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- (71) Applicant: KOCH HEAT TRANSFER COMPANY, LP
[US/US]; 12602 Fm 529, Houston, Texas 77041 (US).
- (72) Inventor: LJUBICIC, Blazo; Rue 6, Michel Weyer, L-2726 Luxembourg (LU).
- (74) Agent: HURD, Michael B.; Hovey Williams LLP, 10801 Mastin Blvd., Suite 1000, 84 Corporate Woods, Overland Park, Kansas 66210 (US).
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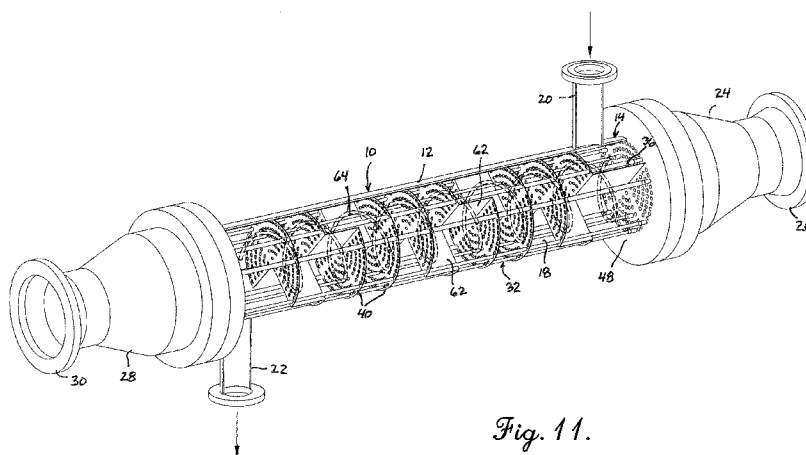


Fig. 11.

(57) Abstract: A tube bundle is provided for a shell-and-tube heat exchanger. The tube bundle includes a plurality of elongated tubes, each of which has an intermediate portion that has a cross section in the form of a flattened circle with at least one axis of symmetry. The tubes are arranged in concentric circles with the axis of symmetry extending tangentially to the circle to facilitate rotational flow of a shell-side fluid.

TUBE BUNDLE FOR SHELL-AND-TUBE HEAT EXCHANGER AND A METHOD OF USE

BACKGROUND OF THE INVENTION

[0001] The present invention relates generally to shell-and-tube type heat exchangers and, more particularly, to the tube bundles used in such heat exchangers and a method of use thereof.

[0002] Shell-and-tube heat exchangers are used in a wide variety of applications to cause heat exchange between fluid streams. In these heat exchangers, a first fluid referred to as the tube-side fluid is directed through elongated tubes in a tube bundle that is housed within a shell that is typically of cylindrical shape. A large number of the tubes are included in the tube bundle and they extend in parallel and spaced-apart relationship to each other. The tubes are fixed at their opposite ends to generally planar header plates that are also known as tube sheets. A second fluid, commonly referred to as the shell-side fluid, flows within the shell in the open space surrounding the tubes and undergoes heat exchange with the first fluid stream flowing within the tubes.

[0003] Shell-and-tube heat exchangers are constructed in different known ways to provide the desired flow arrangement between the tube-side fluid and the shell-side fluid. For example, in a single-pass tube and a single-pass shell arrangement, straight tubes are used and the inlet and outlet nozzles for the tube-side fluid stream are located at opposite ends of the heat exchanger. The inlet and outlet nozzles for the shell-side fluid are likewise located at opposite ends of the heat exchanger. The flow of the fluid streams in such an arrangement can be either co-current or counter-current. In co-current flow, the inlet nozzles for both the tube-side fluid and the shell-side fluid are located at the same end of the heat exchanger and the outlet nozzles for the fluids are located at the opposite end of the heat exchanger. The tube-side and shell-side fluids then

enter at the same end of the heat exchanger, flow along its length, and exit at the opposite end of the heat exchanger. In counter-current flow, the inlet nozzles for the fluids are located at opposite ends of the heat exchanger and the outlet nozzles are likewise located at opposite ends of the heat exchanger. The fluids then enter at opposite ends of the heat exchanger, flow in opposite directions along its length, and exit at opposite ends of the heat exchanger.

[0004] In another flow arrangement, U-shaped tubes are used instead of straight tubes and the inlet and outlet nozzles for the tube-side fluid are located at the same end of the heat exchanger. The tube-side fluid flows along one leg of each U-shaped tube and then reverses direction and flows back along the other leg of the U-shaped tube. The inlet and outlet nozzles for the shell-side fluid in this arrangement can both be located at the same end of the heat exchanger as the inlet and outlet nozzles for the tube-side fluid, in which case a longitudinal baffle is positioned between the legs of the U-shaped tubes to create a divided flow path that allows the shell-side fluid on one side of the longitudinal baffle to flow in one direction before reversing and flowing in the opposite direction along the other side of the longitudinal baffle.

[0005] Alternatively, the inlet and outlet nozzles for the shell-side fluid can be located at opposite ends of the shell so that the shell-side fluid flows in only one direction along the length of the heat exchanger. Other multiple-pass shell and multiple-pass tube arrangements are used conventionally and are further defined in the Standards of the Tubular Exchanger Manufacturers Association, which is incorporated by reference herein in its entirety.

[0006] In many applications, the tubes in the tube bundle pass through baffles that are spaced apart along the longitudinal length of the tube bundle to provide structural support for the tubes and thereby reduce sagging and vibration of the tubes. Each baffle also serve to divert the flow of the shell-side fluid so that it is forced to flow across rather than along the tubes to achieve

better heat transfer with the tube-side fluid. The baffles are typically in the form of single or double segmental cut baffles in which a quadrant or other region of the baffle is open to allow the passage of the shell-side fluid or disc and donut baffles in which the shell-side fluid flows through the annular region surrounding the disc baffles and through the center openings of the donut baffles.

[0007] During initial assembly of the tube bundle, tie rods are typically welded to the baffles to form a cage-like structure in which the baffles are fixed in spaced apart relationship. The rotational orientation of each baffle is set so that the holes in the baffles through which the tubes are inserted are in longitudinal alignment. Because the holes are only slight larger than the tubes to reduce fluid leakage through the holes, the longitudinal alignment of the holes must be within tight tolerances. Once the tubes have been inserted through the holes in the baffles, the ends of the tubes are affixed to the tube sheet(s) to form the completed tube bundle.

[0008] The tube sheets in conventional shell-and-tube heat exchangers are normally formed of high-strength metal or metal alloy and have a thickness much greater than that of shell to withstand the operating pressures within the heat exchanger and to compensate for structural weakness created by the large number of holes that receive the tubes in the tube sheets. Fabrication of the tube sheets is a time-intensive process as the holes must typically be individually drilled through the thickness of the tube sheets. The drilling operation creates holes that are circular in cross section, thereby limiting the tubes to those having the same circular cross section. Although greater heat transfer can be achieved when using tubes having an elliptical or other non-circular cross section, the circular cross section of the holes in the tube sheets has heretofore prevented the use of tubes with an elliptical, obround, oval or egg-shaped cross section in shell-and-tube heat exchangers.

SUMMARY OF THE INVENTION

[0009] In one aspect, the present invention is directed to a tube bundle for use in a shell-and-tube heat exchanger. The tube bundle includes a plurality of hollow, elongated tubes extending in parallel and spaced-apart relationship to each other and arranged in a pattern of a series of concentric circles. Each of the tubes has a first end for entry of a first fluid for flow within the tube along a longitudinal length of the tube and an opposite second end for the first fluid to exit the tube and an intermediate portion between the first and second ends. The intermediate portion of each tube has a cross section in the form of a flattened circle. In one embodiment, the flattened circle has one axis of symmetry. In another embodiment, the flattened circle has two axes of symmetry, with one axis being shorter than the other. The tubes are oriented so that the axis of symmetry or the longer one of the axes of symmetry extends tangentially to the concentric circle in which the tube is positioned.

[00010] The tube bundle also includes a first tube sheet having holes into which the first ends of the tubes extend and are secured and a plurality of baffles positioned at spaced apart positions along the longitudinal length of the tubes for supporting the tubes and guiding flow of a second fluid exteriorly of said tubes. Each of the baffles has a cutout for passage of fluid and a plurality of openings through which at least some of said tubes are inserted. The cutouts of adjacent ones of the baffles are rotationally offset around a center longitudinal axis of said tube bundle. The intermediate portion of each tube is at least a majority of the longitudinal length of each tube, at least 75% of the length of each tube, at least 90% of the length of each tube, or at least 95% of the length of each tube. In one embodiment, the first and second ends of the tubes have a circular cross section with the diameter of the second end being less than that of the first end and being the same or less than the length of the shorter axis of symmetry of the intermediate portion

of each tube. The tube bundle further includes a plurality of flow-diverting plates, each of the plates extending in one direction between and in contact with adjacent ones of the baffles and extending in an opposite direction along the cutouts in said adjacent ones of the baffles. The plates serve to induce rotational flow of the shell-side fluid.

