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(54) **COUNTER FLOW HEAT EXCHANGER**

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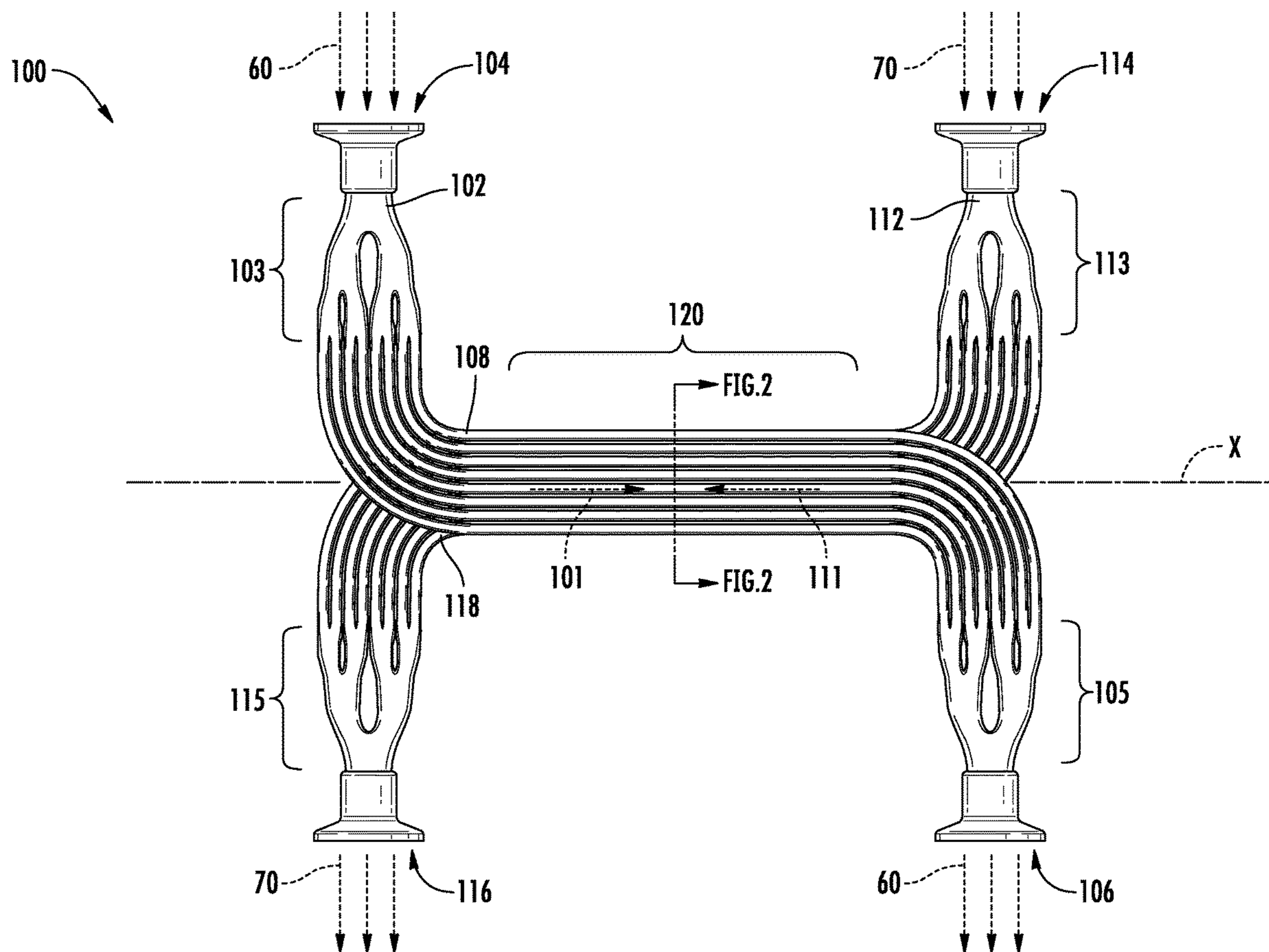
