

April 23, 1968

P. GILLI

3,379,244

HEAT EXCHANGER

Filed April 5, 1965

11 Sheets-Sheet 1

FIG. 1

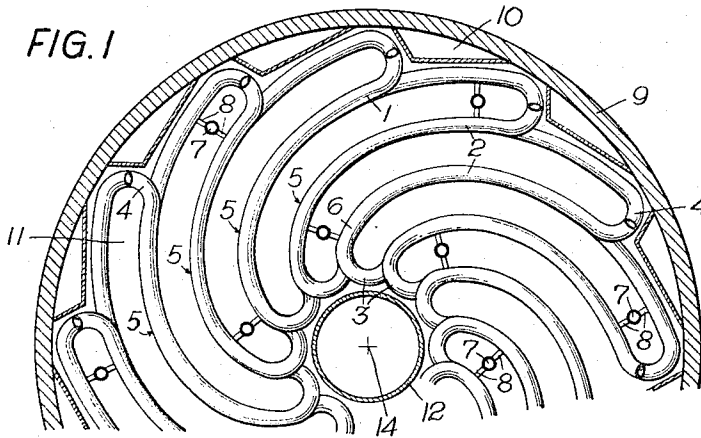


FIG. 2

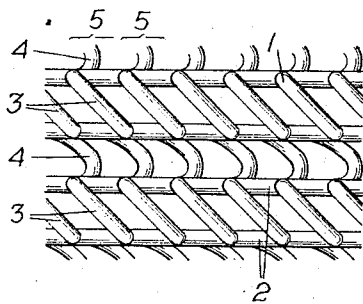


FIG. 3

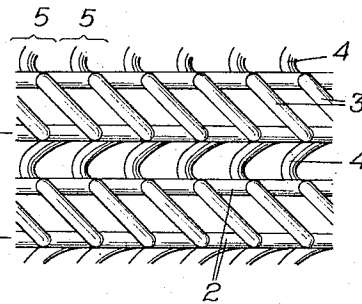


FIG. 4

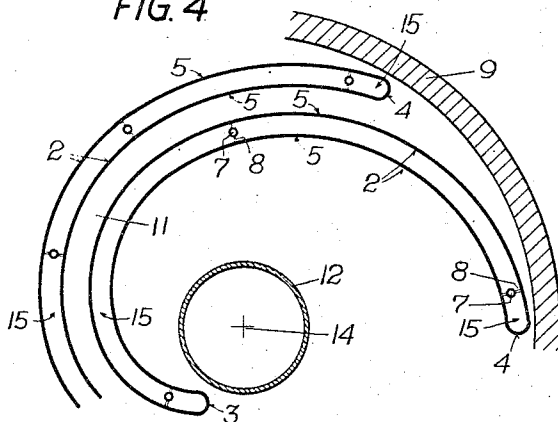
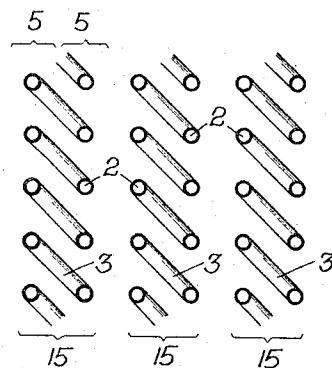


FIG. 5



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FIG. 7

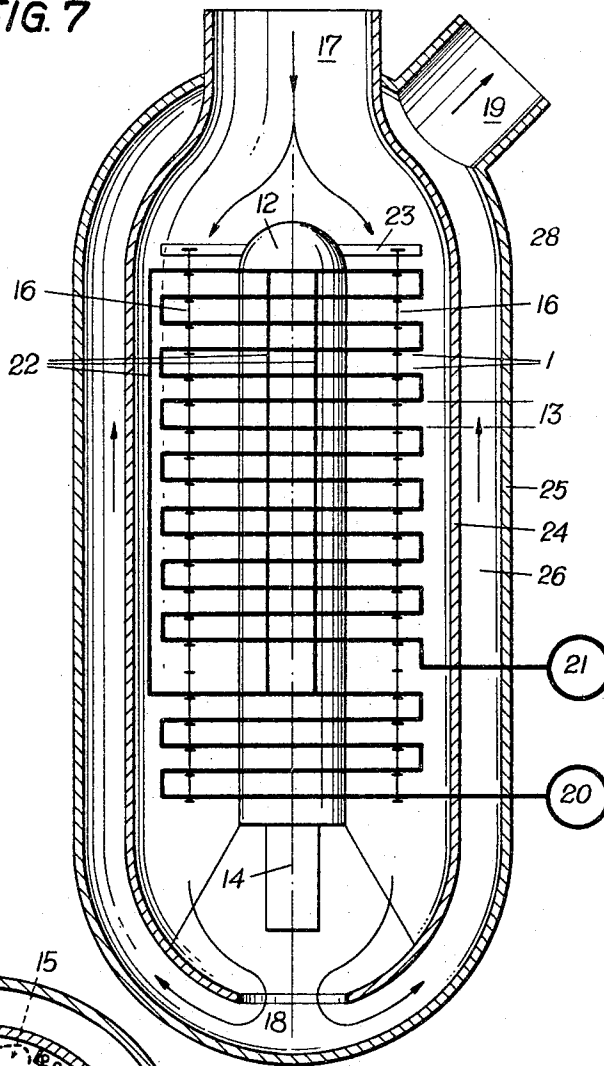


FIG. 6

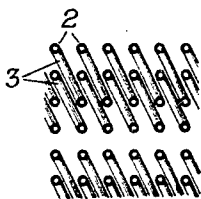
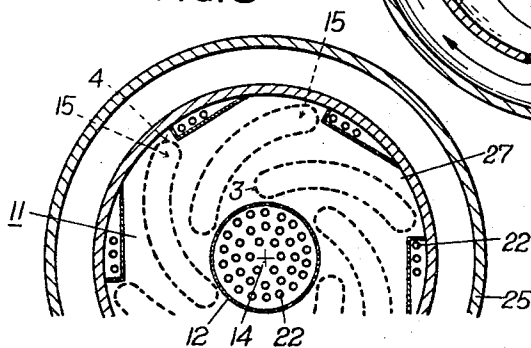


FIG. 8



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FIG. 9

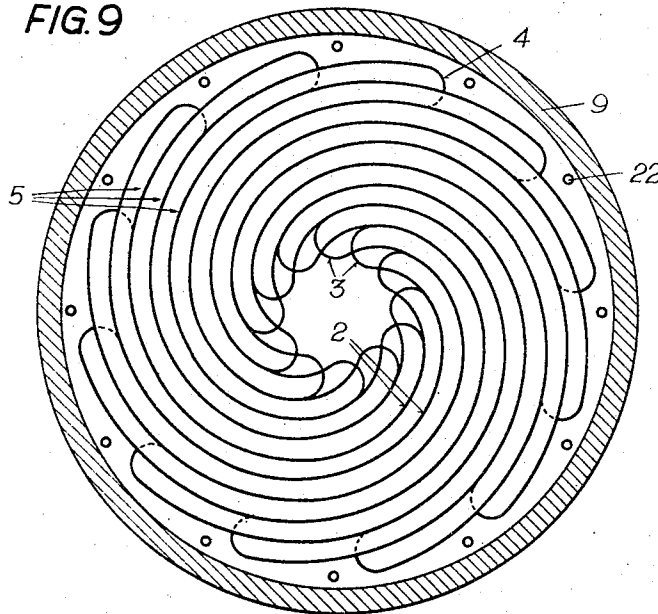


FIG. 10

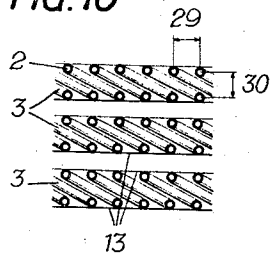


FIG. 12

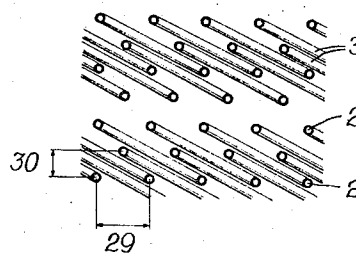


FIG. 11

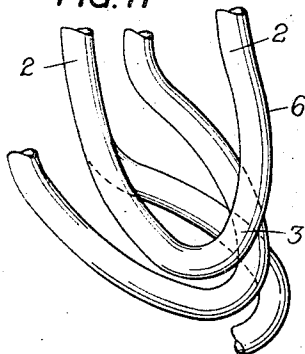
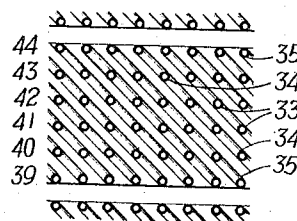