[00011] In another aspect, the invention is directed to a shell-and-tube heat exchanger in which is positioned a tube bundle as described above.

[00012] In a further aspect, the invention is directed to a method of operating the heat exchanger and inducing rotational flow of the shell-side fluid to facilitate heat transfer with the tube-side fluid using the flow-diverting plates described above.

BRIEF DESCRIPTION OF THE DRAWINGS

[00013] Fig. 1 is a perspective view from one end of a heat exchanger made in accordance with one embodiment of the present invention, with portions of a shell of the heat exchanger broken away to show an internal tube bundle;

[00014] Fig. 2 is a perspective view of the heat exchanger shown in Fig. 1 taken from the opposite end;

[00015] Fig. 3 is an enlarged fragmentary perspective view of the heat exchanger showing an end portion of the tube bundle;

[00016] Fig. 4 is an enlarged fragmentary perspective view illustrating the process of assembling the tube bundle by inserting the individual tubes through the openings in the baffles;

[00017] Fig. 5 is a side elevation view of the heat exchanger taken in vertical section;

[00018] Fig. 6 is an enlarged fragmentary end elevation view taken in vertical section along line 6-6 in Fig. 5 to show the tubes and tie-rod inserted through a portion of one of the baffles;

- [00019] Fig. 7 is a fragmentary end elevation view of one of the tubes;
- [00020] Fig. 8 is an elevation view taken from one end of the tube shown in Fig. 7;
- [00021] Fig. 9 is an elevation view taken from the opposite end of the tube;
- [00022] Fig. 10 is an illustration of the variables used in the calculation of the elliptical cross section of a portion of the tube;
- [00023] Fig. 11 is a perspective view from one end of a heat exchanger, with portions of a shell of the heat exchanger broken away to show another embodiment of the internal tube bundle and with most of tubes removed to better illustrate the other components of the tube bundle; and
- [00024] Fig 12 is a fragmentary perspective view of the tube bundle shown in Fig. 11, with the tubes removed to allow illustration of the flow path of the shell-side fluid.

DETAILED DESCRIPTION

[00025] Turning now to the drawings in greater detail and initially to Figs. 1-5, a heat exchanger constructed in accordance with the present invention is represented broadly by the numeral 10. Heat exchanger 10 is a shell-and-tube heat exchanger and includes an elongated shell 12 having a front end 14, an opposed end 16, and an open interior volume 18. The shell 12 is of a generally cylindrical configuration, although other shapes can be used. The shell 12 is formed of a metal, polymer or other material that is generally inert to the fluid within the shell 12 and is able to withstand the pressures and temperatures within the shell 12 during operation of the heat exchanger 10.

[00026] An inlet nozzle 20 extends from the shell 12 at the front end 14 for introducing a shell-side fluid into an interior volume 18 of the shell 12. An outlet nozzle 22 extends from the shell 12 for removing the shell-side fluid from the interior volume 18 of the shell 12. In one

embodiment, the outlet nozzle 22 is positioned at the opposite end 16 of the shell 12 from the front end 14 at which the inlet nozzle 20 is positioned. In another embodiment, the outlet nozzle 22 is positioned at the front end 14 with the inlet nozzle 20 and a longitudinally-extending baffle (not shown) is positioned within the interior volume 18 of the shell 12. The longitudinally-extending baffle forces the shell-side fluid to flow from the inlet nozzle 20 to the opposite end 16 of the shell 12 before reversing direction to flow on the opposite side of the baffle back to the front end 14 where it exits the interior volume 18 of the shell 12 through the outlet nozzle 22. The inlet nozzle 20 and the outlet nozzle 22 typically extend radially from the shell 12, but they may extend from the shell 12 in other orientations, such as tangentially.

[00027] In the illustrated single pass tube-side embodiment, an inlet channel or head 24 defining an interior plenum 25 and having an inlet nozzle 26 for the tube-side fluid is positioned to close the open front end 14 of the shell 12. An outlet channel or head 28 defining an interior plenum 29 and having an outlet nozzle 30 for the tube-side fluid is positioned to close the open end 16 of the shell 12. In a two pass tube-side embodiment, the inlet head 24 and outlet head 28 are both positioned at the front end 14 of the shell 12 and the other end 16 of the shell is closed. The inlet nozzle 26 and outlet nozzle 30 extend along the longitudinal center axis of the shell 12 in the illustrated embodiment, but they may extend in other orientations, such as perpendicularly to the longitudinal center axis of the shell 12.

[00028] A tube bundle 32 is positioned in the open interior volume 18 of the shell 12 and comprises a plurality of hollow, elongated tubes 34 that extend in a parallel and spaced-apart relationship to each other and are positioned in a preselected pattern. Each of the tubes 34 has an open first end 36 for entry of a tube-side fluid for flow within the tube 34 along a longitudinal length of the tube 34 and an opposite open second end 38 for the first fluid to exit the tube 34.

The tubes 34 are formed from thermally-conductive, corrosion-resistant materials, such as various metals, including copper alloy, stainless steel, carbon steel, non-ferrous copper alloy, Inconel alloys, nickel, Hastelloy alloys, and titanium.

[00029] The tube bundle 32 includes a plurality of plate-like baffles 40 positioned at spaced apart positions along the longitudinal length of the tubes 34. The baffles 40 function to redirect the flow of the shell-side fluid as it flows exteriorly of the tubes 34. The baffles 40 also serve to support and maintain the desired positioning of the tubes 34. As best shown in Fig. 4, each of the baffles 40 has individual openings 42 through which the tubes 34 extend. The openings 42 are sized slightly larger than the tubes 34 to permit the tubes 34 to be longitudinally inserted through the openings 42 while minimizing the amount of the shell-side fluid that can pass through the openings 42.

[00030] The baffles 40 are formed as incomplete discs and are sized so that their outer perimeters contact or are closely spaced from the inner surface of the shell 12. When the baffles 40 are positioned perpendicularly to the center longitudinal axis of the shell, the baffles 40 may be formed as incomplete circular discs. When the baffles 40 are inclined from the perpendicular, the baffles 40 may be formed as incomplete elliptical discs. The baffles 40 are referred to as incomplete discs because they each include a cutout 44 that allows for the passage of the shell-side fluid through the baffle 40. The cutout 44 in one embodiment intersects the outer perimeter of the baffle 40. The cutout 44 may be formed as a sector, segment or other portion of the baffle 40. In one embodiment, the cutout 44 is a sector having an angle of between 45 and 270 degrees, between 75 and 240 degrees, between 85 and 230 degrees, 90 degrees, 135 degrees, or 180 degrees.

[00031] The cutouts 44 in adjacent baffles 40 are rotationally or otherwise offset from each other about the longitudinal center axis of the shell 12 to create the desired flow path of the shell-side fluid as it flows within the interior volume 18 of the shell 12 from the inlet nozzle 26 to the outlet nozzle 30. In one embodiment, the cutouts 44 in the baffles 40 are hemispheres and the cutouts 44 in adjacent baffles 40 are rotated 180 degrees from each other to create a sinusoidal flow path for the shell-side fluid. In another embodiment, the cutouts 44 in the baffles 40 are quadrants and the cutouts 44 in adjacent baffles 40 are rotated 90 degrees from each other to cause create a spiral flow of the shell-side fluid.

[00032] The tube bundle 32 may include tie rods 46 that extend longitudinally through and are fixed to the perimeter regions of the baffles 40 to secure the baffles 40 at the desired longitudinal spacing and rotational orientation. The number of tie rods 46 can be varied as needed. In one embodiment, between four and twenty-four tie rods 46 are evenly spaced about the perimeter of the baffles 40.

[00033] The tube bundle 32 includes at least one tube sheet 48 that is positioned at the front end 14 of the shell 12 and separates the open interior volume 18 of the shell 12 from the interior plenum 25 of the inlet head 24. The tube sheet 48 is normally disc-shaped with a perimeter that seals against the inner surface of the shell 12 in a conventional fashion. As best shown in Fig. 5, the tube sheet 48 includes a plurality of holes 49 that extend completely through the thickness of the tube sheet 48 between its opposing faces. The first ends 36 of the tubes 34 are inserted into and secured within the holes 49 of the tube sheet 48. If the tubes 34 are U-shaped, the second ends 38 of the tubes 34 are inserted into and secured within other holes 49 of the tube sheet 48. In the illustrated embodiment in which the tubes 34 are straight, a second tube sheet 50 is positioned at the opposite end 16 of the shell 12 and separates the open interior volume 18 of the

shell 12 from the interior plenum 29 of the outlet head 28. The second ends 38 of the tubes 34 are inserted into and secured within the holes 49 that extend through the second tube sheet 50. As can best be seen in Fig. 3, in the illustrated embodiment, the first and second ends 36 and 38 of the tubes 34 are received within sleeves 51 fitted into the holes 49 in the tube sheets 48 and 50.

