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(54) **Pipe within pipe heat exchanger construction**

(57) A pipe within pipe heat exchanger (10) construction is provided, in which one or more liner tubes (14) are positioned within a shell tube (12), with fluid flow in the liner tube(s) (14) and a different temperature fluid flowing in the space between the liner tube(s) (14) and the shell tube (12). Locations of reduced resistance to

bending are provided at one or more locations in one or both of the liner tube(s) (14) and the shell tube (12). One or more heat transfer structures may be affixed in thermally conductive contact to the outer surface of the liner tube (14), to facilitate heat transfer between the "inner" fluid flow and the "outer" fluid flow.

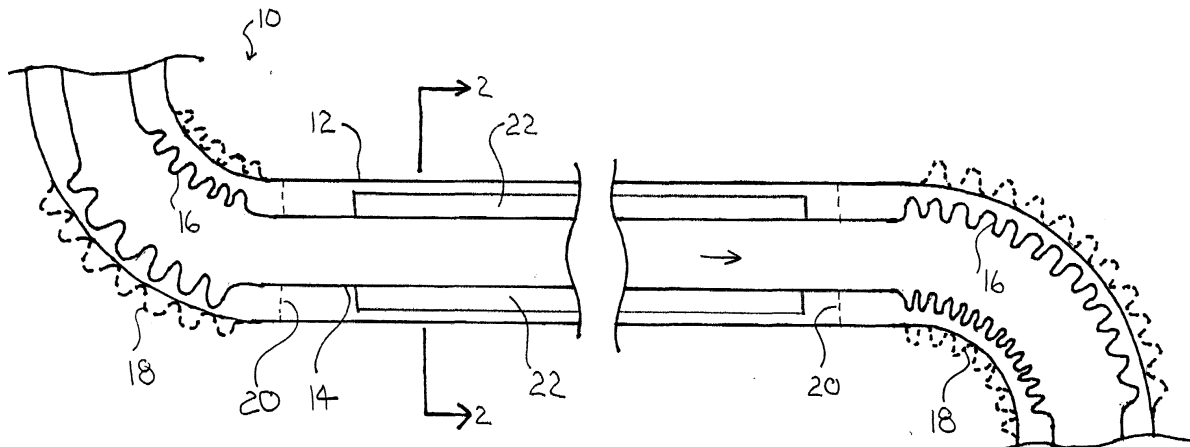


FIG. 1

Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to heat transfer apparatus, such as may be employed in fuel cell systems, internal combustion engine exhaust gas transfer systems, and other power generation systems. In particular, the present invention relates to heat transfer systems that employ two or more fluid conduits that are in heat-exchanging contact with one another.

2. The Prior Art

[0002] Heat transfer apparatus, for accomplishing transfer of heat from one contained flowing fluid to another contained flowing fluid, are known. Typically, such heat transfer apparatus employ two or more fluid conduits that are placed into heat transfer contact with one another.

[0003] One method that is known for constructing such a heat transfer apparatus is to provide a larger fluid conduit, through which one or more smaller fluid conduits are placed. In such a configuration, one fluid is propelled through the smaller, inner conduits, while another different fluid is propelled in the spaced between the outer surfaces of the smaller, inner conduits, and the inner surface of the surrounding conduit. Such heat exchangers are typically known as "shell and tube" heat exchangers. These heat exchangers are differentiated from finned heat exchangers, that pass a contained fluid flow through a fin array, that is cooled (or heated) by air flow, for example. Examples of finned heat exchangers are automotive radiators and refrigerator heat exchanger coils.

[0004] Prior art shell and tube heat exchangers, which may be employed, for example, in fuel cell power plants, and other power generation schemes, may have relatively large diameters, such as 8 - 9 inches. In addition, due to the relatively large scale, as a result of thermally induced dimensional distortions, such heat exchangers may require bellows even in straight runs, to accommodate thermally induced expansion and contraction.

[0005] Such heat exchangers are also typically very robustly built, and are thus relatively heavy, in addition to taking up space.

[0006] Prior art references, which illustrate contained fluid heat exchangers include: Newman et al., U.S. 4,033,381; Newburg, U.S. 4,250,927; Lee, U.S. 4,451,966; and Lee, U.S. 4,585,059.

[0007] It would be desirable to provide a heat exchanger apparatus, for transferring heat between two contained fluid flows, that is lighter, less rigid, and occupies a smaller envelope than such prior art heat exchanger apparatus.

[0008] It would also be desirable to provide a heat ex-

changer apparatus that has an improved and more efficient heat transfer construction.

[0009] These and other desirable characteristics of the invention will become apparent in view of the present specification including claims, and drawings.

Summary of the Invention

[0010] The present invention comprises a heat exchanger apparatus, for facilitating heat transfer between at least two fluids having a temperature gradient between them. The heat exchanger apparatus comprises at least one liner tube, for transporting a first fluid. A shell tube surrounds the at least one liner tube, for transporting a second fluid having a different temperature than the first fluid, in the region between an outer surface of the at least one liner tube and an inner surface of the shell tube.

[0011] The shell tube and the at least one liner tube are mechanically connected to one another in at least two longitudinally spaced locations. At least one region of reduced resistance to bending is arranged at a desired location along the length of at least one of the shell tube and the at least one liner tube, for facilitating coordinated simultaneous bending of the shell tube and the at least one liner tube at substantially longitudinal locations, along each of the shell tube and the at least one liner tube.

[0012] At least one heat transfer structure, is positioned in thermally conductive contact with at least portions of the outer surface of the at least one liner tube, for facilitating transfer of heat between the first and second fluids, when first fluid is being transported by the at least one liner tube and second fluid is being transported between the at least one liner tube and the shell tube.

[0013] The heat exchanger apparatus further comprises fittings disposed at opposite ends of the heat exchanger apparatus, operably connected to the at least one liner tube and the shell liner tube, for connecting the at least one liner shell tube to a source of first fluid and a destination for first fluid, and for connecting the shell tube to a source of second fluid and a destination for second fluid.

[0014] The at least one region of reduced resistance to bending preferably comprises a plurality of radially extending corrugations.

[0015] According to one embodiment of the invention, at least one of the shell tube and the at least one liner tube is formed from substantially smooth tubular material.

[0016] Preferably, the at least one heat transfer structure comprises at least one heat conducting fin, operably connected to the outside surface of the at least one liner tube for projecting into the second fluid, when second fluid is being transported in the region between the at least one liner tube and the shell tube. The at least one heat transfer structure may be formed as an accordion folded metal sheet that is wrapped circumferentially

around and affixed to the at least one liner tube.

[0017] The at least one liner tube, according to an embodiment of the invention, has a radial thickness of from 0.1 mm up to and including 0.5mm. According to an embodiment of the invention, the shell tube has a radial thickness of from 0.1 mm up to and including 0.7mm.

