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(54) Title: RECUPERATIVE HEAT EXCHANGER, FUEL CELL SYSTEM INCLUDING RECUPERATIVE HEAT EXCHANGER, AND METHOD OF OPERATING SAME

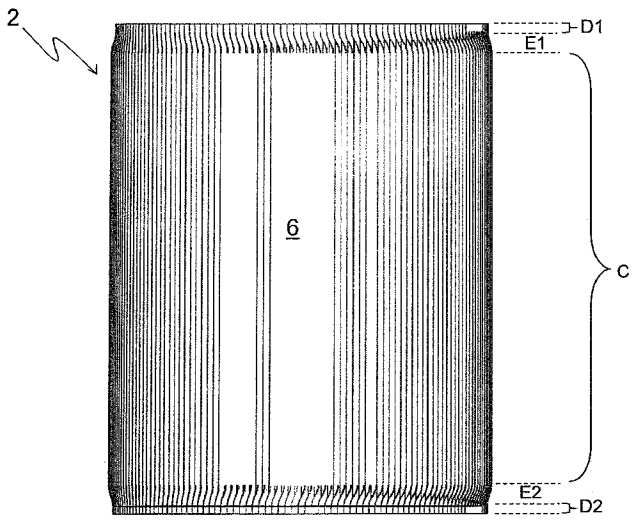


Fig. 4

(57) Abstract: A heat exchanger, such as a cathode recuperator for a high temperature fuel cell system, has a corrugated separator, a barrier and a plurality of flow channels. The corrugated separator has a surface positioned along a heat exchange fluid flow path, opposite ends of the separator having flattened corrugations. The barrier is positioned adjacent the surface. The plurality of flow channels are in the heat exchange fluid flow path and are at least partially defined by the surface and the barrier. The flattened corrugations are positioned adjacent crests in the corrugated separator and secured to the barrier.

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RECUPERATIVE HEAT EXCHANGER, FUEL CELL SYSTEM INCLUDING RECUPERATIVE HEAT EXCHANGER, AND METHOD OF OPERATING SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to U.S. Provisional Patent Application Serial No. 61/095,818, filed September 10, 2008, the entire contents of which is hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] This invention relates to heat exchangers in general and in more particular applications, to recuperative heat exchangers which find many uses in industry, including in fuel cell systems.

BACKGROUND

[0003] A recuperative heat exchanger, or recuperator, is used to optimize the overall system efficiency of a high temperature application, such as a gas turbine or a high temperature fuel cell system, by heating a low temperature incoming air stream to a temperature closer to the desired process operating temperature via the transfer of thermal energy from a high temperature process waste stream of exhaust gas or air. Such a heat exchanger allows for the efficient transfer of heat from the hot stream to the cold stream while maintaining isolation of the two streams from each other. In order to simplify the packaging of the recuperator into the system, and in order to reduce the material costs of the device, it is usually desirable to minimize the physical size and weight of the recuperative heat exchanger. It is also typically a principal object of such a heat exchanger to provide for high heat exchanger effectiveness in order to maximize the degree to which the heat is recuperated.

[0004] Heat exchanger effectiveness is defined as the ratio between the actual rate at which heat is transferred between the two fluids in a heat exchanger and the maximum possible heat transfer rate. The maximum possible heat transfer rate is achieved when the exit temperature of the fluid with the lower heat capacity is made to be equal to the entering temperature of the other fluid, and can theoretically be achieved in a heat exchanger of infinite length with the fluids passing through it in a counter-flow orientation. For most practical heat exchangers the effectiveness will be less than one.

[0005] A cathode recuperator for high temperature fuel cell systems such as, for example, solid oxide fuel cell (SOFC) systems, has some unique performance requirements as compared to recuperators in better-known applications such as, for example, gas turbines. SOFC's are solid-state devices that use an oxide-conducting ceramic electrolyte to produce electrical current by transferring oxygen ions from an oxidizing gas stream at the cathode of the fuel cell to a reducing gas stream at the anode of the fuel cell. This type of fuel cell is seen as especially promising in the area of distributed stationary power generation. SOFC's require an operating temperature range which is the highest of any fuel cell technology, giving it several advantages over other types of fuel cells for these types of applications. The rate at which a fuel cell's electrochemical reactions proceed increases with increasing temperature, resulting in lower activation voltage losses for the SOFC. The SOFC's high operating temperature precludes the need for precious metal catalysts, resulting in substantial material cost reductions. The elevated exit temperature of the flow streams allow for high overall system efficiencies in combined heat and power applications, which are well suited to distributed stationary power generation.