[00034] The tube sheets 48 and 50 must withstand the operating pressures within the heat exchanger 10. Because the presence of the holes 49 significantly reduces the strength of the tube sheets 48 and 50, the tube sheets 48 and 50 are formed from high-strength material with a thickness that is a multiple of that of the shell 12. In one embodiment, each of the tube sheets 48 and 50 is formed of a high-strength metal or metal alloy and has a thickness of between two and ten inches. Because of the hardness and thickness of the material used for the tube sheets 48 and 50, the holes 49 in one embodiment of the tube sheets 48 and 50 are circular in cross section and are formed in a drilling operation.

[00035] An intermediate portion 52 of each tube 34 between the first and second ends 36 and 38 of the tube 34 has a cross section in the form of a flattened circle. In one embodiment, the flattened circle has two axes of symmetry that extend at right angles to each other, with one axis being shorter than the other, to form geometric shapes such as elliptical or obround for the cross section of the tube 34. In another embodiment, the flattened circle has only one axis of symmetry to form a geometric shape such as oval or egg-shaped for the cross section of the tube 34. When the cross section of the tube 34 has two axes of symmetry, such as shown in Fig. 10, the tube 34 has a longer axis 54 of a preselected length at the widest part of the cross section of the tube 34 and a perpendicular shorter axis 56 at the narrowest part of the cross section of the tube 34. In the embodiment shown in Fig. 10, the cross section of the tube 34 is elliptical and the

radii r_1 and r_2 are co-linear at points P_1 and P_2 of tangency of the two curves. At the limits of its domain, radius r_1 intersects the longer elliptical axis “a” at focal points Q_1 and Q_2 , which is also the center point for the radius r_2 . The ratio of the shorter elliptical axis “b” to the longer elliptical axis “a” is in the range of $0.22 < b/a < 0.92$.

[00036] The intermediate portion 52 of each tube 34 comprises at least a majority of the longitudinal length of each tube 26, at least 75% of the length of each tube 34, at least 90% of the length of each tube 34, or at least 95% of the length of each tube 34. As can best be seen in Figs. 7-10, in one embodiment, the first end 36 of each tube 34 is of a circular cross section with a diameter that is greater than that of the second end 36. The diameter of the first end 36 of each tube 34 is also greater than that of the length of the minor axis 56 (Fig. 10) of the cross section of the intermediate portion 52 of the tube 34 and is less than the length of the longer axis 54 (Fig. 10) of each tube 34. The second end 38 of each tube 34 also has a circular cross section with a diameter that is the same as or slightly less than the length of the minor axis 56 (Fig. 10) of the cross section of the intermediate portion 52 of the tube 34.

[00037] Each tube 34 can be fabricated from stock having a circular cross section with a diameter that is the same as that of the first end 36. The tube 34 is then flattened by one or more series of rollers to form the desired geometric shape for the cross section of the intermediate portion 52. The second end 38 is then formed by coning tools to achieve a circular cross section with a smaller diameter. As can be seen in Fig. 7, each tube 34 includes a transition segment 58 between the first end 36 and the intermediate portion 52 and a similar transition segment 60 between the second end 38 and intermediate portion 52. The tubes 34 may either be bare or they may have extended or enhanced internal and/or external surfaces. In one embodiment, the extended surfaces are fins (not shown) that extend longitudinally along the tubes 34.

[00038] In one embodiment, the openings 42 in the baffles 40 have the same elliptical, obround, oval, egg-shaped or other geometric shape as the cross-sectional shape of the intermediate portion 52 of the tubes 34. The openings 42 are slightly larger than the intermediate portion 52 of the tubes 34 so that the tubes 34 can be inserted through and maintain a tight fit within the openings 42 to reduce the amount of shell-side fluid that can pass through the openings 42. As one example, the openings 42 are approximately 0.4 mm larger than the outer dimension of the tubes 34. The openings 42 can be arranged with their longer axes extending vertically, horizontally, or an orientation between vertical and horizontal. The openings 42 may each be oriented in the same direction or they may be independently oriented.

[00039] The openings 42 in the baffles 40 are arranged to place the tubes 34 in a preselected pattern of a series of concentric circles with the longer axis 56 of each tube 34 extending tangentially to the associated circle.

[00040] In the embodiment illustrated in Figs. 11 and 12, the tube bundle 32 also includes a plurality of flow-diverting plates 62 that extend generally perpendicularly to the baffles 40 and are positioned to induce a rotational flow designated by the lines 64 in Fig. 11 and the arrows 66 in Fig. 12 in the shell-side fluid as it travels along the length of the shell 12. Each plate 62 extends between an adjacent pair of baffles 40 or between an end baffle 40 and the tube sheets 48 or tube sheet 50. Each plate 62 extends in one direction between and in contact with the adjacent ones of the baffles 40. Each plate 62 extends in an opposite direction along the entire length of the cutouts 44 of the adjacent ones of the baffles 44. The plates 62 may extend perpendicularly to the baffles 40 and radially from a center longitudinal axis of the tube bundle 32 when one edge of the cutout 44 in one baffle 40 is longitudinally aligned with the opposite edge of the cutout 44 in the paired baffle 40, as illustrated in Fig. 2. When the edges of the

cutouts 44 are not aligned because of additional rotational positioning of the downstream baffle 40, the plates 62 will not extend perpendicularly to the baffles 40 or radially to the center longitudinal axis but will be twisted from that orientation so that the edges of the plates 62 extend along the cutouts 44 of the adjacent baffles 40. The plates 62 may be generally planar or they may be curved in one or more directions to facilitate the flow of the shell-side fluid along the face of the plates 62

[00041] During assembly of the tube bundle 32, the tube sheets 48 and 50 and the baffles 40 are spaced apart the desired preselected distance from each other and with their openings 42 in alignment. The tie-rods 46 are then welded or otherwise fixed to the baffles 40 to secure the baffles 40 in their spaced-apart and rotational relationship to each other. One end of each tie-rod 46 may be screwed into a threaded hole (not shown) in one of the tube sheets 48 and 50 and the other end of the tie-rod 46 is fixed to the last baffle 40 at the opposite end of the tube bundle 32.

[00042] Once the cage-like structure has been formed by the tube sheets 48 and 50, baffles 40, and tie-rods 46, the smaller-diameter, second end 38 of each tube 34 is inserted through one of the holes 49 in the tube sheet 48 and moved longitudinally the second end 38 passes through one of the openings 42 in the first baffle 40 at one end of the tube bundle 32. The tube 34 is then rotated as needed to align the longer and shorter axes 54 and 56 of the intermediate portion 52 of the tube 34 with the corresponding axes of the opening 42 in the end baffle 40. The tube 34 is then fed through the aligned openings 42 in the successive baffles 40 until the first end 36 of the tube 34 passes through the last baffle 40 at the opposite end of the tube bundle 32 and is seated within one of the holes 49 in the other tube sheet 50. The remaining tubes 34 are inserted in the same fashion through the holes 49 in the tube sheet 48, the openings 42 in each of the baffles 40, and the holes 49 in the other tube sheet 50. The first and second ends 36 and 38 of the tubes 34

in one embodiment slightly protrude beyond the tube sheets 48 and 50 are then fixed to the tube sheets 48 and 50, such as by expanding and welding to the tube sheets 48 and 50. The assembled tube bundle 32 is then inserted within the shell 12 of the heat exchanger 10 in a conventional fashion.

[00043] In use, the shell-side fluid is introduced through the inlet nozzle 20 into the interior volume 18 within the shell 12 of the heat exchanger 10. The shell-side fluid encounters the plates 62 which force the shell-side fluid to flow rotationally before entering each cutout 44 that allows passage of the shell-side fluid through successive baffles 40 as it travels along the length of the shell 12. The shell-side fluid is then removed from the interior volume 18 of the shell 12 through the outlet nozzle 22.

[00044] The tube-side fluid is introduced through the inlet nozzle 26 into the interior plenum 25 of the inlet head 24. The tube-side fluid is then distributed to the first ends 36 of the tubes 34 and flows along the length of the tubes 34 before exiting the second ends 38 of the tubes 34. The tube-side fluid then enters the interior plenum 29 of the outlet head 28 before exiting the heat exchanger 10 through the outlet nozzle 30.

[00045] As the shell-side and tube-side fluids travel within the heat exchanger 10, heat transfer occurs from one fluid to the other. The non-circular intermediate portion 52 of the tubes 34 in the tube bundle 32 provides higher tube-side and shell-side heat transfer coefficients than conventional round tubes because the flattened circle cross section of the intermediate portion 52 of the tubes 34 has a greater surface area than the round cross section of the tubes 34 from which the intermediate portion 52 was formed. By placing the tubes 34 in the pattern of concentric circles with the axis of symmetry or the longer one of the two axes of symmetry extending

tangentially to the circle, the desired rotational flow of the shell-side fluid is facilitated, thereby increasing the heat transfer performance of the tube bundle 32.

[00046] From the foregoing, it will be seen that this invention is one well adapted to attain all the ends and objectives hereinabove set forth together with other advantages that are inherent to the structure.

[00047] It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the invention.