FIG. 14



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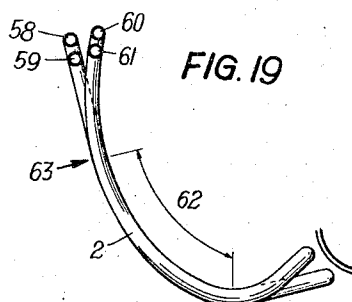
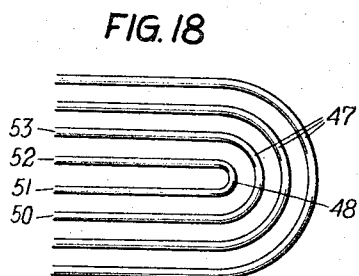
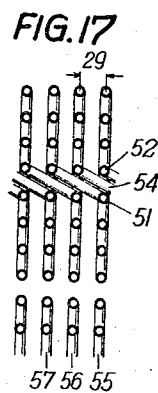
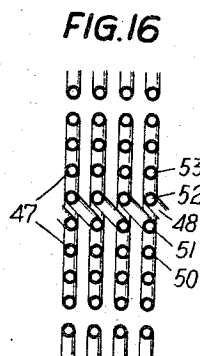
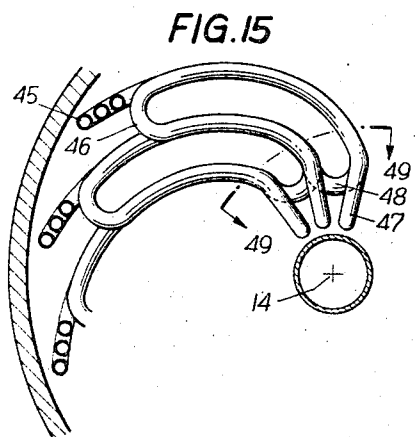
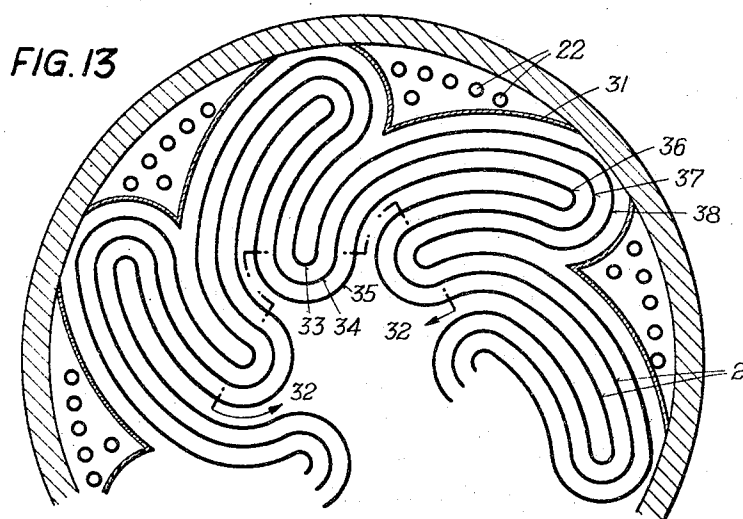
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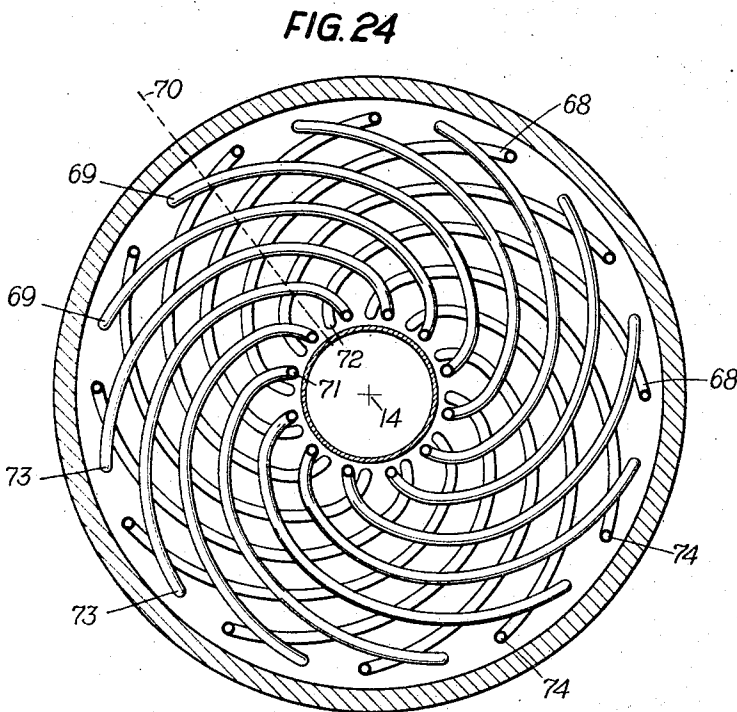
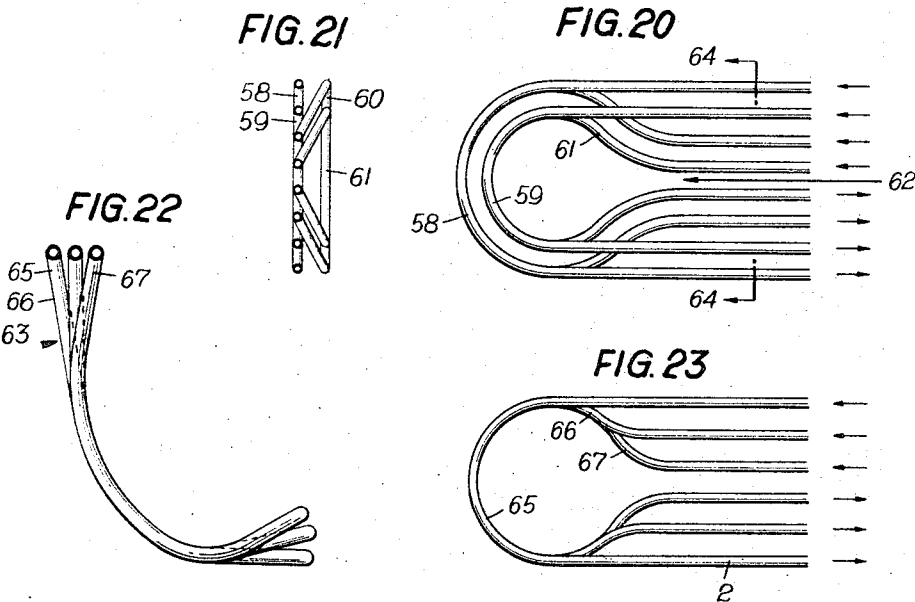
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FIG. 25

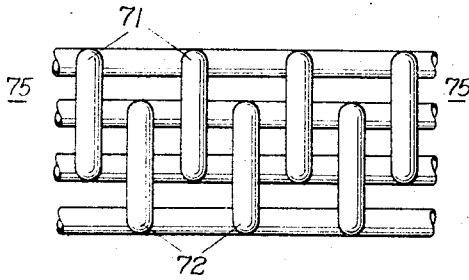


FIG. 26

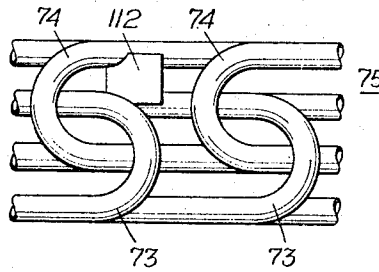
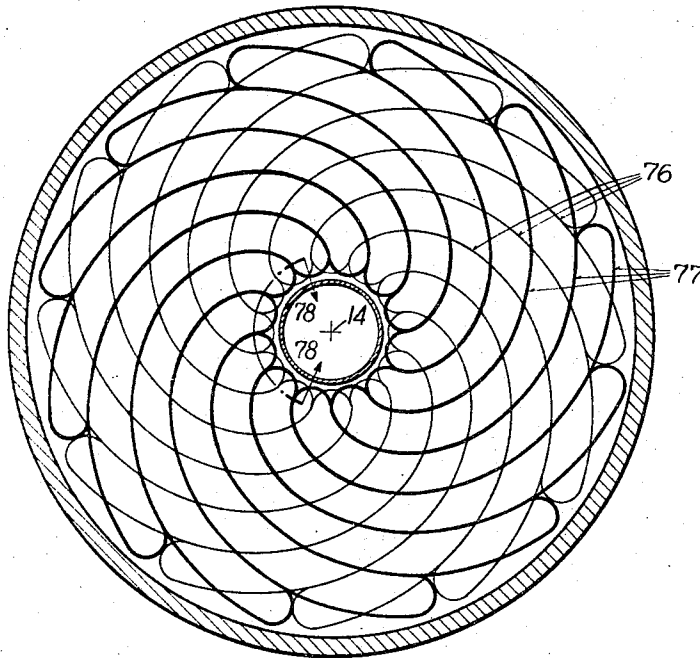