[0018] In an embodiment of the invention, the heat exchanger apparatus may further comprise at least one bulkhead, disposed at one end of the apparatus, for mechanically connecting the shell tube and the at least one liner tube.

[0019] The heat exchanger apparatus may further comprise at least one bracing member, operably disposed at a position longitudinally spaced from the ends of the apparatus, for mechanically connecting the shell tube and the at least one liner tube.

[0020] The heat exchanger apparatus may further include a non-linear flow path heat exchanger unit connected, in fluid transporting communication with the shell tube and the at least one liner tube.

Brief Description of the Drawings

[0021] Fig. 1 is a side elevation, in section, of a length of a heat exchanger, constructed in accordance with the principles of the present invention.

[0022] Fig. 2 is a sectional view, taken along line 2-2 of Fig. 1.

[0023] Fig. 3 is a schematic view of an end region of a heat exchanger according to the principles of the present invention.

[0024] Fig. 4 is a side elevation of a heat exchanger according to an alternative embodiment of the present invention, in which multiple liner tubes are employed.

[0025] Fig. 5 is a perspective view of the heat exchanger of Fig. 4, with the shell tube not shown, to illustrate the liner tubes, the areas of reduced resistance to bending and the bracing members.

[0026] Fig. 6 is a side elevation of a heat exchanger according to another alternative embodiment of the invention, in which an enhanced efficiency dedicated auxiliary heat exchanger unit is positioned in line.

[0027] Fig. 7 is a perspective view of the heat exchanger of Fig. 6, with the shell tube not illustrated.

[0028] Fig. 8 is a side elevation of a heat exchanger according to another alternative embodiment of the invention.

[0029] Fig. 9 is a cross-section of a terminating region of the heat exchanger of Fig. 8.

[0030] Fig. 10 is a side section of the terminating region of the heat exchanger of Fig. 8.

Detailed Description of the Drawings

[0031] While this invention is susceptible of embodiment in many different forms, there is shown herein in the drawings and will be described in detail several specific embodiments, with the understanding that the

present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the invention to the embodiments illustrated.

[0032] A representative length of heat exchanger apparatus 10, in accordance with the principles of the present invention, is shown in side section in Fig. 1, and in cross-section in Fig. 2. Heat exchanger apparatus 10 includes shell tube 12 and liner tube 14. For a typical heat exchanger application, in order to maximize the efficiency of the heat transfer, the two concentric flows will be in opposite directions, as indicated by the respective arrows. Only a section of apparatus 10 is shown in Fig. 1. It is understood that at each end of apparatus 10 (one end of which is illustrated schematically in Fig. 3), suitable termination structures will be provided, so that the two counterflows can be directed to their respective destinations.

[0033] Preferably all the components of heat exchanger apparatus 10 will be fabricated from temperature resistant material that are resistant to chemical attack by the fluids that will be conducted through them. It is additionally preferable that the materials used be resistant to chemical breakdown, when exposed to the fluids being transported, which would result in the creation of electrically conductive ions being released into the fluids. This is a crucial requirement for heat exchanger apparatus that are employed in fuel cell applications, inasmuch as the presence of such ionic materials could result in electrical short-circuiting of the fuel cell. Suitable materials include stainless steels, Inconels, high-nickel steels generally and nickel-chromium steels. The specific formulations of such materials may readily be determined by one of ordinary skill in the art having the present disclosure before them, according to the specific requirements of any given application.

[0034] The specific dimensions of the components of the heat exchanger apparatus 10 may vary from instance to instance, in preferred embodiments of the invention. It is contemplated that the shell tube 12 will typically have a wall thickness from 0.1mm up to 0.7mm, and that the liner tube 14 will typically have a wall thickness from 0.1mm up to 0.5mm, for optimum heat transfer while retaining sufficient strength and flexibility. However, other thicknesses may be employed, as desired or required by any specific application.

[0035] Preferred commercial embodiments of heat exchanger apparatus 10 may be manufactured in a number of standardized, initially straight lengths (e.g., 1 foot, 2 feet, 4 feet, etc.). Each such embodiment will be flexible, to enable the lengths to be bent, *in situ*, to accommodate installations where straight runs are not practical or even possible. Accordingly, In order to make heat exchanger apparatus 10 flexible, at least a portion of liner tube 14 will be provided with circumferential or spiral corrugations 16 as shown in Fig. 1. While shell tube 12 may be smooth, in alternative embodiments of the invention, shell tube 12 may also be provided with corrugations 18 (shown in broken lines in Fig. 1), pref-

erably in regions that substantially surround, axially and circumferentially, corrugations 16 of liner tube 12.

[0036] In the illustrated embodiment, corrugations are provided in the liner tube, to provide regions that are programmed to bend, upon application of force. In alternative embodiments of the invention, the liner tube may be entirely smooth, apart from the heat transfer structures described hereinbelow. However, accomplishing coordinated bending of an outer tube (preferably also noncorrugated) and a smooth liner tube is physically more difficult, though techniques are known for accomplishing such coordinated bending, such as packing a substantially incompressible, but flowable material in the liner tube, and in the space between the liner tube and the shell tube.

[0037] In the illustrated embodiment, the diameters of the corrugations 16 are such that their crests do not contact the inner surface of shell tube 12. In alternative embodiments of the invention, the crests of corrugations 16 may make contact with portions of the inner surface of shell tube 12, in order to facilitate bending.

[0038] Apparatus 10, as shown in the figures may be provided with predominantly straight lengths, combined with localized corrugated regions. Alternatively, apparatus 10 may be provided with greater length corrugated regions, and little or no purely straight lengths. In such embodiments, the corrugations may be varied, from region to region, to make certain regions of the apparatus more likely to bend under application of bending forces than other regions. Corrugated regions having a smaller crest-to-crest pitch, and having higher corrugation amplitude, as compared to other, adjacent corrugated regions, will be more likely to bend under bending forces. Accordingly, bending locations can be predesigned into specific places along the length of apparatus 10.

[0039] At the ends of any apparatus 10, a bracing member 20 will be provided (Fig. 3), to concentrically locate and affix liner tube 14, relative to shell tube 12. Such a spacer may be a simple bulkhead in the form of a disk having the diameter of the inner diameter of the shell tube 12 with an aperture in it, having a diameter that is the outer diameter of liner tube 14. While bracing member 20 is shown in Fig. 3 as forming the end of shell tube 12, in alternative embodiments of the invention, other bracing member configurations may be employed, that do not provide the end bulkhead for a length of apparatus. For example, depending upon the length of apparatus 10, additional bracing members 20 may be provided along the length of apparatus 10, as shown in broken lines in Fig. 1. Of course, any such bracing members 20 that are used between the ends of the apparatus must be provided with suitable apertures in order to permit flow through the bracing member.