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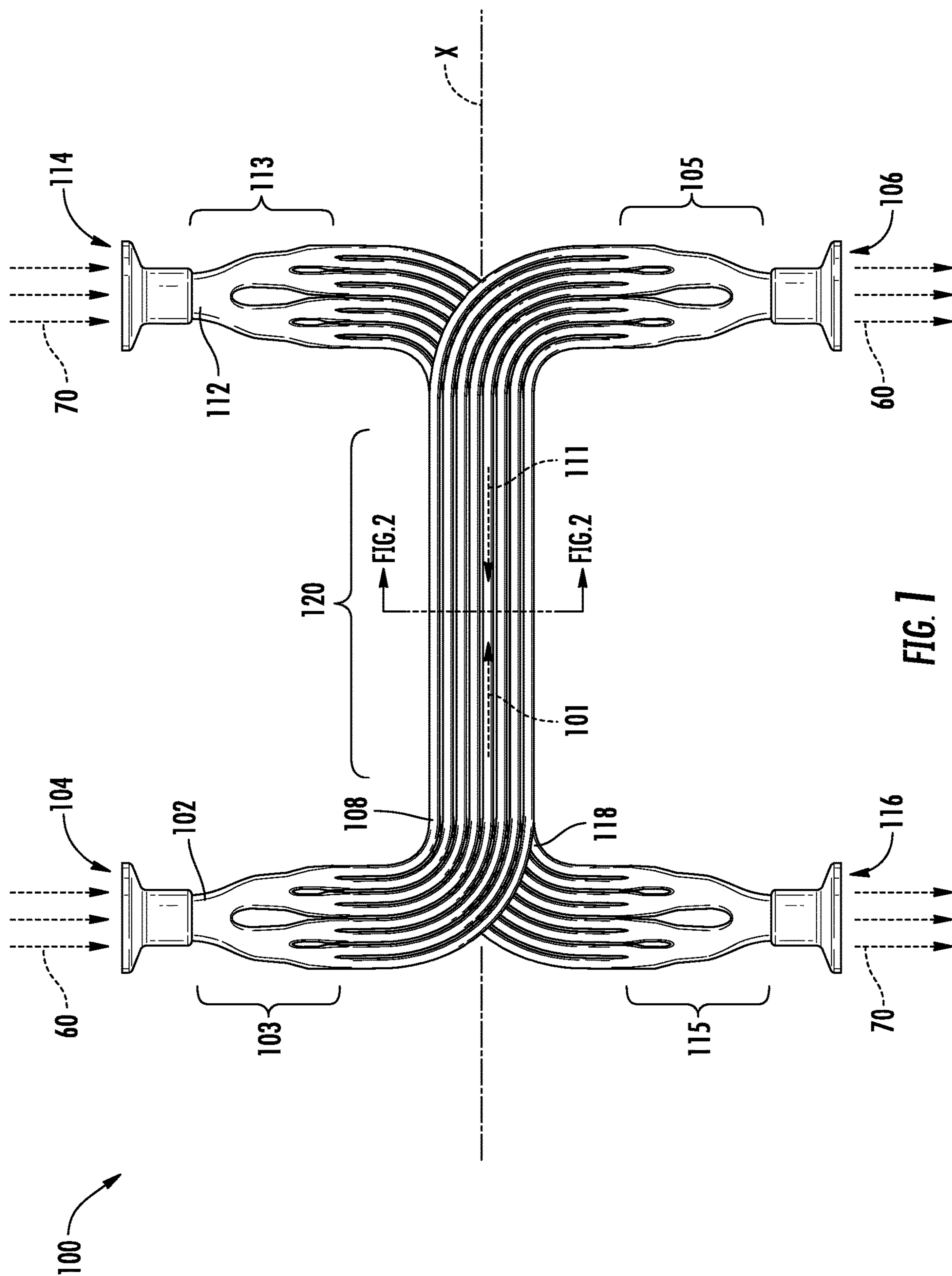
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(57) **ABSTRACT**