FIG. 27



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FIG. 28

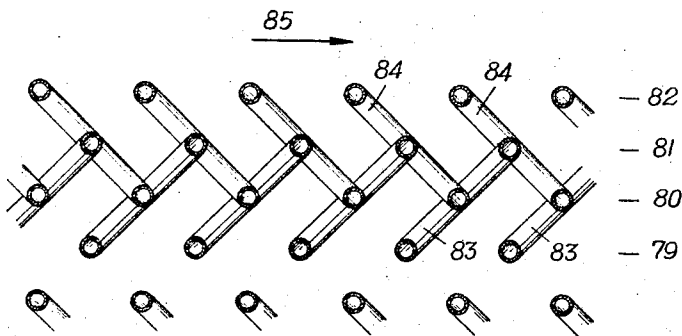
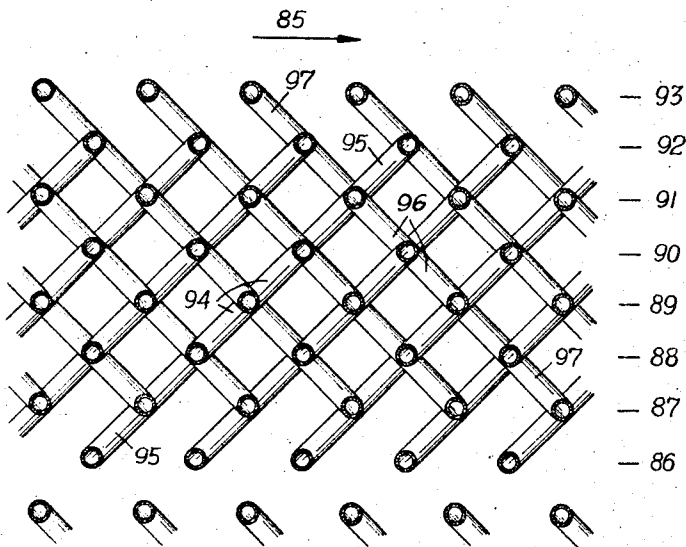


FIG. 29



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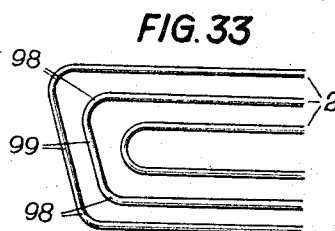
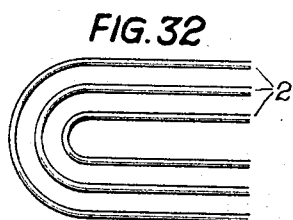
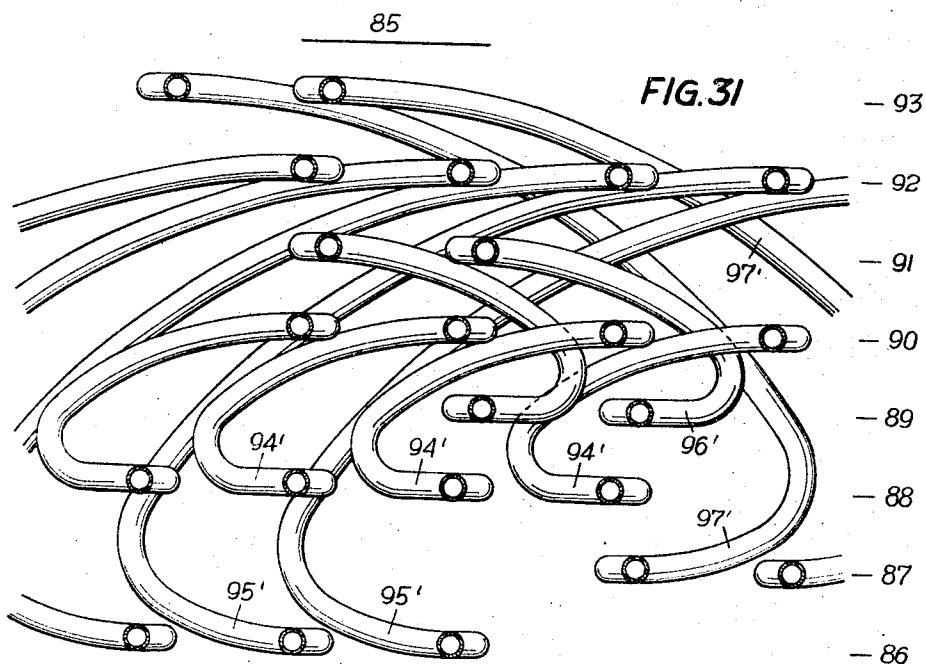
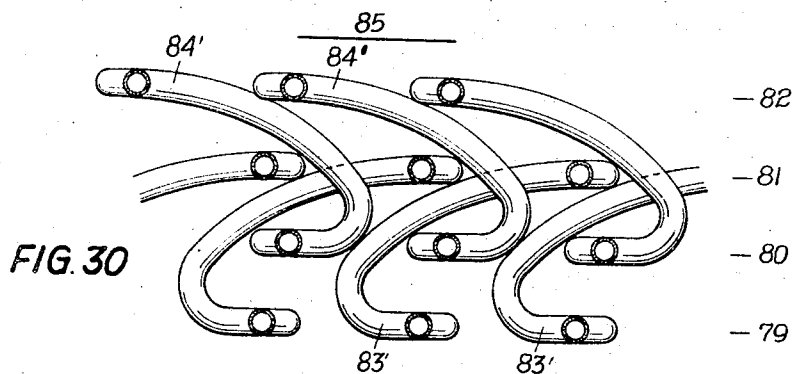
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FIG. 34

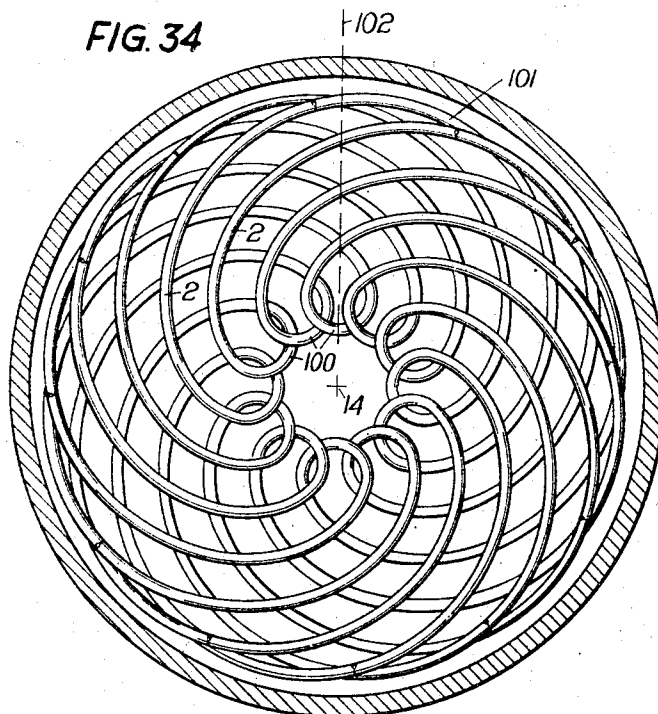


FIG. 35

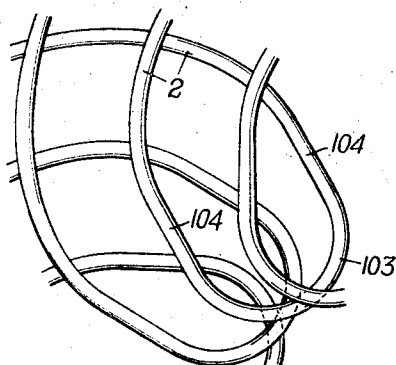
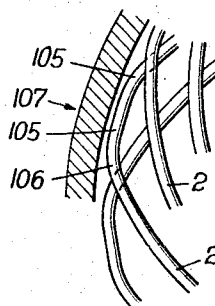