[0040] In other embodiments of the invention, the ends of apparatus 10 may be provided with quick-connect structures, that will enable them to be snapped into corresponding fittings in the destination structures, in which the two flows will be separated from one another,

inside the destination structure. One example would be the use of heat exchanger apparatus 10, to carry coolant and/or fuel and/or oxidant to a combination inlet/outlet for a fuel cell stack, or a reformer for a fuel cell stack. In order to obtain required sealing, it is contemplated that such connections may employ O-rings as part of the connection structure, presuming that the operating temperature regime permits the use of such sealing materials.

[0041] In order to facilitate heat transfer between the fluid being carried by liner tube 14 and the fluid being carried between liner tube 14 and shell tube 12, heat transfer structures may be provided. These heat transfer structures will create additional thermally conductive paths between liner tube 14 and the fluid between liner tube 14 and shell tube 12. For example, heat transfer structure 22 may be provided (Fig. 2, not shown in Figs. 1 and 3), that circumferentially surrounds and is in physical contact with liner tube 12. Heat transfer structure 22 comprises, in one embodiment of the invention, a thin (e.g., 0.2mm - 0.5mm) accordion folded structure that when wrapped around, and affixed to liner tube 12 (such as by welding/brazing), forms a plurality of fins 24 over and through which the "outer" fluid flows. Depending upon the direction of the temperature gradient between the two fluids being transported, heat will pass from the "outer" fluid, into the fins, and into the liner tube; alternatively heat will transfer out of the surface of the liner tube, and some directly into the fluid and some into the fins and then into the "outer" fluid.

[0042] Many different heat transfer structure configurations may be employed. For example, the individual fins may be straight or wavy, solid, or with cross-apertures to promote turbulent flow (and thus more heat transfer). In addition, while the heat transfer structure 22 has been illustrated as surrounding the "straight, smooth" portions of the liner tube 14, suitably configured structures may be used to surround corrugated or other non-smooth sections, to facilitate heat transfer. Also, the fins 24 of heat transfer structure 22 have been shown, as not making contact with the inner surface of shell tube 12. In alternative embodiments, fins 24 may in fact make contact. However, it is believed that heat being conducted along fins 24 will be transferred to or from the outer fluid, and will not be conducted all the way to the shell tube 12.

[0043] While the illustrated heat transfer structure is shown and described as being circumferentially wrapped about the liner tube, other structures and methods of application may be employed. For example, a fin structure may be helically wrapped around the liner tube (s). In addition, the liner tubes may be constructed so that their cross-sectional configuration may vary along their length (e.g., from circular cross-section to rectangular, triangular, polygonal, ellipsoidal, etc.), for example, to provide circular cross-sections in areas where bending is to occur first, and to have one of the other configurations in regions that will have straight runs.

[0044] Preferably, the heat transfer structure will be fabricated from the same type of metal material as the shell tube and liner tube.

[0045] In an alternative embodiment, the heat transfer structures, instead of being applied and affixed to the liner tube(s), may be integrally, monolithically formed into the outer surface of the liner tube(s) if desired. For example, the liner tube(s), or at least portions of their length(s) may be formed with a star-shaped cross-sectional configuration, to create a greater amount of surface area, in proportion to the volume of the flow in the liner tube(s), that is exposed to the fluid in the shell tube.

[0046] Other cross-sectional configurations may be used for the liner tube(s), such as rectangles, ovals or other polygonal shapes. A helical liner tube may be employed.

[0047] It is to be understood that the overall length of heat exchanger apparatus 10 will vary in accordance with the requirements of any given installation application and accordingly, the number of corrugated or finned sections will vary.

[0048] As mentioned herein, heat exchanger apparatus 10 may be usefully employed in many applications, such as heat exchange between the working fluids of a fuel cell, or in cooling recirculated exhaust gases, cooling internal combustion engine lubricating oil, etc.

[0049] While the present invention has been disclosed in the embodiment of a single liner tube concentrically arranged within a shell tube, it is contemplated that the liner tube, held by suitable bracing members, may be non-concentrically arranged in the shell tube. In addition, by using suitable bracing members (as required), instead of one liner tube, two or more liner tubes, carrying similar or different fluids, may be provided in the shell tube.

[0050] Figures 4 and 5 illustrate an alternative heat exchanger embodiment, in which multiple liner tubes are used. The fin-like heat transfer structures on the liner tubes have been omitted from the drawings for simplicity of illustration, but are understood to be present, and may be as shown and described with respect to Figs. 1 - 3, or may be varied in configuration and placement as described hereinabove. Heat exchanger 100 includes shell tube 112 and three liner tubes 114. Shell tube 112 is provided with one or more regions of reduced resistance to bending, exemplified by bellows corrugations 118. Similarly, liner tubes 114 are provided with one or more regions of reduced resistance to bending exemplified by bellows corrugations 116.

[0051] Heat exchanger 100 is provided with terminal bulkheads 122, which close the ends of the flow region for the fluid that flows in the shell tube 112, outside of the liner tubes 114. Entry 124 and exit 126 are provided for the entry and exit of the "outer" fluid. Bulkheads 122 have apertures 128 at which liner tubes 114 align and terminate, creating collection regions 130. Bracing members 120 are provided to stabilize the three liner tubes.

[0052] It is to be understood that while the embodiment of Figs. 4 and 5 has only one region of reduced resistance to bending, depending upon the length of a given embodiment, several such areas of reduced bending resistance may be provided at longitudinally spaced locations along the length of the heat exchanger apparatus.

[0053] Figs. 6 and 7 illustrate another alternative embodiment of the invention. The fin-like heat transfer structures on the liner tubes have been omitted from the drawings for simplicity of illustration, but are understood to be present, and may be as shown and described with respect to Figs. 1 - 3, or may be varied in configuration and placement as described hereinabove. Depending upon the heat transfer requirements of a particular installation, and the space availability, there may be insufficient available running length to obtain a desired degree of heat transfer, using the embodiments of Figs. 1 - 3 or Figs. 4 - 5. Accordingly, it may be desirable to insert into the length of the heat exchanger a dedicated, high-efficiency heat exchanger structure. This means a heat exchanger in which the two fluid paths are non-linear, broken up, spread out and/or intertwined, to maximize the amount of effective heat exchanger surface area.

[0054] Figures 6 and 7 illustrate such an alternative heat exchanger embodiment, in which multiple liner tubes are used, together with a dedicated, high efficiency heat exchanger apparatus. The heat transfer structures on the liner tubes have been omitted from the drawings for simplicity of illustration. Heat exchanger 200 includes shell tube 212a and 212b, and two sets of three liner tubes 214a and 214b. Shell tube 212a is provided with one or more regions of reduced resistance to bending, exemplified by bellows corrugations 218. Similarly, liner tubes 214a are provided with one or more regions of reduced resistance to bending exemplified by bellows corrugations 216.