[00048] Since many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

CLAIMS

What is claimed is:

1. A tube bundle for a shell-and-tube heat exchanger, said tube bundle comprising:
 - a plurality of hollow, elongated tubes extending in parallel and spaced-apart relationship to each other and arranged in a preselected pattern, each of said tubes having a first end for entry of a first fluid for flow within the tube along a longitudinal length of the tube and an opposite second end for the first fluid to exit the tube and an intermediate portion between the first and second ends;
 - a first tube sheet having holes into which the first ends of the tubes extend and are secured;
 - a plurality of baffles positioned at spaced apart positions along the longitudinal length of the tubes for supporting the tubes and guiding flow of a second fluid exteriorly of said tubes, each of said baffles having a cutout for passage of fluid and a plurality of openings through which at least some of said tubes are inserted, wherein said cutouts of adjacent ones of said baffles are rotationally offset around a center longitudinal axis of said tube bundle; and
 - a plurality of flow-diverting plates, each of said plates extending in one direction between and in contact with adjacent ones of said baffles and extending in an opposite direction along said cutouts in said adjacent ones of said baffles.
2. The tube bundle of claim 1, wherein said intermediate portion of each tube has a cross section in the form of a flattened circle with at least one axis of symmetry.
3. The tube bundle of claim 2, wherein said preselected pattern in which said tubes are arranged is a series of concentric circles.

4. The tube bundle of claim 3, wherein the tubes are arranged within each of said concentric circles so that said at least one axis of symmetry of each tube extends tangentially to said concentric circle.

5. The tube bundle of claim 4, wherein said flattened circle is in the form of an elliptical or obround geometric shape.

6. The tube bundle of claim 4, wherein said flattened circle is in the form of an oval or egg-shaped geometric shape.

7. The tube bundle of claim 4, wherein said flattened circle has two axes of symmetry, with one axis being shorter than the other.

8. The tube bundle of claim 4, wherein the cross section of the intermediate portion of each tube has two axes of symmetry, with one axis being shorter than the other, and wherein said first and second ends of the tubes are circular in cross section and one of said first and second ends has a diameter that is less than the length of said shorter axis of symmetry.

9. The tube bundle of claim 4, wherein said intermediate portion of each tube with said cross section in the form of a flattened circle is a majority of the longitudinal length of each tube.

10. The tube bundle of claim 4, wherein said intermediate portion of each tube with said cross section in the form of a flattened circle is at least 75% of the longitudinal length of each tube.

11. The tube bundle of claim 4, wherein said intermediate portion of each tube with said cross section in the form of a flattened circle is at least 90% of the longitudinal length of each tube.

12. The tube bundle of claim 4, wherein said intermediate portion of each tube with said cross section in the form of a flattened circle is at least 95% of the longitudinal length of each tube.

13. The tube bundle of claim 4, wherein said cutout is a sector or segment of the baffle.

14. A tube bundle for a shell-and-tube heat exchanger, said tube bundle comprising:
a plurality of hollow, elongated tubes extending in parallel and spaced-apart relationship to each other and arranged in a preselected pattern of a series of concentric circles, each of said tubes having a first end for entry of a first fluid for flow within the tube along a longitudinal length of the tube and an opposite second end for the first fluid to exit the tube and an intermediate portion between the first and second ends, wherein said intermediate portion of each tube has a cross section in the form of a flattened circle with at least one axis of symmetry, wherein the tubes are arranged within each of said concentric circles so that said at least one axis of symmetry of each tube extends tangentially to said concentric circle;

a first tube sheet having holes into which the first ends of the tubes extend and are secured;

a plurality of baffles positioned at spaced apart positions along the longitudinal length of the tubes for supporting the tubes and guiding flow of a second fluid exteriorly of said tubes, wherein each of said baffles is in the form of a partial disc and is positioned in a plane generally perpendicular to a center longitudinal axis of said tube bundle;

a cutout in each of said baffles and intersecting a periphery of said baffle for passage of fluid, wherein said cutouts of adjacent ones of said baffles are rotationally offset around a center longitudinal axis of said tube bundle;

a plurality of openings in each of said baffles through which at least some of said tubes are inserted, wherein said openings are shaped to conform to the cross section of the intermediate portions of the tubes; and

a plurality of flow-diverting plates, each of said plates extending in one direction between and in contact with adjacent ones of said baffles and extending in an opposite direction along said cutouts in said adjacent ones of said baffles.

15. The tube bundle of claim 14, wherein said first tube sheet has additional openings into which the second ends of the tubes extend and are secured.

16. The tube bundle of claim 14, including a second tube sheet having openings into which the second ends of the tubes extend and are secured.

17. The tube bundle of claim 14, wherein each of said tubes has said cross section in the form of a flattened circle along its entire longitudinal length.

18. A shell-and-tube heat exchanger comprising:

a shell having an interior volume in which a tube sheet in accordance with claim 1 is positioned;

an inlet nozzle extending from said shell for introducing a shell-side fluid into the interior volume of the shell;

an outlet nozzle extending from the shell for removing a shell-side fluid from the interior volume of the shell;

another inlet nozzle for introducing a tube-side fluid into the first ends of the tubes within the tube bundle; and

another outlet nozzle for removing the tube-side fluid from the second ends of the tubes within the tube bundle.

19. A method of operating a shell-and-tube heat exchanger having a shell with an interior volume in which a tube sheet in accordance with claim 1 is positioned, said method comprising the steps of:

introducing a shell-side fluid into the interior volume of the shell at one end thereof;

causing the shell-side fluid to flow rotationally in the interior volume as it encounters each of the plates before entering each of the cutouts;

passing the shell-side fluid through the cutouts in successive ones of the baffles as the shell-side fluid passes from said one end to an opposite end of the shell;

introducing a tube-side fluid into first ends of the tubes;

flowing the tube-side fluid along the length of the tubes;

wherein heat exchange occurs between the tube-side fluid and the shell-side fluid as the tube-side fluid flows along the length of the tubes and the shell-side fluid passes from one end of the shell to the opposite end of shell in said interior volume.

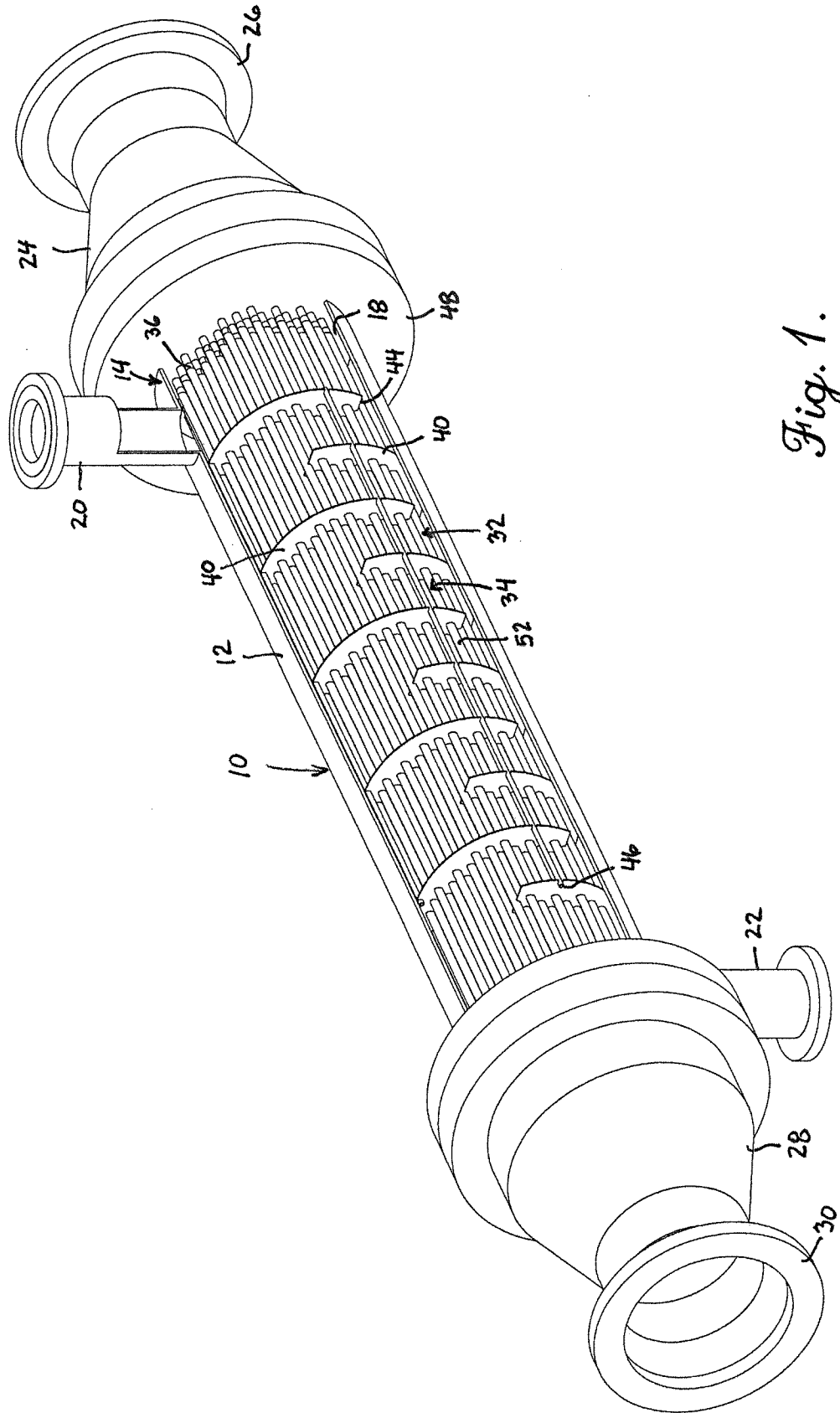


Fig. 1.