FIG. 36



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FIG. 37

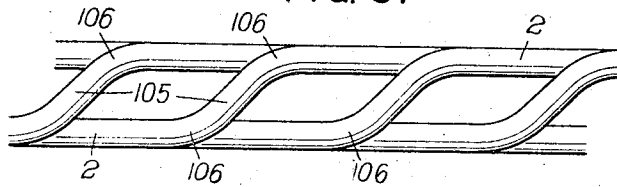


FIG. 38

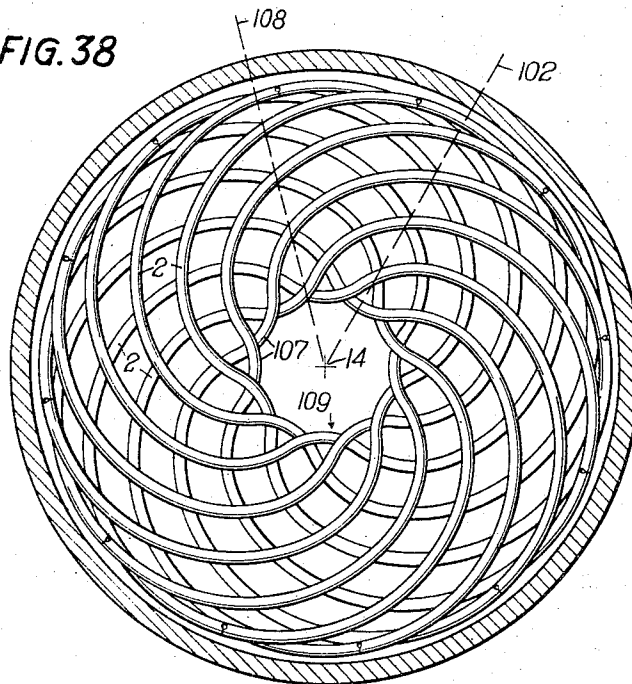
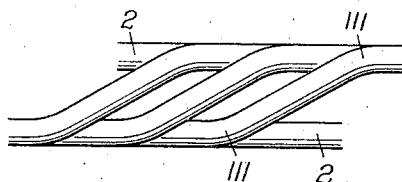


FIG. 39



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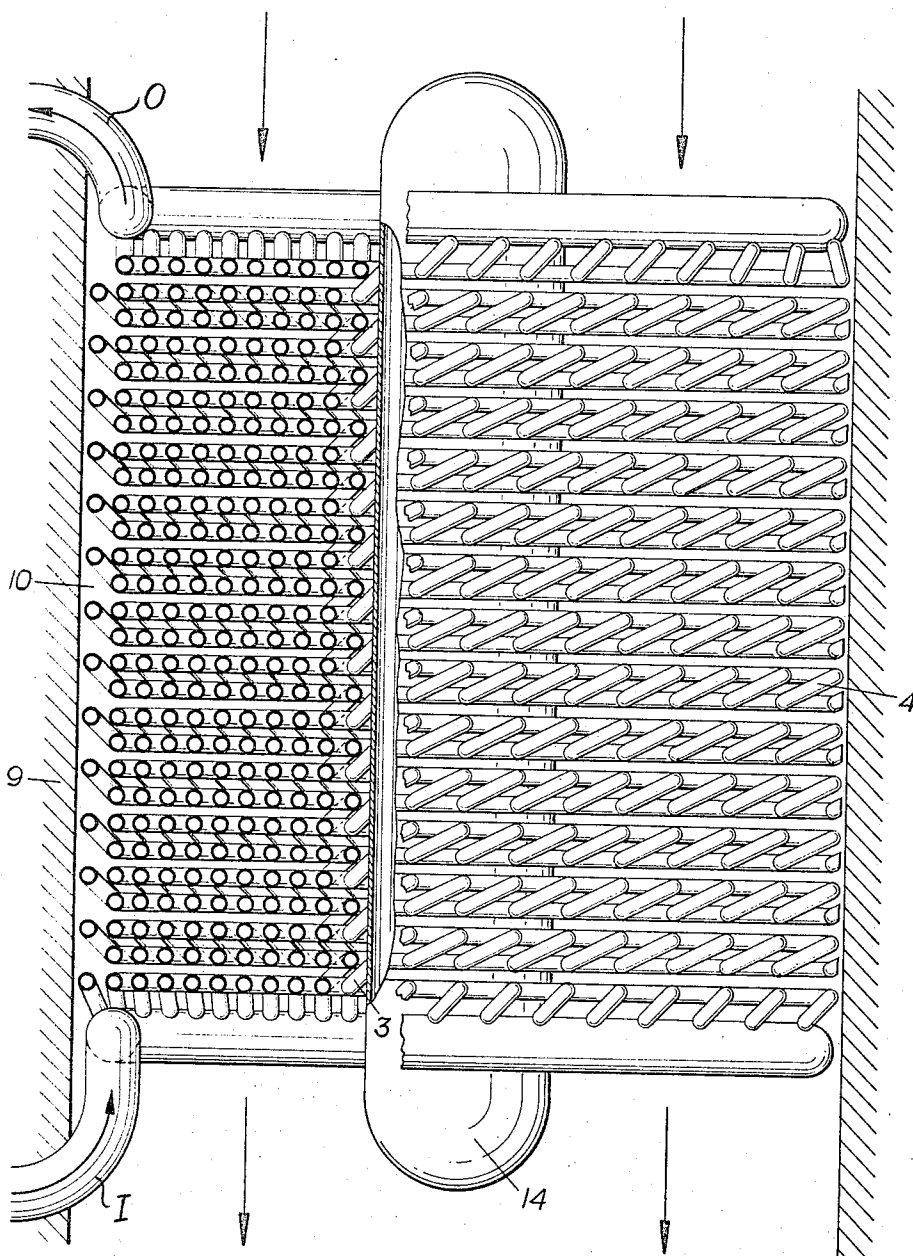


FIG. 40

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HEAT EXCHANGER

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Filed Apr. 5, 1965, Ser. No. 445,394

Claims priority, application Austria, Apr. 6, 1964,

A 2,972/64

19 Claims. (Cl. 165—163)

The present invention relates to a heat exchanger, and more particularly to the arrangement of pipes for a fluid in a vessel of substantially cylindrical shape in which another fluid flows.

It is one object of the invention to provide a heat exchanger in which the pipes are arranged in a pattern which results in a uniform and efficient heat exchange, while permitting easy bending to the necessary curved shape.

Another object of the invention is to provide a heat exchanger with curved pipes which are arranged in such a pattern that no pipe portion has to be bent into an arc having a small radius of curvature.

Another object of the invention is to provide a heat exchanger of high efficiency and compact construction which can be inexpensively manufactured.

Another object of the invention is to provide a heat exchanger with pipes arranged in a vessel in such a pattern that the flow resistance encountered by a first fluid flowing through the pipes, and a second fluid flowing around the pipes in the vessel, is small.

Another object of the invention is to avoid weakening of the pipes of a heat exchanger by arranging and shaping the pipes in such a manner that small bending radii are avoided.

Another object of the invention is to provide in the smallest possible space the greatest possible heat exchange surface.

With these objects in view, the present invention relates to an improved heat exchanger in which pipe means for a fluid at a first temperature are located in a vessel for a fluid at a second temperature. In one embodiment of the invention, the pipe means include a plurality of heat exchanging pipes preferably angularly staggered about the main axis of the vessel. Each pipe has a curved, preferably involute-shaped main portion extending from a central part to an outer part of the interior of the vessel and in planes preferably parallel to each other and extending transverse to the main axis. Curved connecting pipe portions connect the main pipe portions.

Successive main pipe portions of each pipe are located in different planes and are angularly staggered relative to each other so that the radii of curvature of the curved connecting pipe portions are greater than one half of the smallest distance between the planes in which the main pipe portions are located.

In the preferred embodiment, the main pipe portions are of substantially involute-shaped configuration, and have inner and outer ends respectively spaced from each other in circumferential direction of the vessel. The curved connecting pipes may be located in planes slanted to the main axis of the vessel, or be helically shaped.