[0055] Heat exchanger 200 is provided with terminal bulkheads 222, which close the ends of the flow region for the fluid that flows in the shell tubes 212a and 212b, outside of the liner tubes 214a, 214b. Entry 224 and exit 226 are provided for the entry and exit of the "outer" fluid. Bulkheads 222 have apertures 228 at which liner tubes 214a, 214b align and terminate, creating collection regions 230. Bracing members 220 are provided to stabilize the three liner tubes.

[0056] Between the two runs of shell tube and liner tubes, high efficiency non-linear flow path heat exchanger 232 is positioned. Heat exchanger 232 will be provided with suitable inlet and outlet structures that will align with shell tube 212a and liner tubes 214b, and shell tube 212b and 214b. The interior of high efficiency heat exchanger 232 will be provided with numerous labyrinthine non-linear flow paths that create large heat exchange surface areas between the two fluid flows, to provide the additional heat exchange capacity that may be required, when the available running length is insufficient to use the previously described embodiments.

Another method may be to simply provide a cube within a cube, with six sets (for each side of the cube) of adjacent planar surfaces, between which one of the fluids flow. The other fluid may pass into the interior of the inner box. This structure creates increased areas of active heat exchange surface, and is also a non-linear exchanger, as one fluid must go up, down and around the other, to pass through the exchanger. Such high efficiency heat exchanger apparatus are known and commercially available, from such sources as Laminova US Inc., of Old Saybrook, Kentucky, which produces a heat exchanger unit known the "Laminova core design".

[0057] It is to be understood that while the embodiment of Figs. 6 and 7 has only one region of reduced resistance to bending, depending upon the length of a given embodiment, several such areas of reduced bending resistance may be provided at longitudinally spaced locations along the length of the heat exchanger apparatus.

[0058] Figs. 8 - 10 illustrate another embodiment of the invention, featuring multiple liner tubes, and the regions of reduced bending resistance (such as bellows corrugations 318) in which the arrangement of the end connection structures is reversed, relative to the arrangement of the embodiments of Figs. 1 - 7. In each of those embodiments, the fluid from the liner tubes enters or exits the respective heat exchangers either by having the liner tube(s) extend longitudinally out of the ends of the exchanger, passing through apertures in end bulkheads, or by having the liner tube(s) terminate in collection regions 130, 230. In these embodiments, the entry and exit openings for the fluid from the shell tube extend radially from the ends of the shell tube. Each of the entry and exit openings may be connected to suitable fittings on the source and destination components, by known connection techniques, such as threaded connections, bolted flange connections, bayonet connections, etc., to provide quick-connections without the need for welding, etc.

[0059] In Figs. 8 - 10, the fin-like heat transfer structures on the liner tubes have been omitted from the drawings for simplicity of illustration, but are understood to be present, and may be as shown and described with respect to Figs. 1 - 3, or may be varied in configuration and placement as described hereinabove. In the embodiment of Figs. 8 - 10, liner tubes 314 terminate in enclosed, cylindrical (though other shapes may be used) collection regions 330, that are provided with radially extending entry and exit ports 334, 336, that project through shell tube 312. In turn, the fluid flow in the shell tube 312 enters and exits longitudinally, through the annular space between shell tube 312 and collection regions 330.

[0060] Figs. 9 and 10 are cross- and side-sectional views of the terminating regions of heat exchanger 300 of Fig. 8, showing the relationship between shell tube 312, collection regions 330, and liner tube entry or exit ports 334/336.

[0061] The foregoing description and drawings merely explain and illustrate the invention and the invention is not limited thereto except insofar as the appended claims are so limited, as those skilled in the art who have the disclosure before them will be able to make modifications and variations therein without departing from the scope of the invention.

10 Claims

1. A heat exchanger apparatus, for facilitating heat transfer between at least two fluids having a temperature gradient between them, comprising:

at least one liner tube, for transporting a first fluid;

a shell tube, surrounding the at least one liner tube, for transporting a second fluid having a different temperature than the first fluid, in the region between an outer surface of the at least one liner tube and an inner surface of the shell tube;

the shell tube and the at least one liner tube being mechanically connected to one another in at least two longitudinally spaced locations; at least one region of reduced resistance to bending arranged at a desired location along the length of at least one of the shell tube and the at least one liner tube, for facilitating coordinated simultaneous bending of the shell tube and the at least one liner tube at substantially longitudinal locations, along each of the shell tube and the at least one liner tube;

at least one heat transfer structure, positioned in thermally conductive contact with at least portions of the outer surface of the at least one liner tube, for facilitating transfer of heat between the first and second fluids, when first fluid is being transported by the at least one liner tube and second fluid is being transported between the at least one liner tube and the shell tube.

2. The heat exchanger apparatus according to claim 1, further comprising:

fittings disposed at opposite ends of the heat exchanger apparatus, operably connected to the at least one liner tube and the shell liner tube, for connecting the at least one liner shell tube to a source of first fluid and a destination for first fluid, and for connecting the shell tube to a source of second fluid and a destination for second fluid.

3. The heat exchanger apparatus according to claim 1, wherein the at least one region of reduced resistance to bending comprises:

a plurality of radially extending corrugations.

4. The heat exchanger apparatus according to claim 1, wherein at least one of the shell tube and the at least one liner tube is formed from substantially smooth tubular material. 5
5. The heat exchanger apparatus according to claim 1, wherein the at least one heat transfer structure comprises:
at least one heat conducting fin, operably connected to the outside surface of the at least one liner tube for projecting into the second fluid, when second fluid is being transported in the region between the at least one liner tube and the shell tube. 10
6. The heat exchanger apparatus according to claim 1, wherein the at least one heat transfer structure is formed as an accordion folded metal sheet that is wrapped circumferentially around and affixed to the at least one liner tube. 15 20
7. The heat exchanger apparatus according to claim 1, wherein the at least one liner tube has a radial thickness of from 0.1 mm up to and including 0.5mm. 25
8. The heat exchanger apparatus according to claim 1, wherein the shell tube has a radial thickness of from 0.1 mm up to and including 0.7mm.
9. The heat exchanger apparatus according to claim 1, further comprising at least one bulkhead, disposed at one end of the apparatus, for mechanically connecting the shell tube and the at least one liner tube. 30 35
10. The heat exchanger apparatus according to claim 1, further comprising at least one bracing member, operably disposed at a position longitudinally spaced from the ends of the apparatus, for mechanically connecting the shell tube and the at least one liner tube. 40
11. The heat exchanger apparatus according to claim 1, further comprising:
a non-linear flow path heat exchanger unit connected, in fluid transporting communication with the shell tube and the at least one liner tube. 45 50 55