A counter-flow heat exchanger including: a primary flow passageway comprising a primary flow inlet, a primary flow outlet, and a plurality of primary flow subset passageways therebetween; a secondary flow passageway comprising a secondary flow inlet, a secondary flow outlet, and a plurality of secondary flow subset passageways therebetween; and a heat exchanger core comprising portions of the plurality of primary flow subset passageways and the plurality of secondary flow subset passageways, the secondary flow passageway being in thermal communication with the primary flow passageway in the heat exchanger core, wherein the primary flow subset passageways in the heat exchanger core and the secondary flow subset passageways in the heat exchanger core are oriented such that primary fluid flow through the primary flow subset passageways flows opposite secondary fluid flow through the secondary flow subset passageways.





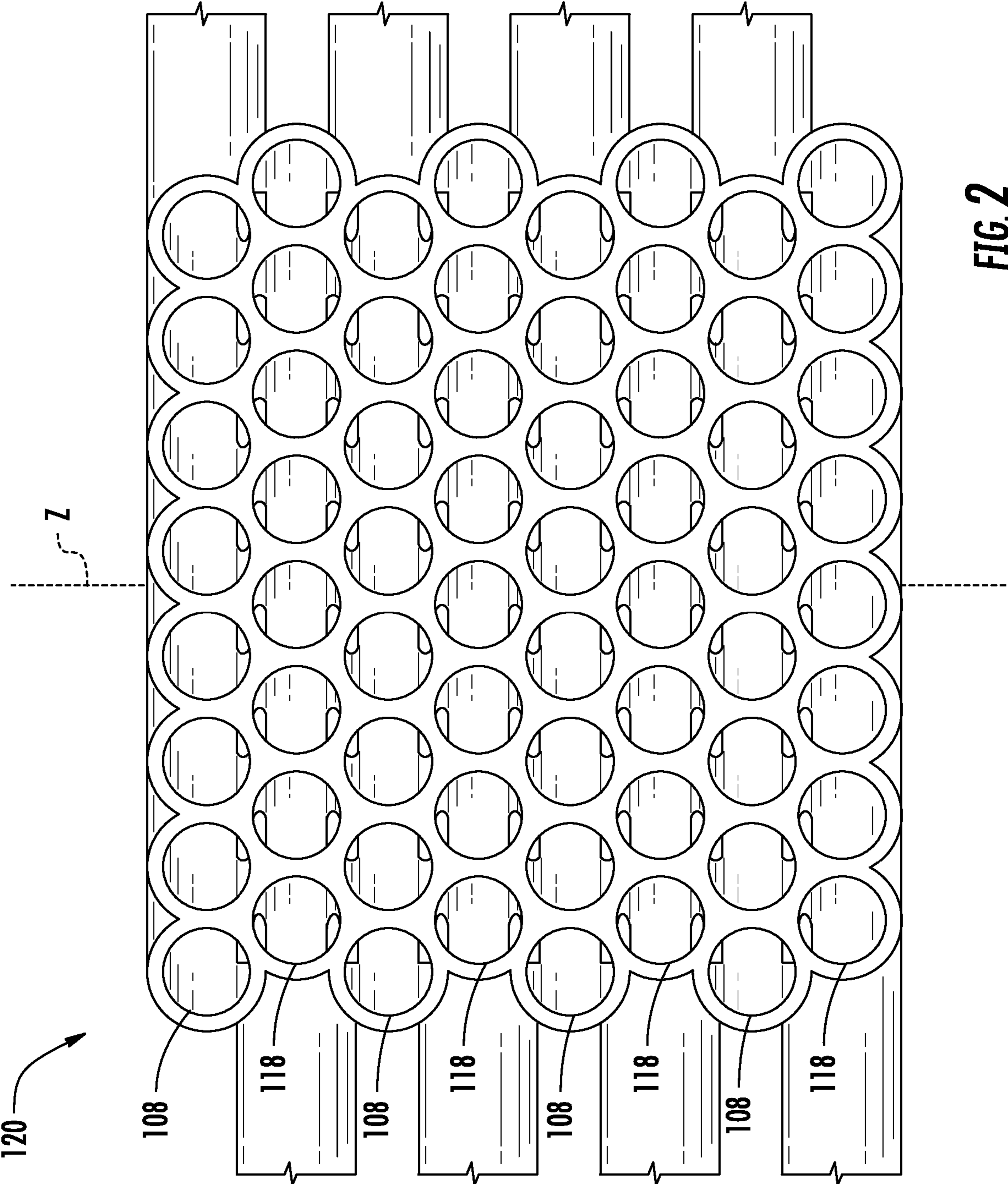


FIG. 2

COUNTER FLOW HEAT EXCHANGER

BACKGROUND

[0001] The subject matter disclosed herein generally relates to the field of heat exchangers, and more particularly to method and apparatus for heat exchangers of aircraft.

[0002] Heat exchangers are conventionally utilized in aircraft to removed heat from fluid flows. Heat exchangers utilized aircraft must be designed to fit in limited volumes, which may reduce overall heat exchange efficiency of the heat exchangers and/or impede the flow of fluid through the heat exchanger.

BRIEF SUMMARY

[0003] According to one embodiment, a counter-flow heat exchanger is provided. The counter-flow heat exchanger including: a primary flow passageway comprising a primary flow inlet, a primary flow outlet, and a plurality of primary flow subset passageways therebetween; a secondary flow passageway comprising a secondary flow inlet, a secondary flow outlet, and a plurality of secondary flow subset passageways therebetween; and a heat exchanger core comprising portions of the plurality of primary flow subset passageways and the plurality of secondary flow subset passageways, the secondary flow passageway being in thermal communication with the primary flow passageway in the heat exchanger core, wherein the primary flow subset passageways in the heat exchanger core and the secondary flow subset passageways in the heat exchanger core are oriented such that primary fluid flow through the primary flow subset passageways flows opposite secondary fluid flow through the secondary flow subset passageways.

[0004] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the primary flow passageway further comprises a primary flow inlet fractal header fluidly connecting the primary flow inlet to each of the plurality of primary flow subset passageways, the primary flow inlet fractal header being configured to fractally branch the fluid flow from a single passageway at the primary flow inlet to the plurality of primary flow subset passageways.