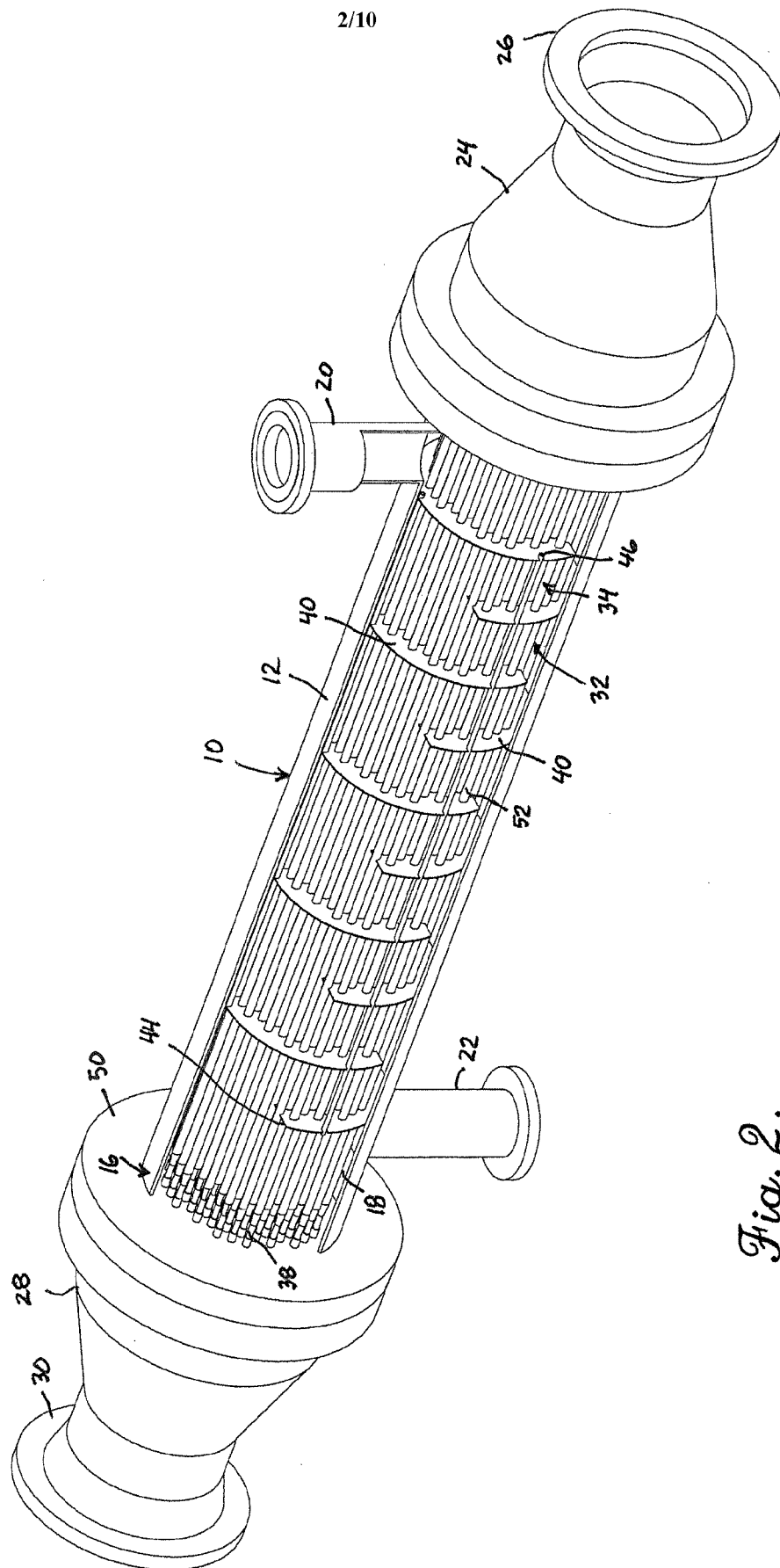


Fig. 2.

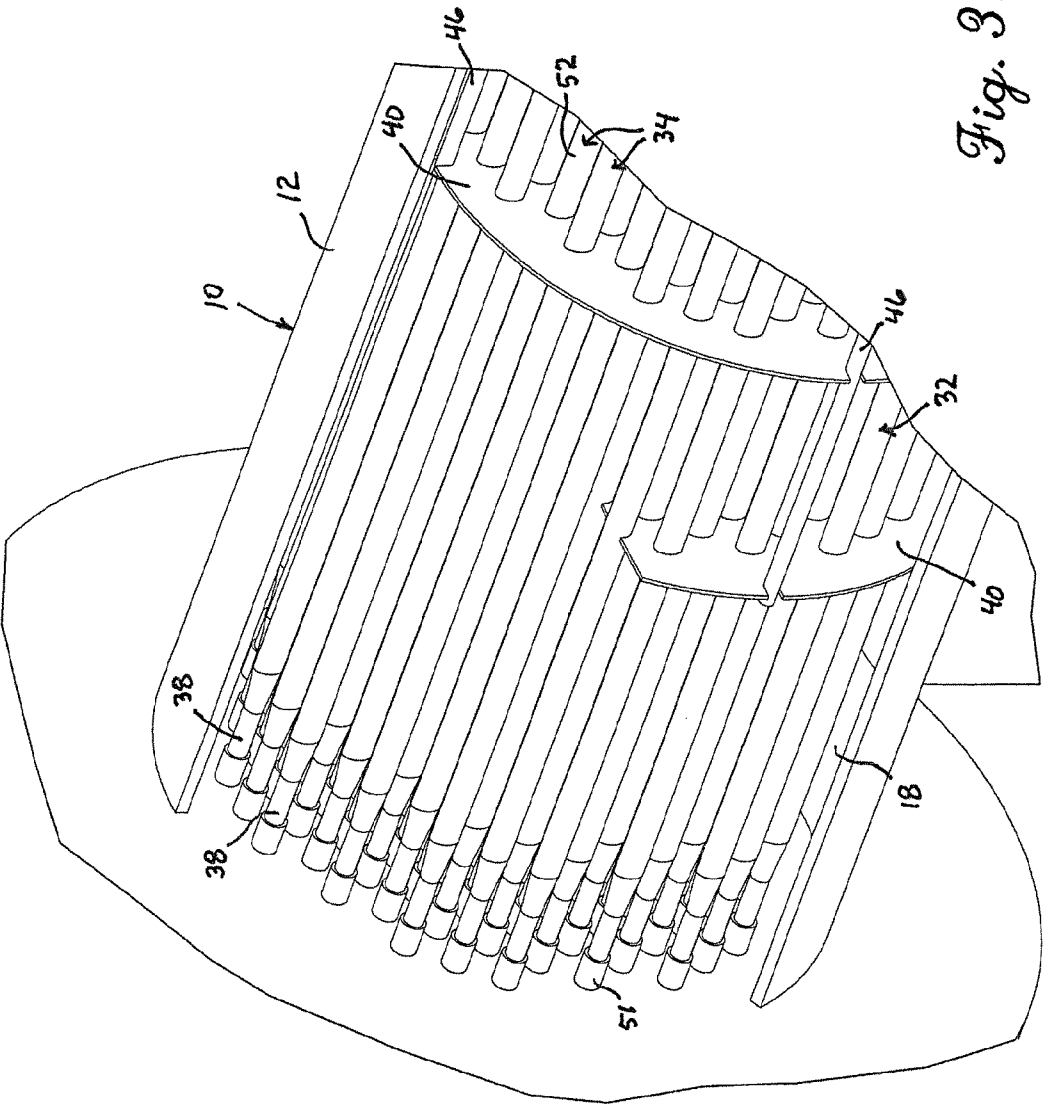


Fig. 3.