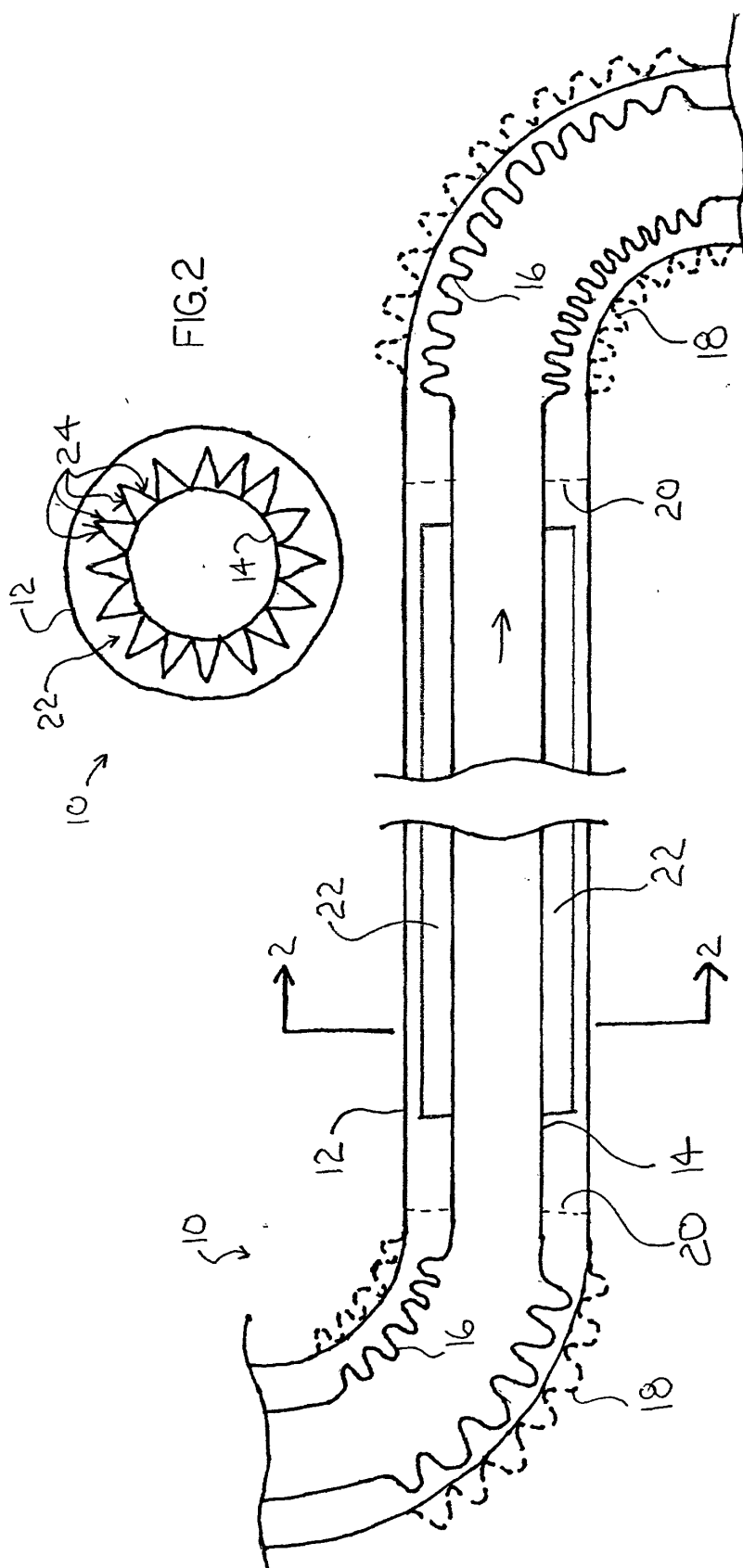
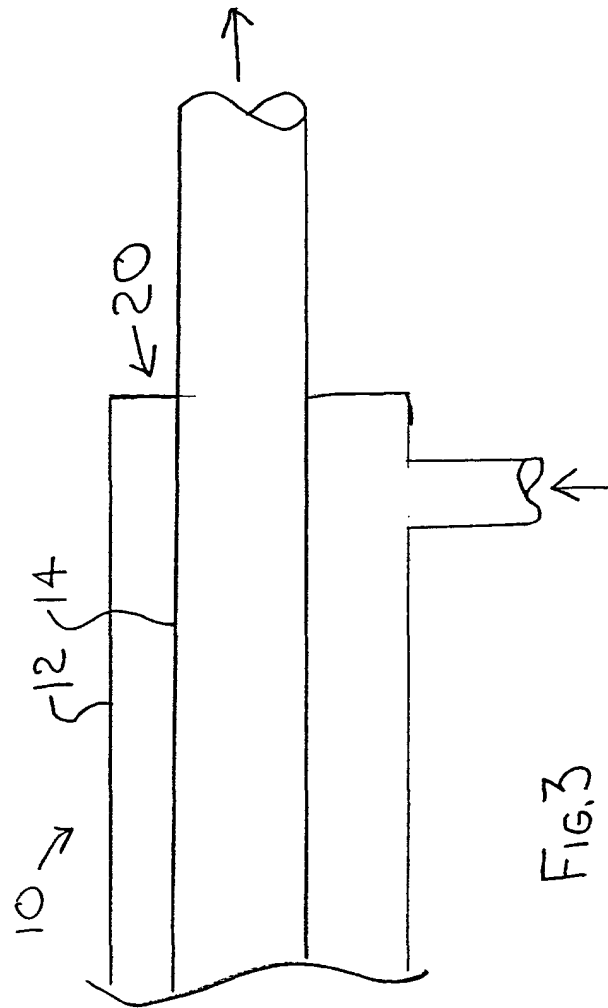
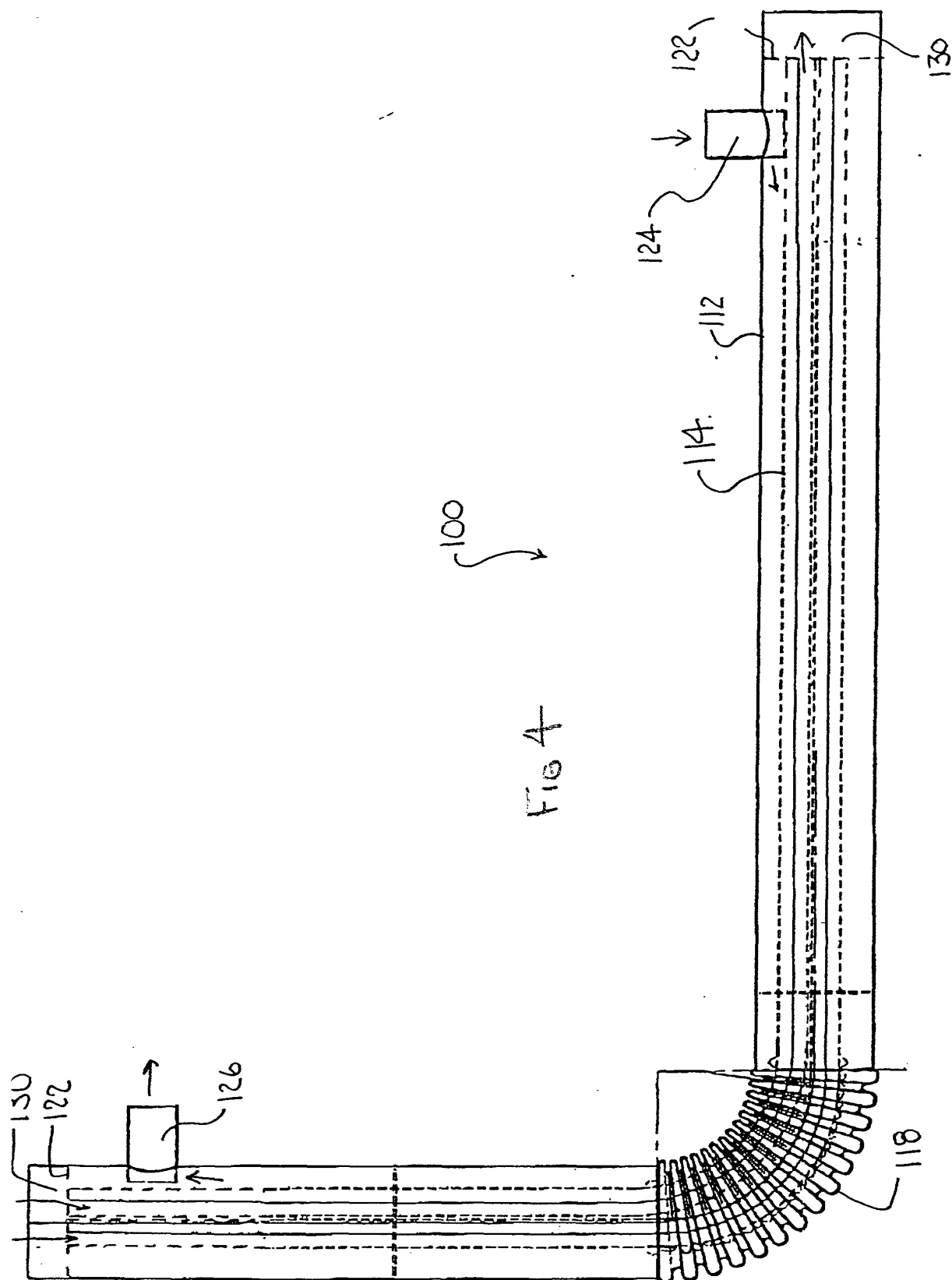