[0005] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the secondary flow passageway further comprises a secondary flow inlet fractal header fluidly connecting the secondary flow inlet to each of the plurality of secondary flow subset passageways, the secondary flow inlet fractal header being configured to fractally branch the fluid flow from a single passageway at the secondary flow inlet to the plurality of secondary flow subset passageways.

[0006] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the secondary flow passageway further comprises a secondary flow inlet fractal header fluidly connecting the secondary flow inlet to each of the plurality of secondary flow subset passageways, the secondary flow inlet fractal header being configured to fractally branch the fluid flow from a single passageway at the secondary flow inlet to the plurality of secondary flow subset passageways.

[0007] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the primary flow passageway further comprises a primary flow outlet fractal header fluidly connecting the

primary flow outlet to each of the plurality of primary flow subset passageways, the primary flow outlet fractal header being configured to fractally unify the primary flow subset passageways to a single passageway at the primary flow outlet.

[0008] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the secondary flow passageway further comprises a secondary flow outlet fractal header fluidly connecting the secondary flow outlet to each of the plurality of secondary flow subset passageways, the secondary flow outlet fractal header being configured to fractally unify the secondary flow subset passageways to a single passageway at the secondary flow outlet.

[0009] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the primary flow passageway further comprises a primary flow outlet fractal header fluidly connecting the primary flow outlet to each of the plurality of primary flow subset passageways, the primary flow outlet fractal header being configured to fractally unify the primary flow subset passageways to a single passageway at the primary flow outlet.

[0010] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the secondary flow passageway further comprises a secondary flow outlet fractal header fluidly connecting the secondary flow outlet to each of the plurality of secondary flow subset passageways, the secondary flow outlet fractal header being configured to fractally unify the secondary flow subset passageways to a single passageway at the secondary flow outlet.

[0011] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the primary flow passageway further comprises a primary flow outlet fractal header fluidly connecting the primary flow outlet to each of the plurality of primary flow subset passageways, the primary flow outlet fractal header being configured to fractally unify the primary flow subset passageways to a single passageway at the primary flow outlet.

[0012] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the secondary flow passageway further comprises a secondary flow outlet fractal header fluidly connecting the secondary flow outlet to each of the plurality of secondary flow subset passageways, the secondary flow outlet fractal header being configured to fractally unify the secondary flow subset passageways to a single passageway at the secondary flow outlet.

[0013] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the primary flow passageway further comprises a primary flow outlet fractal header fluidly connecting the primary flow outlet to each of the plurality of primary flow subset passageways, the primary flow outlet fractal header being configured to fractally unify the primary flow subset passageways to a single passageway at the primary flow outlet.

[0014] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the counter-flow heat exchanger is built in a single piece using additive manufacturing.

[0015] In addition to one or more of the features described above, or as an alternative, further embodiments may include that multiple linearly extending cylinders form each individual primary flow subset passageway and each individual secondary flow subset passageway within the heat exchanger core.

[0016] In addition to one or more of the features described above, or as an alternative, further embodiments may include that multiple curvilinear extending cylinders form each individual primary flow subset passageway and each individual secondary flow subset passageway within the heat exchanger core.

[0017] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the heat exchanger core is composed of parallel alternating layers of the primary flow subset passageways and the secondary flow subset passageways.

[0018] In addition to one or more of the features described above, or as an alternative, further embodiments may include that at least one of the primary flow subset passageways and the secondary flow subset passageways are circular in shape.

[0019] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the primary flow subset passageways are physically connected to the secondary flow subset passageways within the heat exchanger core.

[0020] According to another embodiment, a method of manufacturing a counter-flow heat exchanger is provided. The method including: forming a counter-flow heat exchanger using additive manufacturing, the counter flow heat exchanger comprising: a primary flow passageway comprising a primary flow inlet, a primary flow outlet, and a plurality of primary flow subset passageways therebetween; a secondary flow passageway comprising a secondary flow inlet, a secondary flow outlet, and a plurality of secondary flow subset passageways therebetween; and a heat exchanger core comprising portions of the plurality of primary flow subset passageways and the plurality of secondary flow subset passageways, the secondary flow passageway being in thermal communication with the primary flow passageway in the heat exchanger core, wherein the primary flow subset passageways in the heat exchanger core and the secondary flow subset passageways in the heat exchanger core are oriented such that primary fluid flow through the primary flow subset passageways flows opposite secondary fluid flow through the secondary flow subset passageways.

[0021] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the additive manufacturing is via direct metal laser sintering.

[0022] Technical effects of embodiments of the present disclosure include manufacturing a counter-flow heat exchanger having fractal headers using additive manufacturing.

[0023] The foregoing features and elements may be combined in various combinations without exclusivity, unless expressly indicated otherwise. These features and elements as well as the operation thereof will become more apparent in light of the following description and the accompanying drawings. It should be understood, however, that the following description and drawings are intended to be illustrative and explanatory in nature and non-limiting.