In one embodiment of the invention, the involute-shaped main pipe portions all curve in the same direction, and in another embodiment of the invention, the involute-shaped pipe portions located in alternate planes curve in opposite directions. In some embodiments of the invention, the main pipe portions are connected by the inner connecting pipe portions in a garland-shaped looping pattern, and in other embodiments of the invention, the inner ends of the main pipe portions are connected by

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connecting pipe portions curving in an opposite direction so that successive main pipe portions form heart-shaped loops.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings, in which:

FIG. 1 is a fragmentary plane view, partially in horizontal section, and illustrating one embodiment of the invention;

FIG. 2 is a fragmentary developed elevation as viewed from the center of FIG. 1;

FIG. 3 is a fragmentary developed elevation corresponding to FIG. 2 but illustrating a modification of the embodiment of FIG. 1;

FIG. 4 is a fragmentary plan view, partially in section, illustrating another embodiment of the invention, showing the pipes schematically as single lines;

FIG. 5 is a developed circular section taken adjacent the connecting pipe portions, and illustrating a modification of the embodiment shown in FIG. 4;

FIG. 6 is a developed circular section corresponding to FIG. 5 and illustrating a further modification of the heat exchanger;

FIG. 7 is a vertical sectional, partly schematic view illustrating an embodiment of the invention;

FIG. 8 is a fragmentary horizontal sectional view of the embodiment of FIG. 7;

FIG. 9 is a horizontal sectional view of another embodiment of the invention showing the pipes schematically as single lines;

FIG. 10 is a fragmentary developed circular sectional view of the embodiment of FIG. 9;

FIG. 11 is a fragmentary perspective view illustrating a detail of a modification of the embodiment of FIG. 9;

FIG. 12 is a fragmentary developed schematic circular section of a modification of the embodiment of FIG. 9;

FIG. 13 is a fragmentary horizontal sectional view of another embodiment of the invention, only one group of pipes being schematically shown in single lines;

FIG. 14 is a fragmentary schematic section taken on line 32—32 in FIG. 13;

FIG. 15 is a fragmentary plan view of another embodiment of the invention including groups of parallel pipes;

FIG. 16 is a fragmentary schematic sectional view taken on line 49—49 in FIG. 15;

FIG. 17 is a fragmentary schematic sectional view corresponding to FIG. 16, but illustrating a modification;

FIG. 18 is a side elevation illustrating a group of parallel bent pipes as may be used in the embodiments of FIGS. 16 and 17;

FIG. 19 is a fragmentary plan view partly in horizontal section illustrating the shape of groups of pipe in another embodiment of the invention;

FIG. 20 is a fragmentary side elevation illustrating the shape of connecting pipes in accordance with a modification;

FIG. 21 is a section taken on line 64—64 in FIG. 20;

FIG. 22 is a fragmentary plan view illustrating another modification;

FIG. 23 is a fragmentary side elevation illustrating the shape of the connecting pipe portions in FIG. 22;

FIG. 24 is a fragmentary plan view, partially in section, illustrating another embodiment of the invention;

FIG. 25 is a fragmentary developed elevation as viewed from the center of FIG. 24;

FIG. 26 is a fragmentary developed elevation as viewed from outside of the pipe system in FIG. 24;

FIG. 27 is a horizontal sectional view schematically illustrating the pipes as single lines;

FIG. 28 is a fragmentary developed section taken on line 78—78 in FIG. 27;

FIG. 29 is a fragmentary developed section corresponding to FIG. 28 but illustrating a modification of the embodiment of FIG. 27;

FIG. 30 is a fragmentary developed view illustrating a modified construction of the connecting pipes;

FIG. 31 is a fragmentary developed view illustrating a modified construction of the pipes;

FIG. 32 is a fragmentary elevation illustrating a construction of the connecting pipe portions of a group of parallel pipes;

FIG. 33 is a fragmentary elevation illustrating another construction of the connecting pipe portions of a group of pipes;

FIG. 34 is a fragmentary horizontal sectional view of another embodiment of the invention which is a modification of the embodiment of FIG. 27 and provides inner and outer connecting pipes having a greater radius of curvature;

FIG. 35 is a fragmentary plan view illustrating a detail of a modification of the embodiment of FIG. 34 on a larger scale;

FIG. 36 is a fragmentary plan view illustrating another modification of the embodiment of FIG. 34 on a larger scale;

FIG. 37 is a fragmentary elevation illustrating the modification of FIG. 36 as viewed in the direction of the arrow 107 in FIG. 36;

FIG. 38 is a plan view, partially in section, illustrating another embodiment of the invention;

FIG. 39 is a fragmentary developed elevation as viewed in the direction of the arrow 109 in FIG. 38; and

FIG. 40 is an enlarged fragmentary vertical section through a heat-exchanger embodying the present invention.

Referring now to the drawings, and more particularly to FIGS. 1 and 2, a plurality of pipes 1 is disposed in a substantially cylindrical vessel 9. Pipes 1 are angularly staggered about the axis 14 of the cylindrical vessel 9. Each pipe 1 includes substantially involute-shaped main pipe portions 2 which are located in different planes 13 which are parallel to each other and perpendicular to the main axis 14 as shown in FIG. 2. The inner and outer ends of each main pipe section 2 are angularly staggered from each other in circumferential direction due to the spiral or involute shape of the main pipe portions 2. The inner ends of the main pipe portions 2 of each pipe 1 are connected by curved connecting pipe portions 3 which extend between adjacent planes 13. The outer ends of successive main pipe portions are connected by outer curved connecting pipe portions 4. Due to the fact that the connecting pipe portions connect angularly staggered main pipe portions, the radii of curvature of the connecting pipe portions are greater than one half of the smallest distance between adjacent planes 13. Each pair of connecting pipe portions 3 and 4 connects main pipe portions which are located in different planes, and in different angularly spaced heat exchanger sections 5 which are angularly staggered in circumferential direction of the vessel. Consequently, each pipe meanders between the center portion of the vessel and the outer wall of the vessel and also in axial direction of the vessel.

As a result, the semi-circular connecting portions 3 and 4 are placed in planes slanted to the main axis 14 of vessel 9. In order to facilitate the connection between the semi-circular connecting pipe portions 3 and 4 and the curved main pipe portions 2, short straight portions are provided between the connecting portions and the substantially involute-shaped main pipe portions. The length of the straight connecting piece may be the diameter of the pipe, or multiple of the same.

To facilitate the manufacture, it is advantageous to make the connecting pipe portions of the same material as the main pipe portions, and of the same diameter. It is preferred to bend the outer connecting pipe portions 4, or the inner connecting pipe portions 3, or both connecting pipe portions together with the main pipe portions 2 from one piece of pipe stock.

Supporting pipes or rods 7 have supporting lugs 8 and extend between adjacent main pipe sections 2, and the main pipe sections 2 are supported by the lugs 8 and supporting pipes or rods 7 extending in axial direction of the vessel so that the pipe system can be supported on vessel 9.

A first fluid medium flows in substantially axial direction through the vessel 9, and a second fluid medium flows through pipes 1 so that a heat exchange can take place on the surfaces of the pipes.

Projections 10 project from the inner surface of vessel 9 and have surfaces closely adjacent the outer pipe portions so that the fluid medium flowing through vessel 9 flows between the surfaces of projections 10 and the adjacent pipes. Another part of the fluid medium flows through the spaces 11 between superimposed main pipe portions.

FIG. 2, which may be considered a projection of the pipe means shown in FIG. 1 onto an outer enveloping cylinder concentric with axis 14, shows the inner connecting pipe portions 3 to be located in parallel planes slanted to the axis, while the outer connecting portions appear as part of ellipses. Successive main pipe portions of the same pipe are located in adjacent planes 13 angularly staggered in the same direction of rotation equal angles. Consequently, successive main pipe portions 2 will be in contact with different portions of the fluid flowing in axial direction through vessel 9. This results in a relatively uniform change of temperature of the fluid medium flowing in the pipes, even if the temperature of the fluid medium flowing in the vessel is not uniform, or if one or several pipes become inoperative.

FIG. 3 corresponds to FIG. 2, but the shape of each pipe 1 is different. Connecting pipe portions 3 and 4 connect successive main pipe portions 2 of the same pipe 1 in such a manner that each pipe zigzags between two adjacent heat exchange sections 5. Successive main pipe portions 2 in adjacent planes 13 are displaced relative to each other the same angle about the main axis, but in opposite directions of rotation.

This modification is advantageous if it is desired to divide the stream of fluid flowing in axial direction in vessel 9 by partitions, for example for the purpose of assuring easier testing of leaks in the pipes, or if the heat exchanger is to be divided into a plurality of independently operable circumferentially spaced units. Corresponding elements are indicated in FIGS. 3 to 39 by the same reference numerals as in FIGS. 1 and 2.

FIG. 4 illustrates a modified arrangement which is similar to the construction of FIG. 3. Successive main pipe sections 2 are connected to each other by outer and inner connecting pipe portions 4 and 3, but connecting pipe portions 3 and 4, respectively connect main pipe portions 2 which are located in corresponding pairs of adjacent heat exchange sections 5. Groups 15 of pipes are formed in this manner which are bounded by imaginary surfaces parallel to the axis 14 and having an involute-shaped curvature. Between main pipe sections 2 of each group of pipes 15, supporting pipes 7 are provided with lugs 8 on which the pipes rest so that a rigid pipe unit is formed. Such pipe units are individually manufactured in large series, and tested before being combined into the pipe assembly of the heat exchanger at the location where the heat exchanger is to be used. The last pipe unit 15 is inserted in the direction of the axis 14 of the heat exchanger. FIG. 5 is a developed view of a cylindrical section in the region of the pipes in FIG. 4 between the main pipe portions and the inner connecting

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pipe portions, and it will be seen that successive connected main pipe portions and the respective connecting pipe portions form units 15 which are parallel to the main axis and separated from each other by a substantially involute-shaped space which appears straight in the developed section of FIG. 5.