FIG. 1





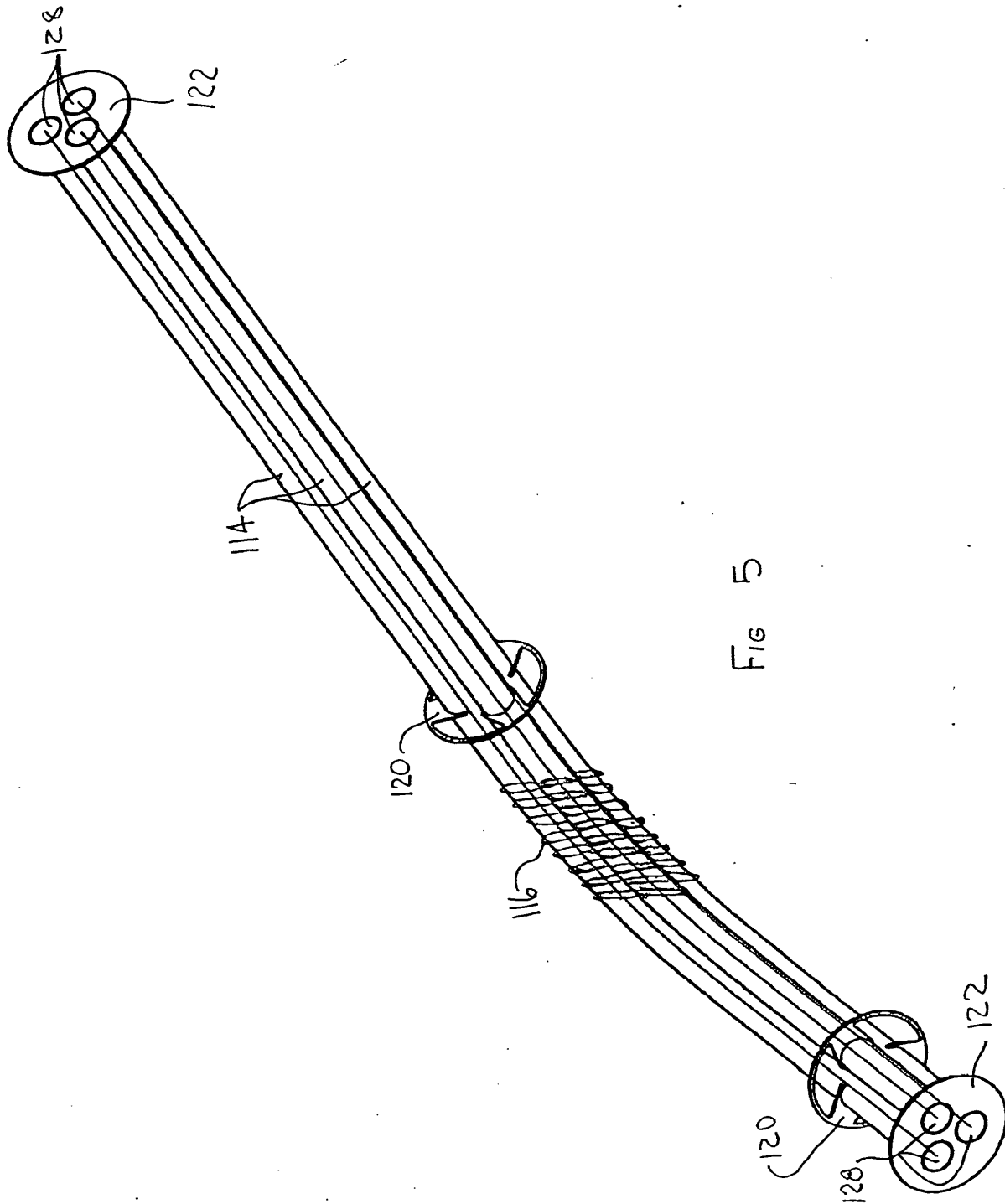


Fig. 5

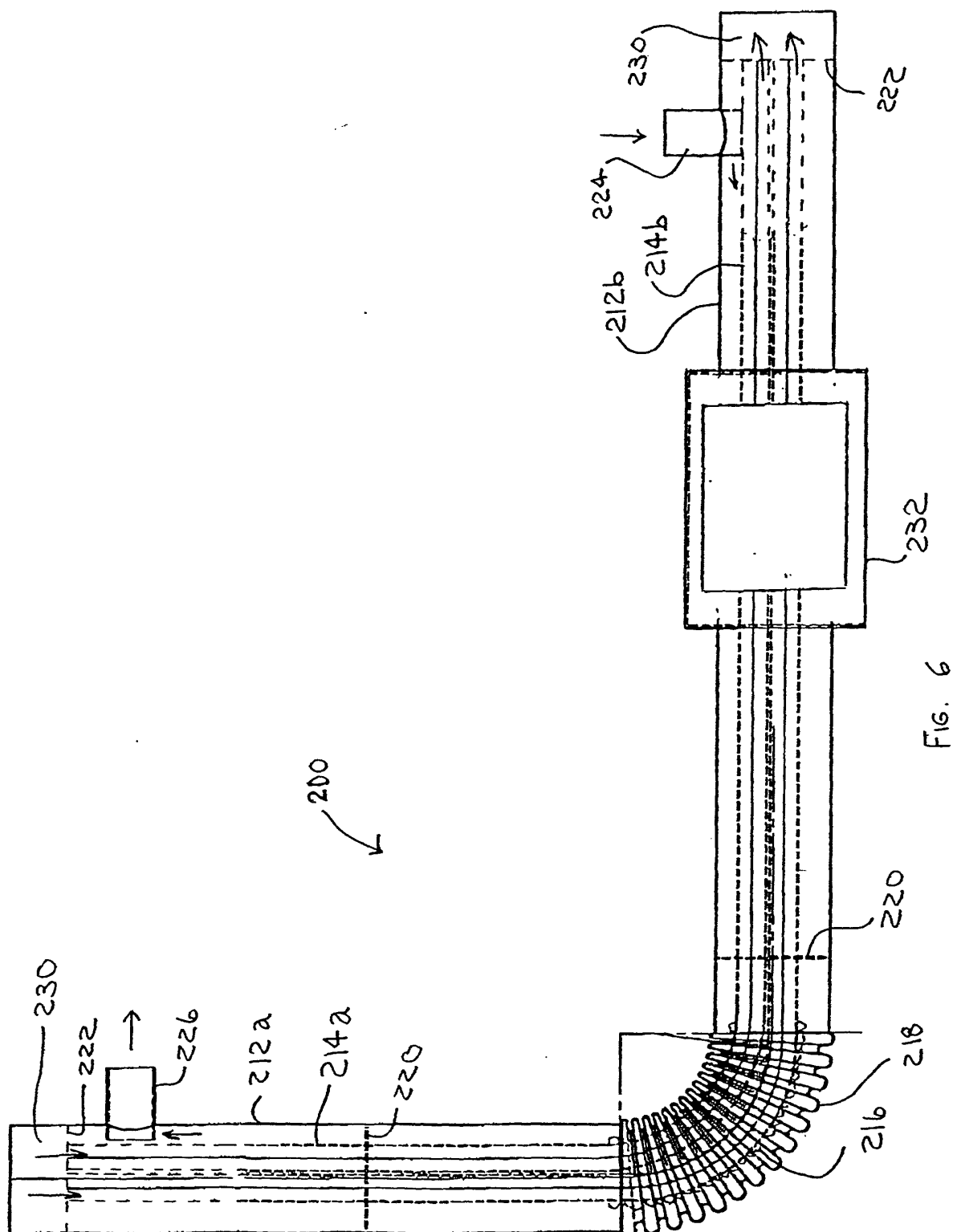