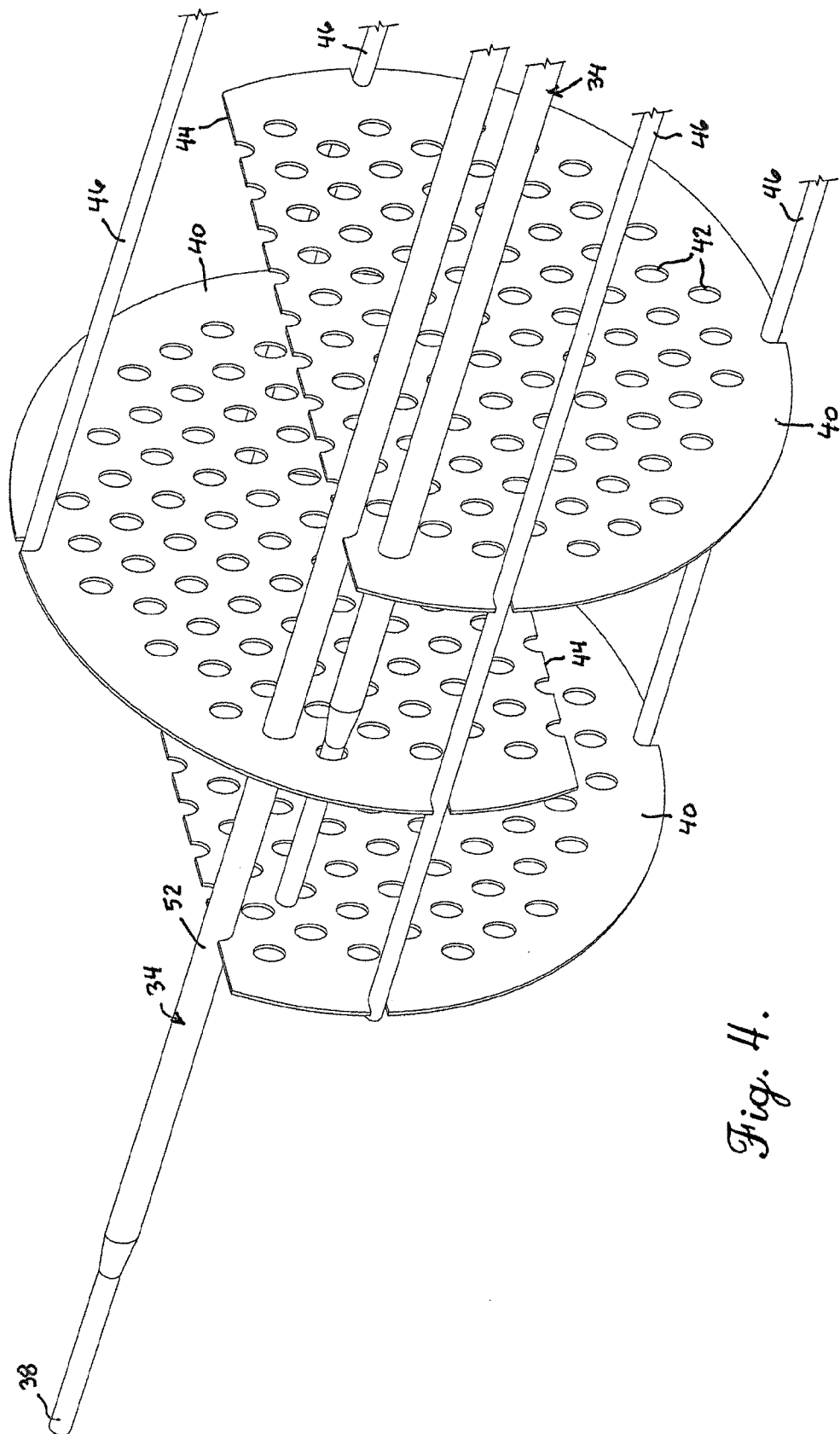


Fig. 4.

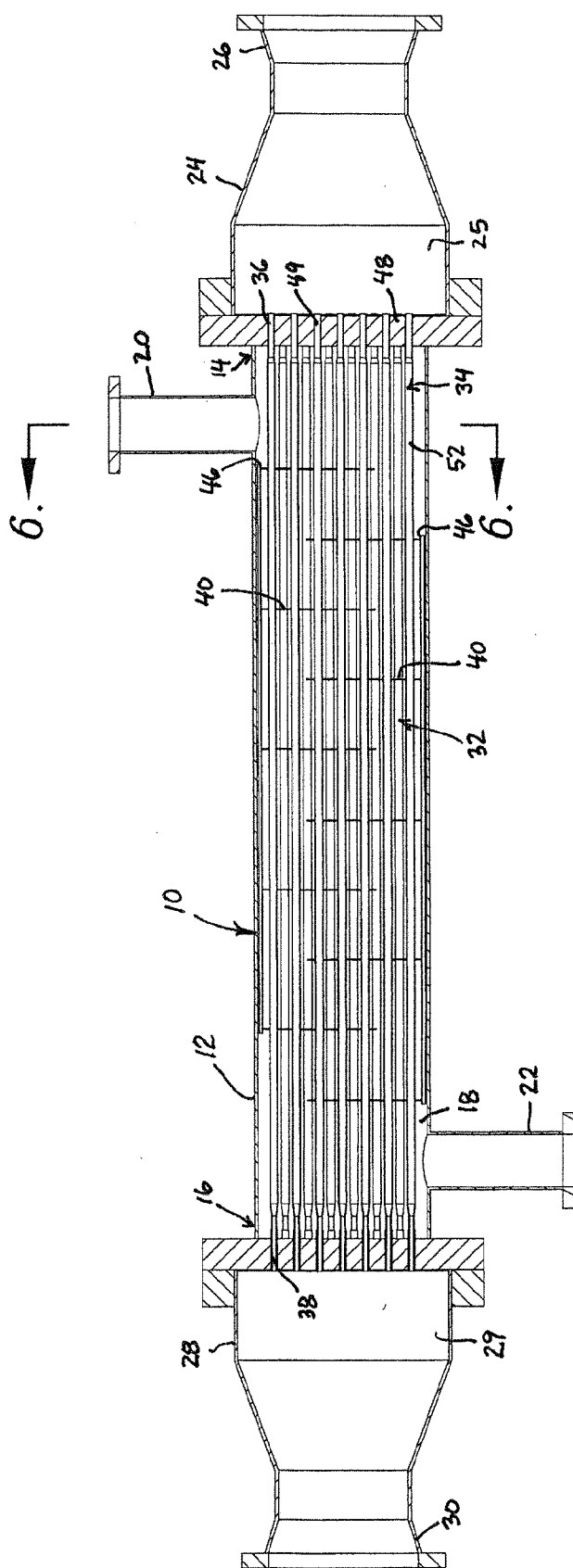


Fig. 5.

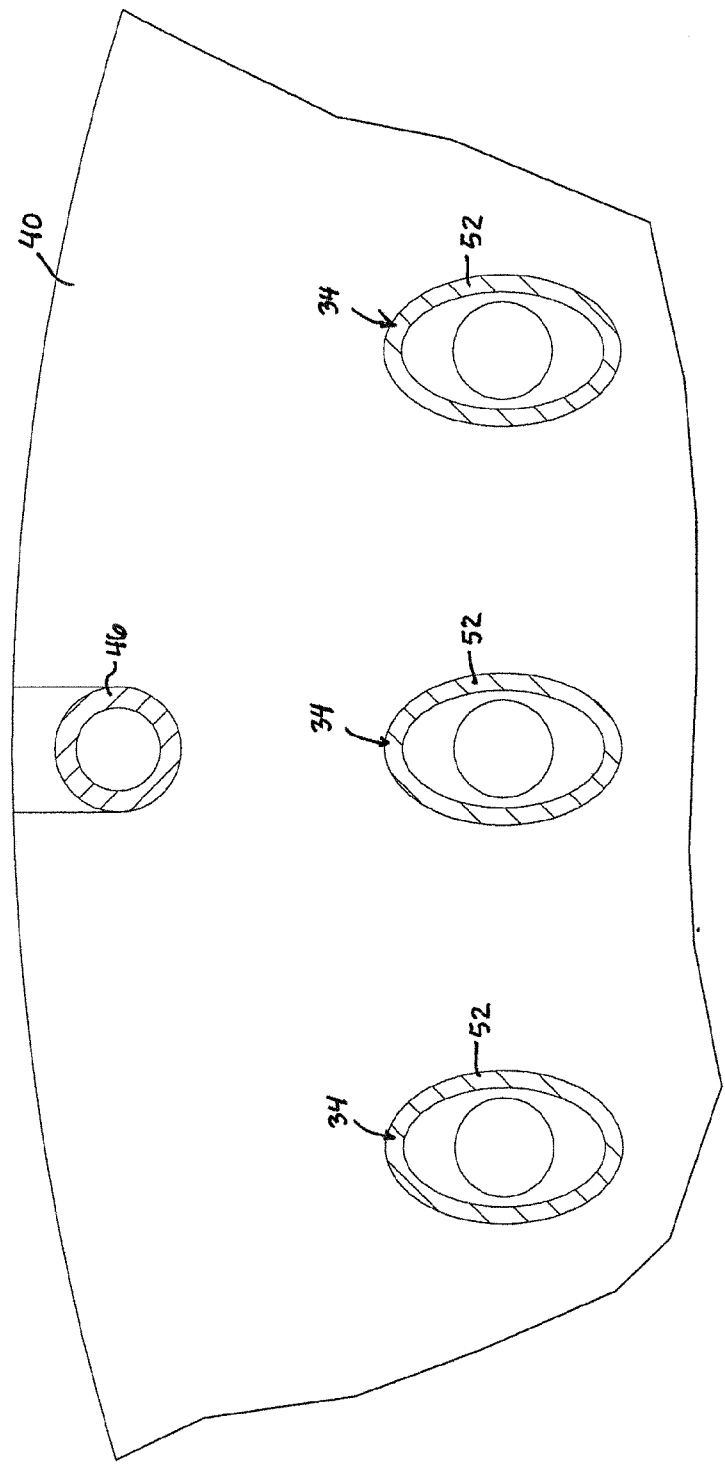


Fig. 6.