FIG. 6 illustrates another modification in which connecting pipe portions 3 connect main pipe portions 2 located in every second plane in which main pipe portions are located. As a result, the radii of curvature of the connecting pipe portions are approximately twice as great as in the embodiment illustrated in FIG. 5, assuming the same spacing in axial direction between the planes of the main pipe portions. This permits an arrangement in which the planes of the main pipe portions are very closely spaced, while nevertheless the radii of curvature of the connecting portions are so great that no sharp bending of the connecting pipe portion is required.

FIGS. 7 and 8 illustrate a practical embodiment of the invention, and it will be understood that pipe means shaped and arranged in accordance to the various modifications of the present invention, may be provided for the heat exchanger shown in FIGS. 7 and 8.

A double-walled vessel includes an outer wall 25 and an inner wall 24 which has an inlet opening 17 on top, and an outlet opening 18 at the bottom so that a fluid medium can flow downwardly through the interior of the interior of the vessel as indicated by arrows, and then upward in the space 26 until discharged through outlet 19 of the outer jacket 25. Pipe means 1 are located in the interior of the vessel, as schematically shown, and have an inlet and an outlet connected to an inlet pipe 20 and an outlet pipe 21 for a fluid medium flowing through pipe means 1 and exchanging heat with the fluid medium flowing through the interior of the vessel.

Pipe means 1 are suspended in vertical rods 16 which are carried by a star-shaped carrier 23 resting on a central column 12, schematically illustrated in FIGS. 1, 4, and 8, and supported by three legs on the inner wall 24. The suspending rods 16 are secured to the lugs 8 described with reference to FIGS. 1 and 4.

As schematically shown in FIG. 7, the fluid from inlet pipe 20 flows first through pipe means located in the lower portion of the vessel, and then passes through vertical pipes 22 into the uppermost main pipe portions of other pipe means from which it is discharged at a lower level into the outlet pipe 21. Projections on the inner surface of the inner wall 24 are used for housing pipes 22, whereas other rising pipes 22, which are connected to the inner ends of the several pipes 1 are disposed within the central column 12. The embodiment shown in FIG. 7 corresponds substantially to the construction shown in FIG. 4 or FIG. 5, and the pipes form units located in heat exchanging sections 15 which are angularly spaced in circumferential direction. Each unit includes involute-shaped main pipe sections 2, and curved connecting portions 3 and 4. The units are independently manufactured, but assembled at the location of the heat exchanger, the last unit being inserted into the vessel in axial direction.

The outlet and inlet pipes of each unit are lead out of the vessel and connected with the inlet and outlet pipes 20, 21. The suspending rods 16 of each unit are secured by a suitable means 28 to an arm of the star-shaped carrier 23 so that even very large heat exchangers can be economically manufactured and assembled on location.

FIGS. 9, 10 and 11 illustrate another embodiment of the invention in which connecting pipe portions 3 and 4 connect involute-shaped main pipe sections 2 which are not located in directly adjacent heat exchange sections 5. In the embodiment of FIG. 10, the main pipe sections 2 of alternate heat exchange sections 5 are connected to each other by curved connecting pipe portions. Vertical inlet pipes 22 are shown in FIG. 9, and perform the function described with reference to FIG. 7. The circumferential spacing between adjacent main pipe sections 2 is

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designated by reference numeral 29, and the axial spacing between successive main pipe portions 2 is designated by reference numeral 30 in FIG. 10.

FIG. 11 illustrates the inner ends of main pipe portions 2, and the corresponding connecting pipe portions 3. In order to facilitate the manufacture, the semi-circular connecting pipe portions 3 are connected to the involute-shaped main pipe portions 2 by straight pipe pieces 6 which have a length at least equal to the diameter of the pipe. The transition between the main pipe portions 2, the straight pipe pieces 6, and the semi-circular connecting pipe portions 3 is gradual and without a break in the curvature.

FIG. 12 illustrates a modification of the embodiment shown in FIGS. 9 and 10. Connecting pipe portions 3 connect main pipe portions located in every third heat exchange section 5. The planes in which the main pipe portions are located are spaced in axial direction the distance 30, and adjacent main pipe sections 2 in the same horizontal planes are spaced the distance 29. Connecting pipe portions 3 connect main pipe portions 2 which are spaced two distances 30 in axial direction of the vessel, and two distances 29 in circumferential direction of the vessel. The main pipe sections may be connected in accordance with other multiples of the distances 29 and 30, as will be understood by those skilled in the art. Generally speaking, the diameter of the connecting pipe portions d can be computed in accordance with the following equation:

$$d = \sqrt{\left(\frac{n}{2}t_1\right)^2 + (mt_2)^2}$$

wherein n and m are integers, t_1 is the circumferential distance 29, and t_2 is the axial distance 30.

FIGS. 13 and 14 illustrate an embodiment of the invention in which groups of parallel pipes are used instead of single pipes as in the embodiment of FIG. 1, for example. FIG. 13 schematically shows only a single group of pipes, the other angularly spaced groups of pipes being omitted in FIG. 13 for the sake of simplicity and clarity, but illustrated in FIG. 14. Each pipe of the group has an involute-shaped main pipe portion 2 connected by inner connecting pipe portions 33, 34, 35, respectively, and outer connecting pipe portions 36, 37 and 38. Due to the fact that the pipes of the group are parallel, the connecting pipe portions have different radii of curvature. In the embodiment of FIGS. 13 and 14 corresponding connecting portions are disposed in a plane and extend along parts of concentric circles. The radii of connecting pipe portions 33 and 36 are the smallest, and of connecting pipe portions 35 and 38 are the greatest. Main pipe sections 2 are located in planes which are perpendicular to the main axis of the vessel, and the connecting pipe portions connect, respectively, two main pipe sections 2 located in different planes, as shown in FIG. 14. Vertical inlet pipes 22 are disposed in hollow projections along the inner surface of the vessel as described with reference to FIGS. 7 and 8. In the embodiment of FIG. 13, the projections are helical, and preferably have walls including several metal sheets, with intermediate layers of a stagnant medium. The inner surfaces of the projections preferably follow the curvature of the connecting pipe portions 38 and of the main pipe portions 2 to provide narrow path for the fluid medium flowing in axial direction through the vessel.

As shown in FIG. 14, connecting pipe portions 33 connect main pipe sections located in the planes 41 and 42 in which adjacent main pipe portions are located. The connecting pipe portions 34 connect main pipe portions 2 located in planes 40 and 43, and the connecting pipe portions 35 connect main pipe portions located in planes 39 and 44. Since the connecting pipe portion 33 having the smallest radius of curvature is connected to one end of a main pipe portion whose other end is connected to the connecting pipe portion 38 having the greatest radius

of curvature, the total length of each pipe section including a main pipe portion and half of the length of two outer and inner connecting pipe portions is the same for all pipes of the group.

FIGS. 15, 16 and 18 illustrate a modification of the embodiment in which groups of parallel pipes are provided. Outer connecting pipe portions 45 and 46, and inner connecting pipe portions 47 and 48 connect the substantially involute-shaped main pipe portions. Connecting pipe portions 45 and 47 are located in planes parallel to the main axis 14. As is apparent from FIG. 16, connecting pipe portions 47 connect main pipe portions located in pairs of planes, for example planes 50 and 53 in the same axial plane, whereas connecting pipe portions 48 connect main pipe portions located in adjacent planes 51 and 52, but angularly staggered relative to each other about the main axis 14. The modification of FIG. 17 is similar, but connecting pipe portions 54, which are the innermost of the respective group, connect main pipe portions which are located in every second circumferentially spaced group of pipes. For example, the main pipe portion 51 in the heat exchange section 55 is connected to the main pipe portion 52 in the heat exchange section 57, and not to the main pipe portion in the heat exchange section 56 so that successive main pipe portions are spaced twice the distance 29 between adjacent heat exchange sections. Evidently, the connecting pipes can also connect main pipe portions located in heat exchange sections between which two or more other heat exchange sections are located. In this manner, even greater radii of curvature can be provided for the connecting pipe portions which facilitates the manufacture of the bent pipes, and reduces pressure losses occurring if a fluid medium passes through curved pipe portions having a small radius of curvature.

FIG. 18 shows the semi-circular connecting pipe portions 47, 48 to be substantially parallel. The radius of curvature of the connecting pipe portion 48 is greater than the diameter of the pipe, and greater than one half of the distance between planes 51 and 52.