Fig. 6

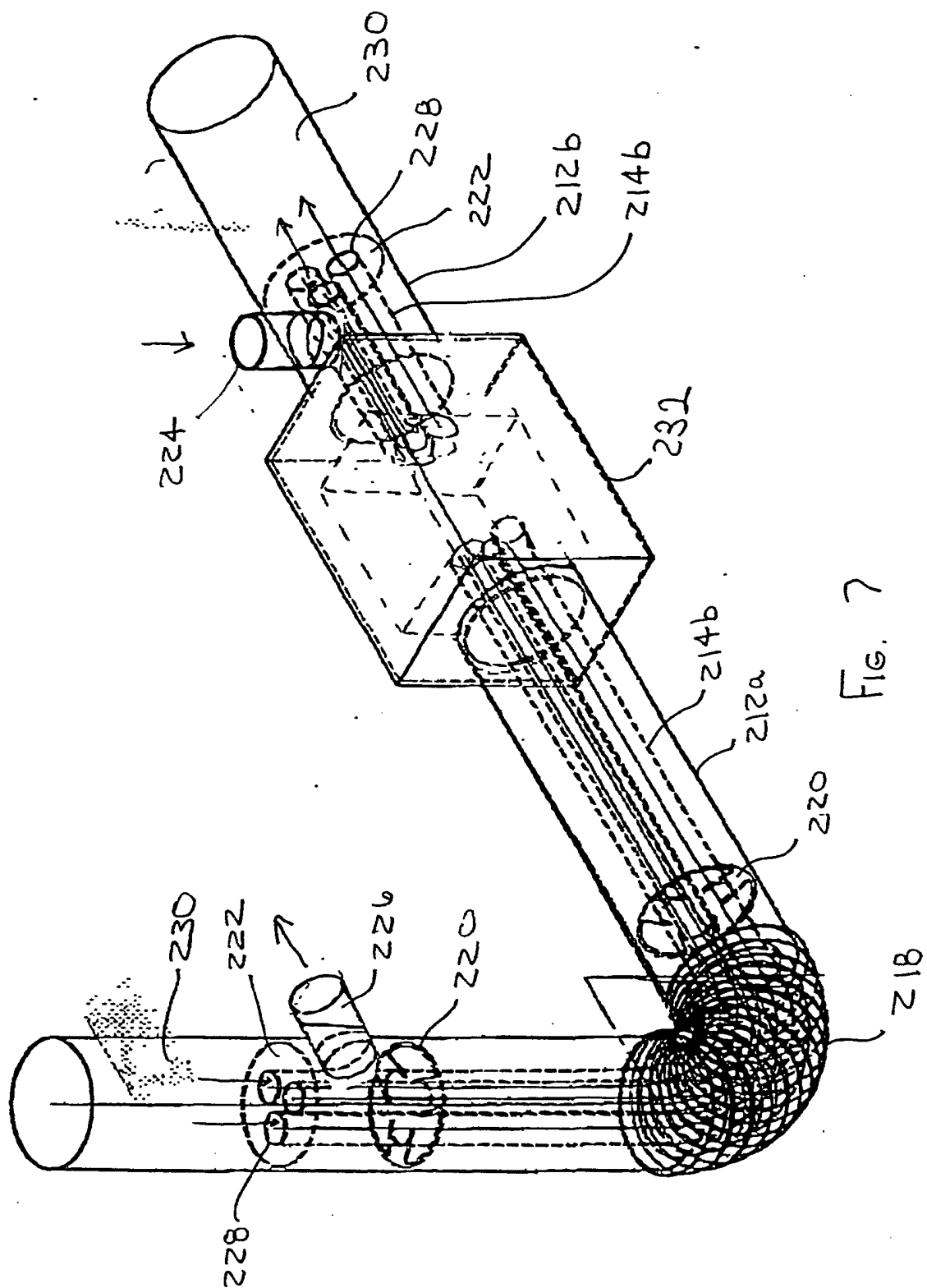
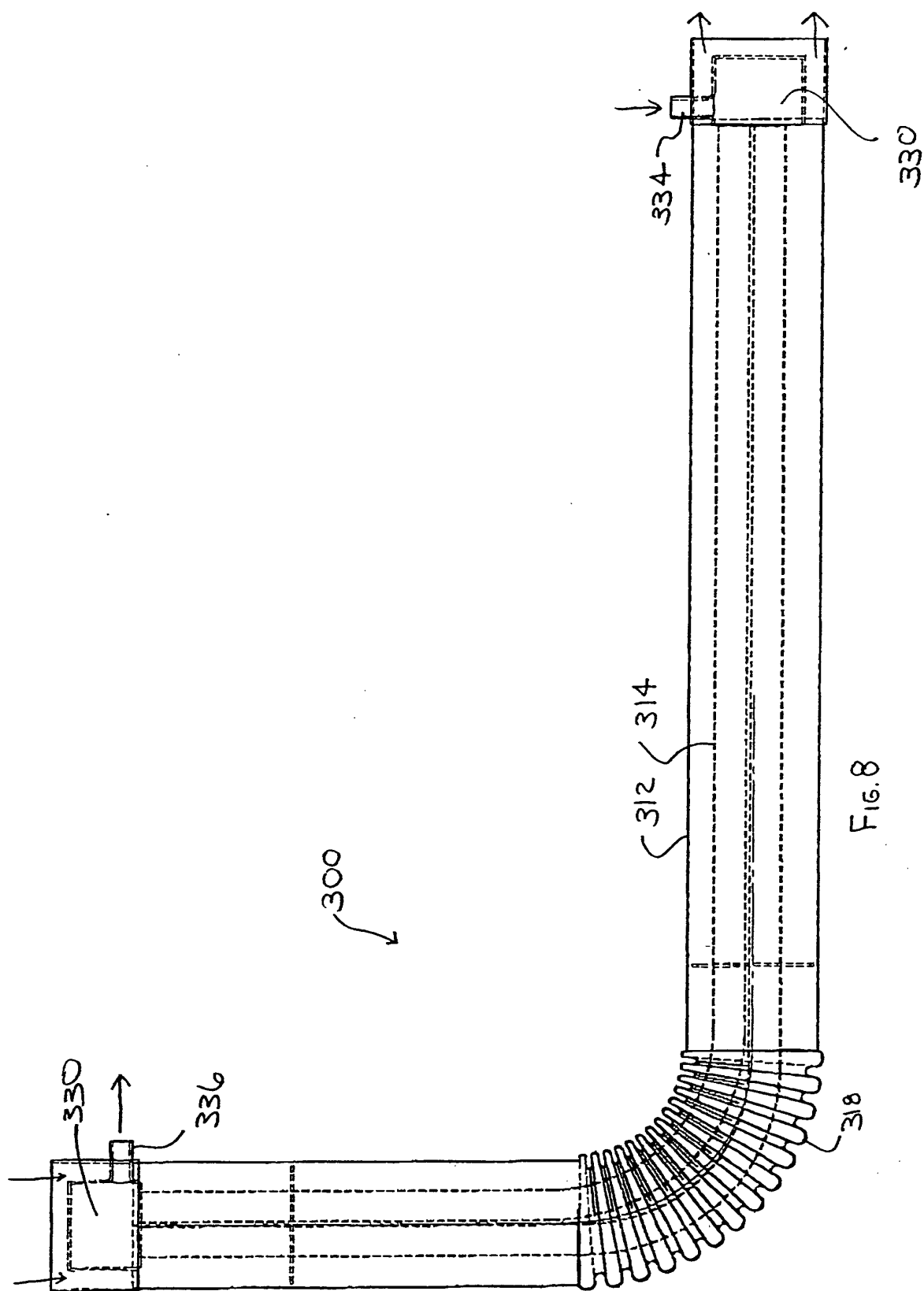


Fig. 7



