073166 A	30-07-2019
		EP 3339792 A1	27-06-2018
		EP 3559583 A1	30-10-2019
		JP 2020502468 A	23-01-2020
		KR 20190098190 A	21-08-2019
		US 2019383565 A1	19-12-2019
		WO 2018114237 A1	28-06-2018
US 2017205156 A1	20-07-2017	EP 3239642 A1	01-11-2017
		US 2017205156 A1	20-07-2017
EP 3193125 A1	19-07-2017	EP 3193125 A1	19-07-2017
		US 2017205146 A1	20-07-2017

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82