BRIEF DESCRIPTION

[0024] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

[0025] FIG. 1 is a top view of a counter-flow heat exchanger, according to an embodiment of the present disclosure; and

[0026] FIG. 2 is a cross-sectional view of a heat exchanger core of the counter-flow heat exchanger, according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0027] A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

[0028] FIG. 1 is a top view of a counter-flow heat exchanger **100**, according to an embodiment of the present disclosure. The counter-flow heat exchanger **100** may be utilized in a variety of applications requiring thermal dynamic transfer of heat including but not limited to an aircraft, a combustion engine, a car, a space craft, a power-plant, a satellite, satellite, etc. In an embodiment, the counter-flow heat exchanger **100** may be utilized in an aircraft. In another embodiment, the counter-flow heat exchanger **100** may be utilized in an aircraft air conditioning system.

[0029] The counter-flow heat exchanger **100** includes a heat exchanger core **120** that may be oriented along a longitudinal axis X. The counter-flow heat exchanger **100** includes a primary flow passageway **102** and a secondary flow passageway **112** in thermal communication with the primary flow passageway **102**. In an embodiment, the primary flow passageways **102** is configured to convey a primary fluid **60** and the secondary flow passageway **112** is configured to convey a secondary fluid **70**. The primary fluid **60** may be at a temperature greater than the secondary fluid **70**. The primary fluid **60** may be a liquid or a gas and the secondary fluid **70** may be a liquid or a gas. In another embodiment, the hot fluid and the cooling fluid may be airflow.

[0030] The counter-flow heat exchanger **100** includes a primary flow inlet **104**, a primary flow outlet **106**, and a plurality of primary flow subset passageways **108** therebetween. The flow direction of the primary fluid **60** is indicated schematically by the arrow **101**. In an embodiment, the primary flow subset passageways **108** in the heat exchanger core **120** and the secondary flow subset passageways **118** in the heat exchanger core **120** are oriented such that primary fluid flow **60** through the primary flow subset passageways **108** flows opposite secondary fluid flow **70** through the secondary flow subset passageways **118**.

[0031] The primary flow inlet **104** is fluidly connected to the primary flow subset passageways **108** by a primary flow inlet fractal header **103**. The primary flow passageway **102** may be a single fluid passageway at the primary flow inlet **104** and then branches out into multiple primary flow subset passageways **108**. The primary flow passageway **102** may branch out into two or more primary flow subset passageways **108**. The primary flow passageway **102** may branch out into the multiple primary flow subset passageways **108** in progressive steps. For example, as shown in FIG. 2, the primary flow passageway **102** may branch out from a single fluid passageway at the primary flow inlet **104** into two

primary flow subset passageways **108** that each branch into four primary flow subset passageways **108** (i.e., eight primary flow subset passageways **108** in total) that each branch into four primary flow subset passageways **108**, thus bringing the total to thirty-two primary flow subset passageways **108**. The primary flow inlet fractal header **103** is configured to fractally branch the fluid flow from the single passageway at the primary flow inlet **104** to the plurality of primary flow subset passageways **108**, such that pressure drops in the primary fluid **60** flowing through the primary flow inlet fractal header **103** is optimized and/or reduced. In an embodiment, the primary flow subset passageways **108** includes thirty-two separate fluid passageways, thus the primary flow inlet fractal header **103** divides the primary fluid **60** flow from a single passageway at the primary flow inlet **104** to thirty-two separate primary flow subset passageways **108**. Advantageously, the primary flow inlet fractal header **103** gently divides the primary fluid **60** flow into separate primary flow subset passageways **108** in accordance with the physical flow characteristics of the primary fluid **60** to avoid large pressure drops in the fluid. The shape and flow area of the transition regions where the primary flow subset passageways **108** branch out are designed to minimize recirculation zones and to provide a uniform amount of flow to each branch.

[0032] The primary flow outlet **106** is fluidly connected to the primary flow subset passageways **108** by a primary flow outlet fractal header **105**. The primary flow passageway **102** fractally unifies (i.e., branch down) the plurality of primary flow subset passageways **108** to a single fluid passageway at the primary flow outlet **106**. The primary flow passageway **102** may unify from the two or more primary flow subset passageways **108**. The primary flow passageway **102** unifies from the multiple primary flow subset passageways **108** in progressive steps. For example, as shown in FIG. 2, the primary flow passageway **102** may unify from the thirty-two primary flow subset passageways **108** down to eight primary flow subset passageways **108**, then from the eight primary flow subset passageways **108** down to two primary flow subset passageways **108** that unify into to a single fluid passageway at the primary flow outlet **106**. The primary flow outlet fractal header **105** is configured to fractally unify the primary flow subset passageways **108** to a single passageway at the primary flow outlet **106**, such that pressure drops in the primary fluid **60** flowing through the primary flow outlet fractal header **105** is optimized and/or reduced. In an embodiment, the primary flow subset passageways **108** includes thirty-two separate fluid passageways, thus the primary flow outlet fractal header **105** unifies the primary fluid **60** flow from thirty-two separate primary flow subset passageways **108** to a single passageway at the primary flow outlet **106**. Advantageously, the primary flow outlet fractal header **105** gently unifies the primary fluid **60** flow from separate primary flow subset passageways **108** into a single fluid passageway in accordance with the physical flow characteristics of the primary fluid **60** to avoid large pressure drops in the fluid. The shape and flow area of the transition regions where the primary flow subset passageways **108** unify are designed to minimize recirculation zones and turbulence due to mixing of the flows from each branch.