[0006] The traditional method of constructing solid oxide fuel cells has been as a large bundle of individual tubular fuel cells. Systems of several hundred kilowatts of power have been successfully constructed using this methodology. However, there are several known disadvantages to the tubular design which severely limit the practicality of its use in the area of 25kW-100kW distributed stationary power generation. For example, producing the tubes can require expensive fabrication methods, resulting in achievable costs per kW that are not competitive with currently available alternatives. As another example, the electrical interconnects between tubes can suffer from large ohmic losses, resulting in low volumetric power densities. These disadvantages to the tubular designs have led to the development of planar SOFC designs. The planar designs have been demonstrated to be capable of high volumetric power densities, and their capability of being mass produced using inexpensive fabrication techniques is promising.

[0007] As is known in the art, a single planar solid oxide fuel cell (SOFC) consists of a solid electrolyte that has high oxygen ion conductivity, such as yttria stabilized zirconia (YSZ); a cathode material such as strontium-doped lanthanum manganite on one side of the electrolyte, which is in contact with an oxidizing flow stream such as air; an anode material such as a cermet of nickel and YSZ on the opposing side of the electrolyte, which is in

contact with a fuel flow stream containing hydrogen, carbon monoxide, a gaseous hydrocarbon, or a combination thereof such as a reformed hydrocarbon fuel; and an electrically conductive interconnect material on the other sides of the anode and cathode. A number of these cells are assembled into a fuel cell stack, with the electrically conductive interconnect material providing both the electrical connection between adjacent cells and the flow paths for the reactant flow streams to contact the anode and cathode. Such cells can be produced by well-established production methodologies such as screen-printing and ceramic tape casting.

[0008] It is critical in operation to prevent the anode flow from mixing with the cathode flow, since the cathode flow will act as an oxidizer to combust the fuel in the anode flow, leading to potentially damaging combustion occurring within the fuel cell system. High temperature gas-tight seals are therefore required between the individual fuel cells and the interconnect material in order to prevent such mixing from occurring. In order to meet the requirements of operating at high temperatures, remaining stable in both oxidizing and reducing environments, and other considerations necessary for usage with SOFCs, these seals are typically constructed of cements, glasses, or glass-ceramics.

[0009] As is known to those in the art, these types of sealing materials are not capable of withstanding large differential pressures. As a consequence, planar SOFC systems are typically not capable of operation at elevated pressures, as are gas turbines. This has resulted in the need for very low pressure drop, high thermal efficiency recuperative heat exchangers to recover the waste heat from the cathode exhaust in order to preheat the cathode air feed. The power required to pressurize the cathode air is quite often the largest single parasitic power draw of a SOFC system, so minimizing the pressure drop in such a recuperator can provide substantial gains in the overall electrical efficiency of the system, thus potentially providing a critical commercial advantage.

SUMMARY

[0010] In some embodiments, the invention provides a primary surface annular heat exchanger suitable for use as a recuperator in solid oxide fuel cell systems.

[0011] In some embodiments, the invention provides a heat exchanger having a corrugated separator, a barrier and a plurality of flow channels. The corrugated separator has

a surface positioned along a heat exchange fluid flow path, opposite ends of the separator having flattened corrugations. The barrier is positioned adjacent the surface. The plurality of flow channels are in the heat exchange fluid flow path and are at least partially defined by the surface and the barrier. The flattened corrugations are secured to the barrier.

[0012] The invention also provides a method of making a heat exchanger. The method includes the acts of providing a corrugated separator sheet having corrugations extending in a longitudinal direction, flattening the corrugations into flattened portions positioned at first and second longitudinal ends of the corrugated separator sheet, positioning the corrugated separator sheet adjacent a non-corrugated barrier to create a heat exchange flow path between the corrugated separator sheet and the non-corrugated barrier, and securing the flattened portions to a surface of the non-corrugated barrier.

[0013] The invention provides a corrugated separator sheet for a heat exchanger. The corrugated separator sheet can include a plurality of corrugations and a flattened region. The plurality of corrugations extend parallel to one another in a longitudinal direction, and have a plurality of peaks and a plurality of troughs opposite the plurality of peaks. The flattened region is proximate a longitudinal end of the separator sheet and is adjacent the plurality of peaks.

[0014] The invention can also provide a primary surface annular heat exchanger that is capable of achieving a high degree of heat exchanger effectiveness with minimal pressure drop and minimal size and weight impact on a system making use of such a heat exchanger.