FIGS. 19, 20 and 21 illustrate a modified configuration of the connecting pipe portions for groups of parallel pipes. FIG. 19 shows only one group of pipes, with the outer connecting pipe portions 58 to 61 sectioned in the middle. The main pipe portions have substantially the same curvature along the greater part of it, but the portions adjacent connecting pipe portions 60 and 61 are bent differently from the portions adjacent the connecting pipe portions 58 and 59. As best seen in FIG. 20, straight pipe pieces form the connections between the main pipe portions and the connecting pipe portions 58 and 59, and the respective pipe portions are located in a plane. The pipe pieces connected to connecting pipe portions 60 and 61 are bent outwardly out of the plane of the main pipe portions and also away from each other so that connecting pipe portions 60 and 61 extend through angles greater than 180°. FIG. 21 is a section on line 64—64 in FIG. 20 and shows the circumferential displacement of connecting pipe portions 60 and 61 in relation to the connecting pipe portions 58 and 59.

FIGS. 22 and 23 illustrate a modification in which the connecting pipe portions of a group of pipes are angularly displaced relative to each other so that all three connecting pipe portions 65, 66, 67 can have the same radius of curvature. Connecting pipe portion 67 extends over the greatest angle, connecting pipe portion 66 over a smaller angle, and connecting pipe portion 65 extends over 180° and is connected to tangentially extending straight pipe pieces which are gradually bent into the involute shape of the respective main pipe portions 2.

FIG. 24 illustrates another embodiment of the invention in which the main pipe portions located in alternate planes perpendicular to the main axis 14, are bent and curved in opposite directions. Main pipe sections 68 and 69 are located in adjacent horizontal planes. The curva-

ture of main pipe portions 68 and 69 is mirror symmetrical to imaginary planes 70 passing through the axis 14. Main pipe portions 68 and 69 form a grid with axial passages for the fluid medium flowing through the enveloping vessel. The outer connecting pipe portions 74 are shown in FIG. 26 to connect main pipe portions located in alternate planes, and a corresponding arrangement of the inner connecting pipe portions 71 is shown in FIG. 25. It will be seen that connecting pipe portions 71 are located in axial planes, while connecting pipe portions 74 are parallel to the main axis but inclined to the radial direction permitting a crossing of the main pipe portions which are located in adjacent planes. Spacing elements 112 are advantageously provided between main pipe portions located in adjacent horizontal planes.

FIG. 27 illustrates another embodiment of the invention in which the pipes may be connected as shown in FIGS. 28 or 29. FIG. 27 schematically shows the pipes as single lines. As shown in FIG. 28, the connecting pipe portions 84 are located in planes inclined to the main axis, and successive main pipe portions are located in every second plane and also staggered in circumferential direction a distance which is twice the distance between circumferentially adjacent main pipe portions located in two adjacent horizontal planes. The horizontal planes are indicated by reference numerals 79 to 82 in FIG. 28, and the oppositely curving main pipe portions 76 and 77 are located in adjacent planes. Connecting pipe portions 83 connect main pipe portions in main pipe portions in every second plane curving in the same direction, and connecting pipe portions 84 connect successive main pipe portions curving in the opposite direction. The curvature of the pipes in each layer is similar to the arrangement of FIG. 9.

FIG. 29 illustrates a modification of this construction as applied to eight horizontal planes 86 to 93 which are perpendicular to the main axis of the vessel. Connecting pipe portions 94 and 95 are concentric and parallel. The inner connecting pipe portion 94 connects main pipe portions located in planes 88 and 90. Connecting pipe portion 95 is concentric and parallel with connecting pipe portion 94, connects main pipe portions located in planes 86 and 92, and is located in the same plane as connecting pipe portion 94.

Connecting pipe portions 95 and 97 are located in a common plane inclined in the opposite direction and are concentric and parallel with each other. Connecting pipe portion 95 connects main pipe portions located in planes 89 and 91, and connecting pipe portion 97 connects main pipe portions located in planes 87 and 93 so that connecting pipe portions located in oppositely slanted planes connect main pipe portions located in alternate horizontal planes.

The pattern of FIG. 29 corresponds to the pattern of FIG. 28, but instead of single pipes, groups of two parallel pipes are used. FIGS. 28 and 29 illustrate the inner connecting pipe portions, and the outer connecting pipe portions are arranged in the same manner. It will be understood that groups of three or more pipes can be bent and arranged in a corresponding pattern to connect main pipe portions located in alternate planes.

The embodiment of FIGS. 30 and 31 is similar to the embodiment of FIGS. 27, 28 and 29, and like reference numerals are used. The difference between the embodiments of FIGS. 27 to 29 and the embodiments of FIGS. 30 and 31 is that at the transition point from the involute-shaped main pipe portions to the connecting pipe portions, in the region of the section line 78 shown in FIG. 27, for example, the tangent on the pipe is not parallel to the main axis 14. Consequently, the semi-circular connecting pipe portions 84', 83' in FIG. 30 and 94' to 97' in FIG. 31, do not appear as straight lines, but as ellipses. It will be noted that FIG. 30 shows an arrangement corresponding to FIG. 28 with single pipes bent in the desired pattern, whereas FIG. 31 shows groups of two parallel

pipes, for example 94', 95' bent in the respective pattern to connect main pipe portions located in every second plane, whereas parallel pipes 96' and 97' connect main pipe portions curving in the opposite direction as described with reference to FIG. 27, and located in the other group of alternate planes, for example the odd numbered planes in FIG. 31.

FIG. 32 shows concentric and parallel semi-circular connecting pipe portions connected to parallel main pipe portions 2 of a group of pipes which corresponds to the arrangement of the connecting pipe portions of FIG. 29, assuming that three pipes form a group. A modified arrangement of the connecting pipe portions is shown in FIG. 33, and instead of semi-circular connecting pipe portions, each connecting pipe portion includes a straight central part 99, and two curved knees connected to straight and parallel pieces of the main pipe portions 2. The innermost connecting pipe portion may be made semi-circular, and have the same radius of curvature as the curved knee portions 98 which, however, extend over different angles. The arrangement of FIG. 33 has the advantage that all curved connecting pipe portions can be bent to the same radius of curvature. The construction of FIG. 33 may be used in any embodiment of the invention in which groups of parallel pipes are bent in the same pattern.

FIG. 34 illustrates an embodiment in which the main pipe portions 2 in alternate planes perpendicular to the main axis 14 curve in opposite directions to form a grid-like structure. As compared with the embodiment of FIG. 27, the inner connecting pipe portions 100 have a greater radius of curvature, and the outer connecting pipe portions 101 do not connect main pipe portions curving in the same direction and being adjacent each other as in the embodiment of FIG. 27, but have a very great radius of curvature and connect main pipe portions curving in opposite directions and located in an adjacent horizontal plane, for example. The outer connecting pipe portions 101 have a helical shape, but a construction as shown in FIG. 33 can also be used. The angle of the connecting pipe portion 101 is smaller than 180°, and the radius of curvature is great. The oppositely curving main pipe portions located in alternate planes are mirror symmetrical to imaginary axial planes 102. Two inner connecting pipe portions 100, two main pipe portions 2 curving in opposite directions, and one outer connecting pipe portion 101 form a heart-shaped loop.

FIG. 35 illustrates a construction of the inner connecting pipe portions including a semi-circular part 103 and two straight pipe pieces 104 which are connected to the involute shaped oppositely curving main portions 2. This construction permits it to place the inner connecting pipe portions close to the main axis 14 and to the outer surface of the column 12 described with reference to FIG. 7. FIG. 36 shows a construction of the outer connecting pipe portions in which instead of a helically curved pipe, a straight center part 105 is connected by two curved parts 106 to the respective oppositely curving main pipe portions 2. The radii of curvature of the curved portions 106 are great, and connecting pipe portions of this shape are easier to manufacture. FIG. 37 which is a view in the direction of the arrow 107 in FIG. 36 shows how the combination of straight pipe portions 105 with curved pipe portions 106 achieve the same connection as an exactly helical connecting pipe portion.

FIGS. 38 and 39 show a modification in which main pipe portions curving in opposite directions and being located in adjacent planes are connected to each other. However, the inner connecting pipe portions 107 curve in a direction opposite to the direction of the connected main pipe portions, and extend over a small angle, whereas in the embodiment of FIG. 34 the inner connecting pipe portions 100 extend over an angle greater than 180°. Consequently, two adjacent main pipe portions do not form the garland-shaped pattern of FIG. 34, but a pair of main pipe portions and the corresponding connecting portions

form a wide loop. Connecting pipe portions 107 can be made helical, or two curved knees connected by a central straight part may be substituted, as described with reference to FIG. 37. Small radii of curvature are entirely eliminated in the arrangement of FIG. 38. The pattern is symmetrical to imaginary planes 102 and 108 passing through the main axis 14. The wide loops formed in two adjacent horizontal planes are angularly staggered in circumferential direction. FIG. 39 shows the inner connecting pipe portions to consist of a straight central part 110 and two curved knee parts 111.