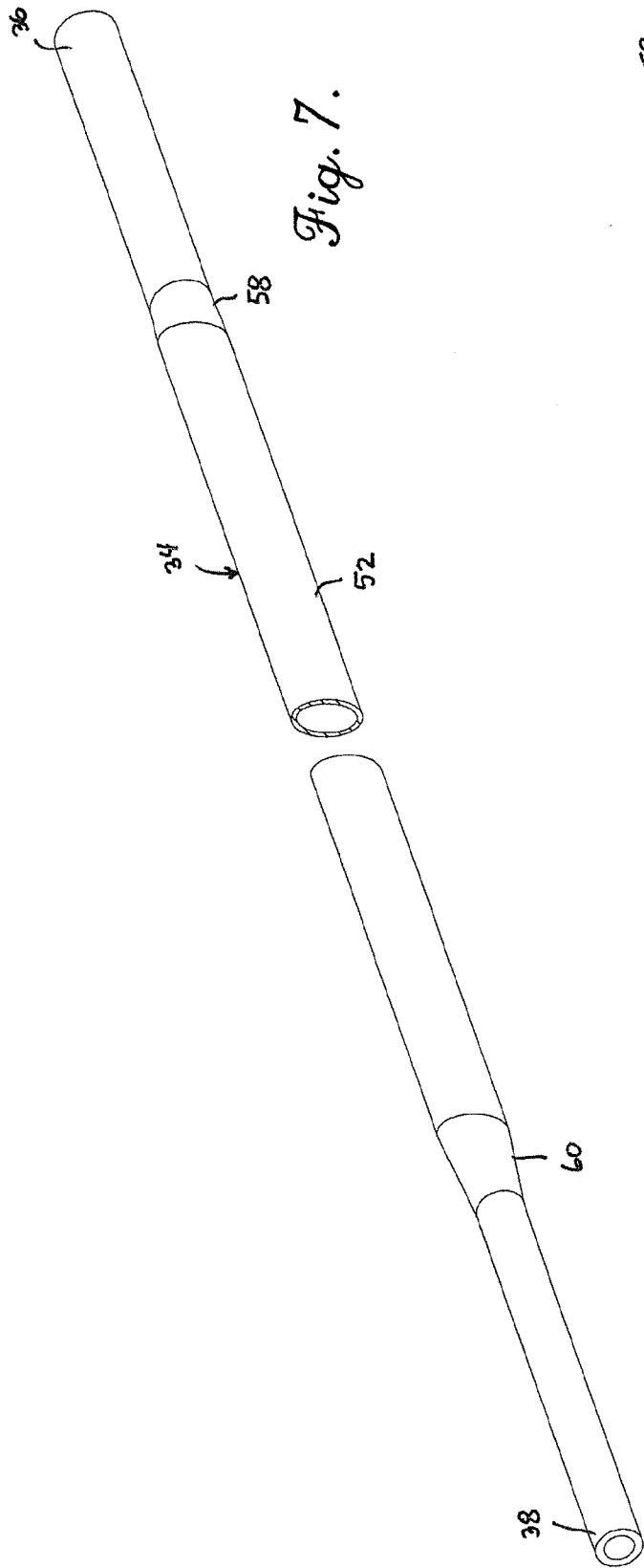


Fig. 7.

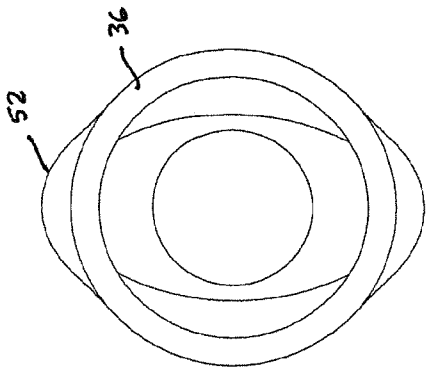


Fig. 9.

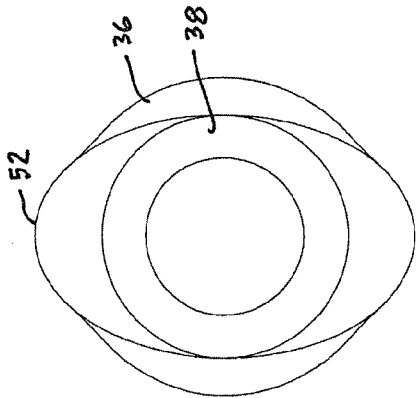


Fig. 8.

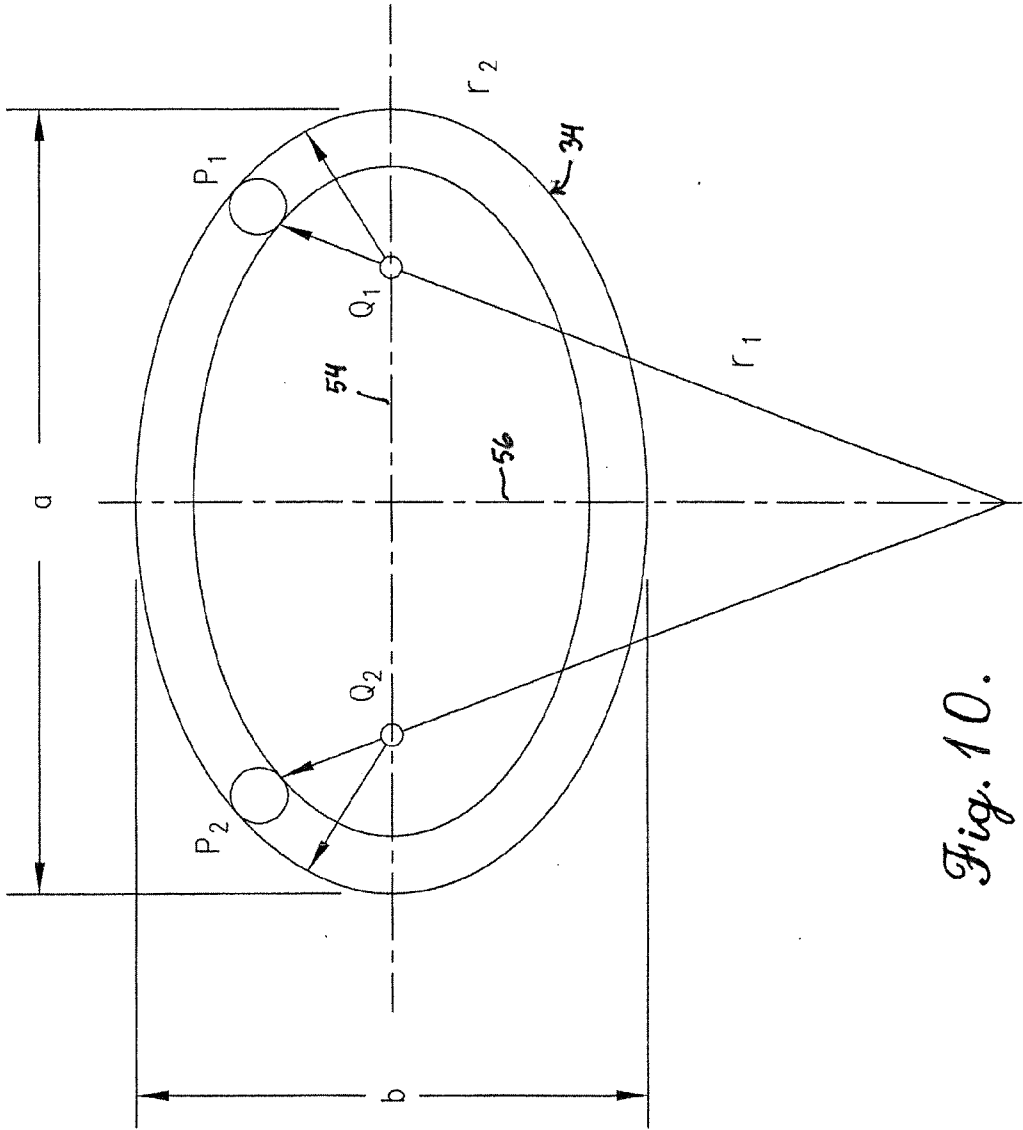


Fig. 10.