[0015] In some embodiments, the invention provides a method of constructing a primary surface annular heat exchanger to exchange heat between two flowstreams, the method providing reliable sealing of the flowstreams from one another with a minimum number of parts and low overall cost.

[0016] In one aspect of the invention, a primary surface annular heat exchanger comprises a corrugated separator sheet with a first surface exposed to a first heat exchanging fluid and a second surface exposed to a second heat exchanging fluid. The first fluid flows through a plurality of flow channels bounded by the first surface of the corrugated separator sheet and a radially inwardly located cylinder. The second fluid flows through a plurality of flow channels bounded by the second surface of the corrugated separator sheet and a radially

outwardly located cylinder. Each of the ends of the corrugated separator sheet has the corrugations flattened and bonded to the radially inwardly located cylinder.

[0017] In another aspect of the invention, a method is provided for constructing a primary surface annular heat exchanger. The method of making the heat exchanger includes the steps of corrugating a separator sheet and forming it into a corrugated cylinder by joining a first corrugation located at a first edge oriented parallel to the corrugations and a second corrugation located at a second edge oriented parallel to the corrugations. The method of making the heat exchanger may further include the steps of flattening the corrugations at either end of the corrugated cylinder, and bonding the flattened portions of the corrugations to the surface of a non-corrugated cylinder.

[0018] Other aspects of the invention will become apparent by consideration of the detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. 1 is a plan section view of a portion of a fuel cell system employing a heat exchanger according to an embodiment of the present invention;

[0020] FIG. 2 is a detail view of the portion II-II of the heat exchanger of FIG. 1;

[0021] FIG. 3 is a perspective view of a single convolution of a primary surface of a heat exchanger according to an embodiment of the present invention;

[0022] FIG. 4 is an elevation view of a corrugated separator for use in a heat exchanger according to an embodiment of the present invention;

[0023] FIG. 5 is a partial perspective view of portions of a heat exchanger according to an embodiment of the present invention;

[0024] FIG. 6 is a somewhat diagrammatic section view through a flow channel of a heat exchanger according to the present invention in order to illustrate the flowpaths;

[0025] FIG. 7 is a somewhat diagrammatic section view similar to a portion of FIG. 6 but showing aspects of an alternate embodiment of a heat exchanger according to the present invention;

[0026] FIG. 8 is a section view in the direction VIII-VIII of FIG. 6;

[0027] FIG. 9 is a perspective view of a corrugated separator for use in a heat exchanger at a stage of manufacture according to an embodiment of the present invention;

[0028] FIG. 10 is a detail view of the portion X-X of FIG. 9;

[0029] FIG. 11 is a somewhat diagrammatic view of a stage of manufacture of a heat exchanger according to an embodiment of the present invention; and

[0030] FIG. 12 is a diagrammatic view illustrating the geometric relationship between certain of the components shown in FIG. 11.

DETAILED DESCRIPTION

[0031] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having" and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms "mounted," "connected," "supported," and "coupled" and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings. Further, "connected" and "coupled" are not restricted to physical or mechanical connections or couplings.

[0032] FIG. 1 illustrates an embodiment of a heat exchanger according to the present invention employed in a solid oxide fuel cell system. As has been previously disclosed in pending U.S. patent application 2008/0038622 to Valensa et. al., whose contents are hereby incorporated by reference in their entirety, a recuperative heat exchanger to preheat cathode air for solid oxide fuel cells using a cathode exhaust can be incorporated in an annular volume surrounding the solid oxide fuel cell stacks and associated high-temperature balance-of-plant in a solid oxide fuel system. As shown in FIG. 1, an embodiment of a primary surface recuperative heat exchanger 1 according to the present invention is so incorporated

into a solid oxide fuel cell system 100. The heat exchanger 1 is arranged in an annular volume surrounding the solid oxide fuel cell stacks and associated high-temperature balance-of-plant, collectively 101. The advantages of such an arrangement has been well-discussed in the aforementioned application 2008/0038622.

[0033] As can be better seen in FIG. 2, the heat exchanger 1 as depicted in the embodiment of FIG. 1 comprises a first plurality of flowpaths A and a second plurality of flowpaths B. The plurality of flowpaths A are bounded by a first surface 5 of a corrugated separator sheet 2 and a first cylinder 4, or first barrier. The plurality of flowpaths B are bounded by a second surface 6 of the corrugated separator sheet 2 and a second cylinder 3, or second barrier, said cylinder 3 being concentric to the cylinder 4 and furthermore being larger in diameter than cylinder 4. The corrugated separator sheet 2 is located in the annular gap between the cylinders 3 and 4. In other embodiments, the first and second cylinders may be substantially planar barriers or barriers having other geometrical configurations such that flowpaths A and B are configured to exchange heat.