[0033] The counter-flow heat exchanger **100** includes a secondary flow inlet **114**, a secondary flow outlet **116**, and a plurality of secondary flow subset passageways **118** ther-

ebetween. The flow direction of the secondary fluid **70** is indicated schematically by the arrow **111**.

[0034] The secondary flow inlet **114** is fluidly connected to the secondary flow subset passageways **118** by a secondary flow inlet fractal header **113**. The secondary flow passageway **112** may be a single fluid passageway at the secondary flow inlet **114** and then branches out into multiple secondary flow subset passageways **118**. The secondary flow passageway **112** may branch out into two or more secondary flow subset passageways **118**. The secondary flow passageway **112** may branch out into the multiple secondary flow subset passageways **118** in progressive steps. For example, as shown in FIG. 2, the secondary flow passageway **112** may branch out from a single fluid passageway at the secondary flow inlet **114** into two secondary flow subset passageways **118** that each branch into four secondary flow subset passageways **118** (i.e., eight secondary flow subset passageways **118** in total) that each branch into four secondary flow subset passageways **118**, thus bringing the total to thirty-two secondary flow subset passageways **118**. The secondary flow inlet fractal header **113** is configured to fractally branch the fluid flow from the single passageway at the secondary flow inlet **114** to the multiple fluid passageways in the secondary flow subset passageways **118**, such that pressure drops in the secondary fluid **70** flowing through the secondary flow inlet fractal header **113** is optimized and/or reduced. In an embodiment, the secondary flow subset passageways **118** includes thirty-two separate fluid passageways, thus the secondary flow inlet fractal header **113** divides the secondary fluid **70** flow from a single passageway at the secondary flow inlet **114** to thirty-two separate secondary flow subset passageways **118**. Advantageously, the secondary flow inlet fractal header **113** gently divides the secondary fluid **70** flow into separate secondary flow subset passageways **118** in accordance with the physical flow characteristics of the secondary fluid **70** to avoid large pressure drops in the fluid. The shape and flow area of the transition regions where the secondary flow subset passageways **118** branch out are designed to minimize recirculation zones and to provide a uniform amount of flow to each branch.

[0035] The secondary flow outlet **116** is fluidly connected to the secondary flow subset passageways **118** by a secondary flow outlet fractal header **115**. The secondary flow passageway **112** unify (i.e., branch down) the plurality of secondary flow subset passageways **118** to a single fluid passageway at the secondary flow outlet **116**. The secondary flow passageway **112** may unify from the two or more secondary flow subset passageways **118**. The secondary flow passageway **112** unifies from the multiple secondary flow subset passageways **118** in progressive steps. For example, as shown in FIG. 2, the secondary flow passageway **112** may unify from the thirty-two secondary flow subset passageways **118** down to eight secondary flow subset passageways **118**, then from the eight secondary flow subset passageways **118** down to two secondary flow subset passageways **118** that unify into to a single fluid passageway at the secondary flow outlet **116**. The secondary flow outlet fractal header **115** is configured to fractally unify the secondary flow subset passageways **118** to a single passageway at the secondary flow outlet **116**, such that pressure drops in the secondary fluid **70** flowing through the secondary flow outlet fractal header **115** is optimized and/or reduced. In an embodiment, the secondary flow subset passageways **118** includes thirty-two separate fluid passageways, thus the secondary flow

outlet fractal header **115** unifies the secondary fluid **70** flow from thirty-two separate secondary flow subset passageways **118** to a single passageway at the secondary flow outlet **116**. Advantageously, the secondary flow outlet fractal header **115** gently unifies the secondary fluid **70** flow from separate secondary flow subset passageways **118** into a single fluid passageway in accordance with the physical flow characteristics of the secondary fluid **70** to avoid large pressure drops in the fluid. The shape and flow area of the transition regions where the secondary flow subset passageways **118** unify are designed to minimize recirculation zones and turbulence due to mixing of the flows from each branch.