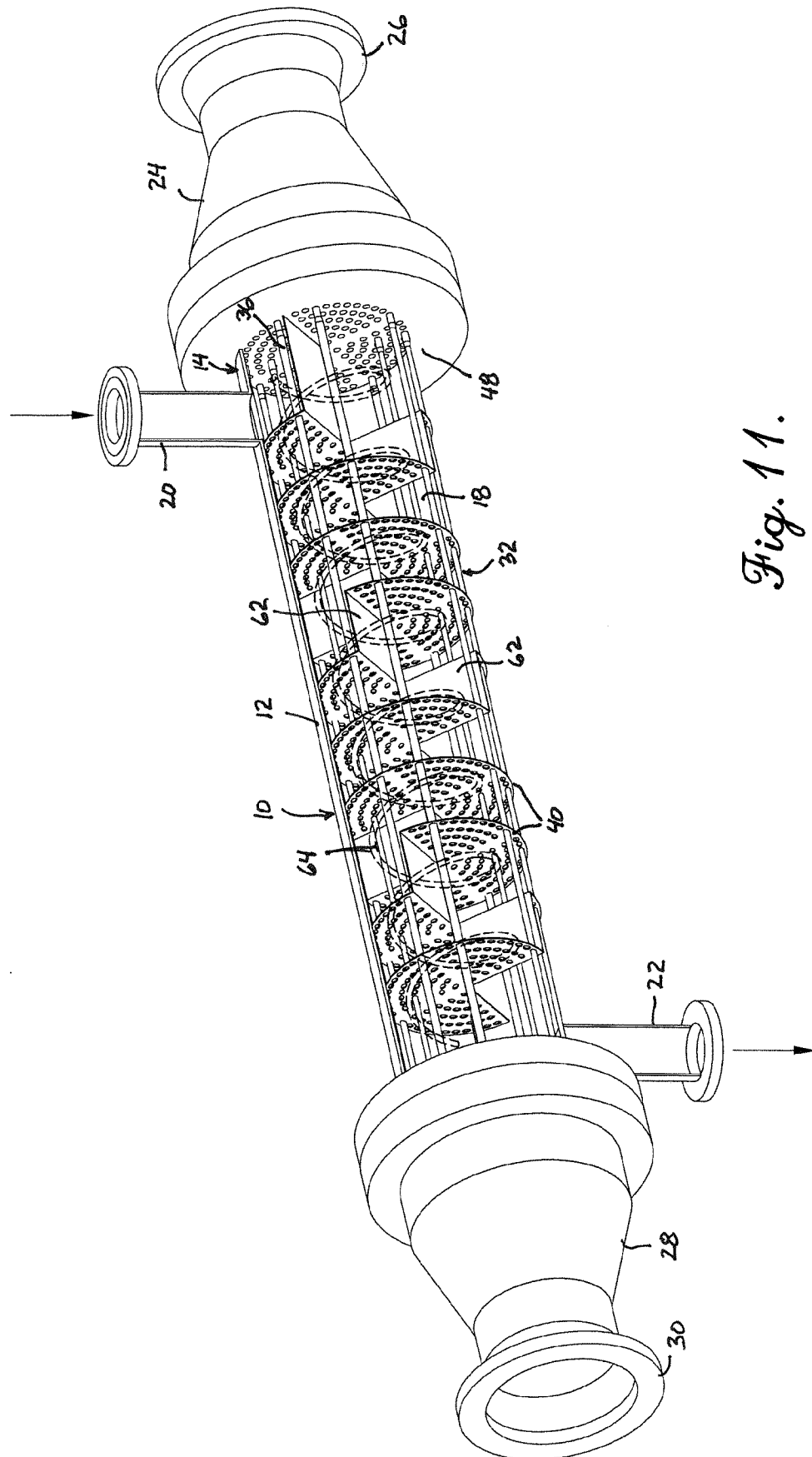


Fig. 11.

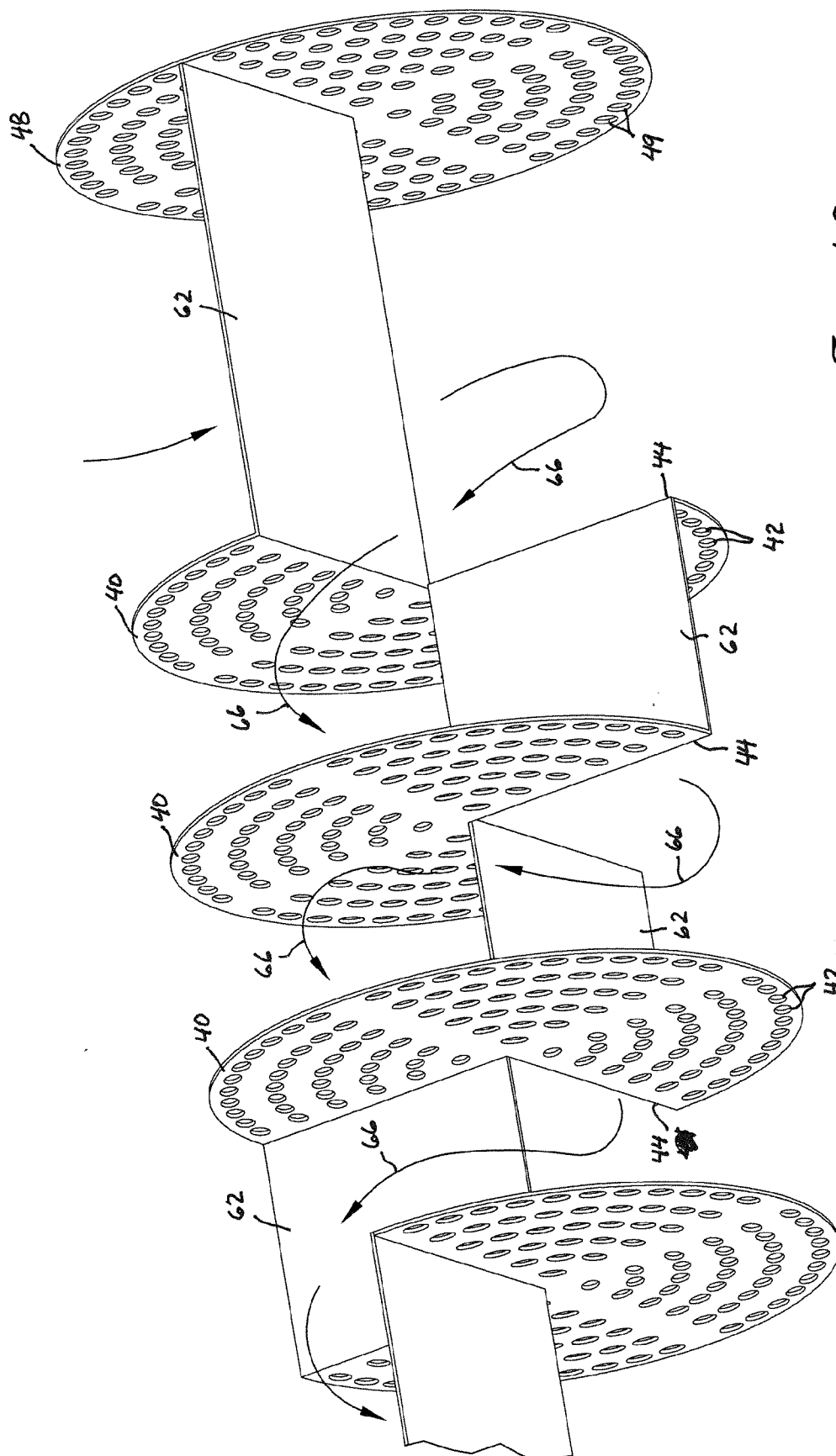


Fig. 12.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2014/014239

A. CLASSIFICATION OF SUBJECT MATTER		
F28D 7/00 (2006.01) F28F 9/013 (2006.01) According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
F28D 7/00, F28F 9/00, 9/007, 9/013, 9/22, 27/00, 27/02, F15D 1/00, 1/02, 1/04		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) PatSearch (RUPTO internal), USPTO, PAJ, Esp@cenet, DWPI, EAPATIS, PATENTSCOPE, Information Retrieval System of FIPS		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4699211 (BALTIMORE AIRCOIL COMPANY, INC.) 13.10.1987	1-19
A	CN 102313467 A (HUI LU) 01.11.2012	1-19
A	RU 2272232 C1 (GOSUDARSTVENNOE OBRAZOVATELNOE UCHREZHDENIE VYSSHEGO PROFESSIONALNOGO OBRAZOVANIJA "ROSSIJSKIJ UNIVERSITET DRUZHBY NARODOV") 20.03.2006	1-19
☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
23 April 2014 (23.04.2014)		07 May 2014 (07.05.2014)
Name and mailing address of the ISA/ FIPS Russia, 123995, Moscow, G-59, GSP-5, Berezhkovskaya nab., 30-1		Authorized officer
Facsimile No. +7 (499) 243-33-37		N. Fetisova
		Telephone No. 8 499 240 25 91