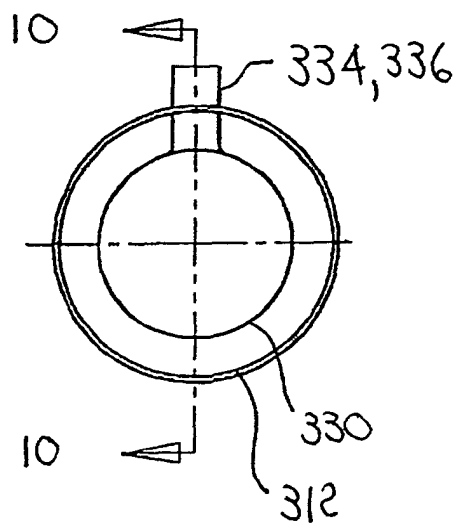


FIG. 9

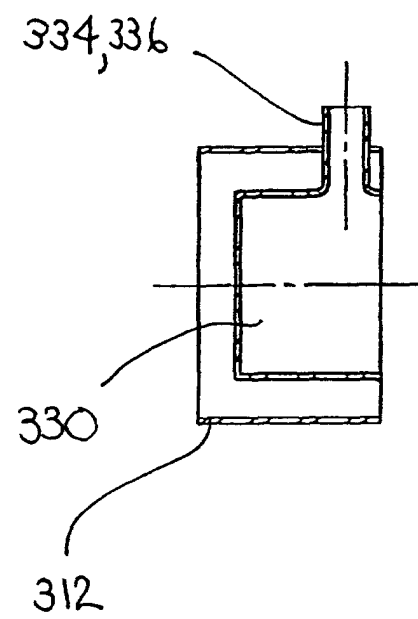


FIG. 10