[0036] Referring now to FIGS. **1** and **2**. As shown in FIG. **1**, in the heat exchanger core **120**, the flow direction of the secondary fluid **70** as indicated schematically by the arrow **111** is directly opposite of the flow direction of the primary fluid **60** as indicated schematically by the arrow **101**. While the heat exchanger core **120** is shown as a straight section in FIG. **1**, the actual heat exchanger core **120** may be bent in one or more planes to accommodate for local interferences. FIG. **2** is a cross-sectional view of the heat exchanger core **120**, according to an embodiment of the present disclosure. FIG. **2** shows that the heat exchanger core **120** may be composed of parallel alternating layers of primary flow subset passageways **108** and secondary flow subset passageways **118**. As shown in FIG. **2**, the primary flow subset passageways **108** and secondary flow subset passageways **118** may be circular in shape. The primary flow subset passageways **108** and secondary flow subset passageways **118** may also be shaped in various other shapes including but not limited to hexagons, rectangular, non-regular, or any other geometric shapes/sections needed to maximize heat transfer and structural needs. Further, the shape of the primary flow subset passageways **108** may differ from the shapes of the secondary flow subset passageway **118**. Additionally, each individual primary flow subset passageway **108** may have different shapes and each individual secondary flow subset passageway **118** may have different shapes. The shapes of each individual primary flow subset passageway **108** need not be symmetric within a flow layer or between flow layers of the heat exchanger core **120**. Also, the shapes of each individual secondary flow subset passageway **118** need not be symmetric within a flow layer or between flow layers of the heat exchanger core **120**. Although shown at a right angle in FIG. **1**, the heat exchanger core **120** may be oriented at any angle in any plane relative to the primary flow inlet **104**, the primary flow outlet **106**, the secondary flow inlet **114**, and/or the secondary flow outlet **116**.

[0037] The counter-flow heat exchanger **100** may be formed using additive manufacturing such as, for, example, direct metal laser sintering. It is contemplated that the heat exchanger core **120** can be manufactured in a vertical direction, e.g. along vertical axis *Z* to build the heat exchanger core **120** along with the rest of the counter-flow heat exchanger **100** in a single piece. In an embodiment, the primary flow subset passageways **108** are physically connected to the secondary flow subset passageways **118** within the heat exchanger core **120**, as shown in FIG. **2**. It is also contemplated the heat exchanger core **120** can be composed of multiple linearly extending cylinders forming each individual primary flow subset passageway **108** and each individual secondary flow subset passageway **118** within the heat exchanger core **120**. It is also contemplated that instead

of being composed of multiple linearly extending cylinders, the heat exchanger core **120** could be built along a curvilinear path (i.e., non-linear, sinusoidal path) creating wavy or ruffled sets of passageways as opposed to straight ones for increased heat transfer or bend around obstructions.

[0038] The term fractal may be defined as a complex geometric pattern exhibiting self-similarity in that small details of its structure viewed at any scale repeat elements of the overall pattern. Advantageously, the fractals headers **103**, **105**, **113**, **115**, serve to gradually ease the transition between a single fluid passageway and multiple fluid passageways with minimal interference to the fluid flow. The term “about” is intended to include the degree of error associated with measurement of the particular quantity based upon the equipment available at the time of filing the application. For example, “about” can include a range of $\pm 8\%$ or 5% , or 2% of a given value.

[0039] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present disclosure. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, element components, and/or groups thereof.

[0040] While the present disclosure has been described with reference to an exemplary embodiment or embodiments, 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 present disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the present disclosure without departing from the essential scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this present disclosure, but that the present disclosure will include all embodiments falling within the scope of the claims.

What is claimed is:

1. A counter-flow heat exchanger, comprising:
 - a primary flow passageway comprising a primary flow inlet, a primary flow outlet, and a plurality of primary flow subset passageways therebetween;
 - a secondary flow passageway comprising a secondary flow inlet, a secondary flow outlet, and a plurality of secondary flow subset passageways therebetween; and
 - a heat exchanger core comprising portions of the plurality of primary flow subset passageways and the plurality of secondary flow subset passageways, the secondary flow passageway being in thermal communication with the primary flow passageway in the heat exchanger core, wherein the primary flow subset passageways in the heat exchanger core and the secondary flow subset passageways in the heat exchanger core are oriented such that primary fluid flow through the primary flow subset passageways flows opposite secondary fluid flow through the secondary flow subset passageways.
2. The counter-flow heat exchanger of claim **1**, wherein the primary flow passageway further comprises a primary

flow inlet fractal header fluidly connecting the primary flow inlet to each of the plurality of primary flow subset passageways, the primary flow inlet fractal header being configured to fractally branch the fluid flow from a single passageway at the primary flow inlet to the plurality of primary flow subset passageways.

3. The counter-flow heat exchanger of claim **1**, wherein the secondary flow passageway further comprises a secondary flow inlet fractal header fluidly connecting the secondary flow inlet to each of the plurality of secondary flow subset passageways, the secondary flow inlet fractal header being configured to fractally branch the fluid flow from a single passageway at the secondary flow inlet to the plurality of secondary flow subset passageways.