It will be understood that in the embodiments of FIGS. 34 and 38, instead of single pipes arranged in the respective pattern, groups of parallel pipes can be arranged in a corresponding pattern.

The embodiments of the invention are illustrated in simplified partly schematic views, and it will be understood that the practical embodiment as illustrated in FIGS. 7 and 8 can include pipes arranged in any of the described patterns. Rising pipes parallel to the axis of the vessel, as shown at 22 in FIG. 7 are provided in each of the embodiments of the invention, although they are not illustrated for the sake of simplicity.

Heat exchangers in accordance with the invention have a very great heat exchanging surface per unit volume of casing, without causing unduly or unnecessarily high pressure losses of the medium flowing in the pipes and of the medium flowing in the vessel that is around the pipes. This is of particular importance for gases having a pressure higher than atmospheric pressure, as occurs in boiler systems for nuclear reactors where the cost of the outer pressure vessel is very high so that the arrangement of the invention results in great economic advantages.

The distance between planes perpendicular to the axis of the vessel where the main pipe portions are disposed should be substantially constant in order to obtain a uniform heat exchange and temperature, and is generally determined by the smallest radius of curvature of the connecting pipe portions connecting main pipe portions in two adjacent planes. The arrangement of the invention eliminates small radii of curvature which has the advantage that weakening of thick walls of high pressure pipes during bending is avoided. It is not necessary to forge the connecting pipe portions which would require welding seams and accumulations of material which would cause high thermal stresses.

Particularly when the connecting pipe portions are placed in slanted positions in accordance with the present invention, so that main pipe portions in alternate planes or farther spaced planes can be connected, comparatively large radii of curvature are obtained even though the main pipe portions located in adjacent planes are closely spaced from each other in axial direction of the vessel.

The main pipe portions are preferably substantially involute-shaped, but a cycloid-shaped main pipe portion, or a spiral-shaped main pipe portion, or similar curved shapes will serve the purpose of the invention, particularly if the radius of curvature of the main pipe portion becomes gradually greater in the outwardly located parts of the main pipe portion. The main pipe portion may also be made of straight pipe portions connected by curved pipe portions whose radius of curvature increases toward the outer parts of the main pipe portion in relation to the main axis of the vessel. Another possibility of arriving at the desired shape of the main pipe portion is the use of short part-circular pipe pieces having the same radius, connected by straight pipe pieces whose lengths are increased with the distance from the axis of the vessel. Broadly speaking, the preferred shape of the main pipe portions results in a closer angular spacing of the inner ends thereof than of the outer ends thereof.

To facilitate understanding of the invention FIG. 40 shows in fragmentary vertical section a heat-exchanger embodying the invention. This figure is largely self-ex-

planatory, and it need merely be pointed out that reference numeral 1 indicates the inlet for the fluid medium which flows through the pipes 1—of which only the pipe portions 3 and 4 are identified—whereas reference numeral 0 identifies the outlet for this fluid medium. The vessel is identified with reference numeral 9.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of heat exchangers differing from the types described above.

While the invention has been illustrated and described as embodied in a heat exchanger including a plurality of pipes angularly staggered about the main axis of an enveloping vessel and having curved main pipe portions located at different levels of the vessel, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can by applying current knowledge readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

What is claimed as new and desired to be secured by Letters Patent is:

1. A heat exchanger comprising, in combination, a vessel having a main axis and inlet and outlet means for a first fluid; and pipe means located in the interior of said vessel and having inlet and outlet means for a second fluid, said pipe means including a plurality of heat exchanging pipes, each pipe having similarly curved main pipe portions extending between a central part and an outer part of said interior of said vessel in superimposed spaced planes substantially transverse to said main axis, each similarly curved main pipe portion of each of said pipes being located angularly offset relative to such main pipe portions of the same pipe which are located in adjacent ones of said superimposed spaced planes, and a plurality of curved connecting pipe portions each connecting the ends of two main pipe portions of the same pipe which are located in adjacent superimposed spaced planes and which are angularly offset so that said curved connecting pipe portions are inclined to said main axis, said curved connecting pipe portions having a radius of curvature greater than half the distance between adjacent superimposed spaced planes.

2. A heat exchanger as set forth in claim 1, said main pipe portions each having an inner end portion and an outer end portion circumferentially spaced from said inner end portion wherein successive main pipe portions located in alternate planes curved in opposite directions and cross each other adjacent the connecting pipe portions which connect said inner end portions of said main pipe portions, and wherein the inner connecting pipe portions extend over an angle greater than 180°.

3. A heat exchanger as set forth in claim 1, said main pipe portions each having an inner end portion and an outer end portion circumferentially spaced from said inner end portion wherein the connecting pipe portions located in alternate planes curved in opposite directions and at the inner end portions of said main pipe portion are curved in opposite sense to the respective main pipe portions so that said pipes form wide loops.

4. A heat exchanger as defined in claim 1, wherein each of said main pipe portions has a smaller radius of curvature near its inner end than near its outer end.

5. A heat exchanger as set forth in claim 1 wherein said curved main pipe portions have straight pipe pieces at the ends thereof, said straight pipe pieces having a length at least equal to the diameter of said main pipe

portion and of said connecting pipe portions and being connected to the latter without a break.

6. A heat exchanger as set forth in claim 1 wherein said connecting pipe portions are located in said vessel.

7. A heat exchanger as set forth in claim 1, wherein each of said main pipe portions is composed of several part-circular parts, the radii of curvature of said part-circular parts located closer to the center of said vessel being smaller than the radii of curvature of said parts located outward and near the inner surface of said vessel.

8. A heat exchanger as set forth in claim 1, wherein each of said main pipe portions is composed of alternating curved pieces and straight pieces, said curved pieces having the same radius of curvature, and said straight pieces including shorter pieces located near the center of said vessel and longer pieces located near the inner surface of said vessel.

9. A heat exchanger as set forth in claim 1, wherein said vessel has an inner cylindrical surface concentric with said main axis, and projections projecting from said cylindrical inner surface and having surface portions following the contour of said pipe means and located closely adjacent said connecting pipe portions and the outer parts of said main pipe portions to form narrow passages for said first fluid.

10. A heat exchanger as set forth in claim 9, wherein said projections are hollow, and including pipes parallel to said main axis and located in said hollow projections, said pipes being connected with said pipe means and including inlet pipes and outlet pipes for said second fluid.

11. A heat exchanger as set forth in claim 1, wherein said connecting pipe portions are circular and extend over an angle greater than 180°, and including short pipe pieces bent in opposite direction in relation to the curvature of said connecting pipe portions and connecting the same with the corresponding main pipe portions.

12. A heat exchanger as set forth in claim 1 wherein said heat exchanging pipes are arranged in a plurality of groups of parallel pipes angularly staggered about said main axis of said vessel, and wherein said main pipe portions of pipes of the same group have the same curvature at least in the center portions thereof, and have at least in the region of one group of ends thereof angularly staggered portions connected to angularly staggered connecting pipe portions.

13. A heat exchanger as set forth in claim 1, wherein said connecting pipe portions comprise outer connecting pipe portions connecting the outer ends of said main pipe portion and inner connecting pipe portions connecting the inner ends of said main pipe portions, and wherein the outer connecting pipe portions are located in planes parallel to said main axis, and the inner connecting pipe portions are located outwardly of said last-mentioned planes.

14. A heat exchanger as set forth in claim 13 wherein said inner connecting pipe portions are located in planes slanted to said main axis and connect main pipe portions angularly staggered from each other the same angle and being located in different planes of said planes.

15. A heat exchanger as set forth in claim 1, wherein the radii of curvature of all said connecting pipe portions are equal.

16. A heat exchanger as set forth in claim 1, wherein the distance between said parallel planes is equal to the diameter of said pipes.

17. A heat exchanger as set forth in claim 1, and including spacing means located between main pipe portions which are located in different planes of said superimposed spaced planes for supporting said pipes.

18. A heat exchanger as set forth in claim 1, wherein each of said pipes forms a structure bounded by surfaces parallel to said main axis.

19. A heat exchanger as set forth in claim 1, and including supporting means for each of said pipes so that said structures form rigid units adapted to be independent-

ly constructed and assembled by insertion into said vessel
in the direction of said main axis.

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