4. The counter-flow heat exchanger of claim **2**, wherein the secondary flow passageway further comprises a secondary flow inlet fractal header fluidly connecting the secondary flow inlet to each of the plurality of secondary flow subset passageways, the secondary flow inlet fractal header being configured to fractally branch the fluid flow from a single passageway at the secondary flow inlet to the plurality of secondary flow subset passageways.

5. The counter-flow heat exchanger of claim **1**, wherein the primary flow passageway further comprises a primary flow outlet fractal header fluidly connecting the primary flow outlet to each of the plurality of primary flow subset passageways, the primary flow outlet fractal header being configured to fractally unify the primary flow subset passageways to a single passageway at the primary flow outlet.

6. The counter-flow heat exchanger of claim **1**, wherein the secondary flow passageway further comprises a secondary flow outlet fractal header fluidly connecting the secondary flow outlet to each of the plurality of secondary flow subset passageways, the secondary flow outlet fractal header being configured to fractally unify the secondary flow subset passageways to a single passageway at the secondary flow outlet.

7. The counter-flow heat exchanger of claim **2**, wherein the primary flow passageway further comprises a primary flow outlet fractal header fluidly connecting the primary flow outlet to each of the plurality of primary flow subset passageways, the primary flow outlet fractal header being configured to fractally unify the primary flow subset passageways to a single passageway at the primary flow outlet.

8. The counter-flow heat exchanger of claim **3**, wherein the secondary flow passageway further comprises a secondary flow outlet fractal header fluidly connecting the secondary flow outlet to each of the plurality of secondary flow subset passageways, the secondary flow outlet fractal header being configured to fractally unify the secondary flow subset passageways to a single passageway at the secondary flow outlet.

9. The counter-flow heat exchanger of claim **4**, wherein the primary flow passageway further comprises a primary flow outlet fractal header fluidly connecting the primary flow outlet to each of the plurality of primary flow subset passageways, the primary flow outlet fractal header being configured to fractally unify the primary flow subset passageways to a single passageway at the primary flow outlet.

10. The counter-flow heat exchanger of claim **4**, wherein the secondary flow passageway further comprises a secondary flow outlet fractal header fluidly connecting the secondary flow outlet to each of the plurality of secondary flow

subset passageways, the secondary flow outlet fractal header being configured to fractally unify the secondary flow subset passageways to a single passageway at the secondary flow outlet.

11. The counter-flow heat exchanger of claim **10**, wherein the primary flow passageway further comprises a primary flow outlet fractal header fluidly connecting the primary flow outlet to each of the plurality of primary flow subset passageways, the primary flow outlet fractal header being configured to fractally unify the primary flow subset passageways to a single passageway at the primary flow outlet.

12. The counter-flow heat exchanger of claim **1**, wherein the counter-flow heat exchanger is built in a single piece using additive manufacturing.

13. The counter-flow heat exchanger of claim **1**, wherein multiple linearly extending cylinders form each individual primary flow subset passageway and each individual secondary flow subset passageway within the heat exchanger core.

14. The counter-flow heat exchanger of claim **1**, wherein multiple curvilinear extending cylinders form each individual primary flow subset passageway and each individual secondary flow subset passageway within the heat exchanger core.

15. The counter-flow heat exchanger of claim **1**, wherein the heat exchanger core is composed of parallel alternating layers of the primary flow subset passageways and the secondary flow subset passageways.

16. The counter-flow heat exchanger of claim **1**, wherein at least one of the primary flow subset passageways and the secondary flow subset passageways are circular in shape.

17. The counter-flow heat exchanger of claim **1**, wherein the primary flow subset passageways are physically connected to the secondary flow subset passageways within the heat exchanger core.

18. A method of manufacturing a counter-flow heat exchanger, the method comprising:

forming a counter-flow heat exchanger using additive manufacturing, the counter flow heat exchanger comprising:

a primary flow passageway comprising a primary flow inlet, a primary flow outlet, and a plurality of primary flow subset passageways therebetween;

a secondary flow passageway comprising a secondary flow inlet, a secondary flow outlet, and a plurality of secondary flow subset passageways therebetween; and

a heat exchanger core comprising portions of the plurality of primary flow subset passageways and the plurality of secondary flow subset passageways, the secondary flow passageway being in thermal communication with the primary flow passageway in the heat exchanger core,

wherein the primary flow subset passageways in the heat exchanger core and the secondary flow subset passageways in the heat exchanger core are oriented such that primary fluid flow through the primary flow subset passageways flows opposite secondary fluid flow through the secondary flow subset passageways.

19. The method of claim **18**, wherein the additive manufacturing is via direct metal laser sintering.