[0034] A single convolution 7, or corrugation, of the corrugated separator sheet 2 is shown in greater detail in FIG. 3. In the embodiment shown, the convolution comprises a first crest 8, or peak, formed so that the first separator sheet surface 5 assumes a concave shape at the crest 8 and the second separator sheet surface 6 assumes a convex shape at the crest 8, and a second crest 9, or trough, formed so that the first separator sheet surface 5 assumes a convex shape at the crest 9 and the second separator sheet surface 6 assumes a concave shape at the crest 9. A plurality of generally straight sections 22 of the corrugated separator sheet 2 join the crests 8 and 9 of adjacent convolutions 7.

[0035] In some embodiments, the crests 8 are joined to the cylinder 3 by a method such as brazing, welding, gluing, or other methods of joining known to those skilled in the art. In some embodiments, the crests 9 are joined to the cylinder 4 by a method such as brazing, welding, gluing, or other methods of joining known to those skilled in the art. In some embodiments, it may be preferable to have a bond between the crests 8 and the cylinder 3 in only certain limited areas. In some embodiments, it may be preferable to have a bond between the crests 9 and the cylinder 4 in only certain limited areas.

[0036] Methods of corrugating a sheet to take such a form are well-known to those skilled in the art of heat exchangers. It should be understood that the shape of the

corrugations shown in the figures is meant to be illustrative of the overall concept, and is not meant to be limiting with regard to the specific shape of the corrugations. In other embodiments, the corrugated separator sheet may have other geometrical configurations, such as triangular corrugations (i.e., straight sections joining at crests of sharp points), rectangular corrugations (i.e., straight sections joining at flat crests) or curved corrugations (i.e., a sinusoidal pattern), amongst others. Other types of corrugations commonly used in heat exchangers, such as for example a corrugated separator sheet having flat-crested convolutions, would be equally valid substitutes for the geometry shown.

[0037] As is best seen in the elevation view of FIG. 4, the corrugated separator sheet 2 can be divided into several distinct regions along the flow length of the channels A and B: a zone D1 at a first longitudinal end of the corrugated separator 2, wherein the convolutions 7 are flattened in order to seal off a first end of the plurality of flow channels A; a zone D2 at a second longitudinal end of the corrugated separator 2 opposite the first longitudinal end, wherein the convolutions 7 are similarly flattened in order to seal off a second end of the plurality of flow channels A, the second end of the flow channels A being located opposite the first end of the flow channels A; a center zone C wherein the convolutions are in an unflattened shape as described above in reference to FIG. 3; a transition zone E1 located between and connecting the zones D1 and C; and a transition zone E2 located between and connecting the zones D2 and C.

[0038] The flow paths through an embodiment of the heat exchanger 1 can be seen in FIG. 6. A first fluid flow 18 enters the flow channels A by passing first through an annular flow channel 11 formed by the inner surface of cylinder 4 and a wall 16 located radially inward therefrom, and second through an inlet 10 in the cylinder 4. In the embodiment of FIG. 6 the inlet 10 is located in the zone C of the corrugated separator sheet 2, adjacent the zone E1. In one embodiment of the invention, depicted in FIG. 5, the inlet 10 comprises a plurality of trapezoid-shaped openings in the cylinder 4, each opening having a 180° rotated orientation as compared to its neighboring openings so that adjacent openings are separated by a thin web oriented in a direction non-parallel to the direction of the flow channels, thereby ensuring that all of the flow channels A are fluidly connected to the annular flow channel 11.

[0039] Referring again to the embodiment of the heat exchanger 1 shown in FIG. 6, the fluid flow 18 exits the flow channels A by passing through an outlet 20 in the cylinder 4 and

into an annular flow channel 12 formed by the inner surface of cylinder 4 and a wall 17 located radially inward therefrom, the outlet 20 being located in the zone C of the corrugated separator sheet 2, adjacent the zone E2. In one embodiment, the outlet 20 is constructed to be similar to the inlet 10 of the embodiment shown in FIG. 5. A second fluid flow 19 passes through the flow channels B in a direction counter to the flow direction of the first fluid flow 18 passing through the flow channels A. As shown in FIG. 6, the second fluid flow 19 passes through an annular flow channel 13 located between the cylinders 3 and 4, enters the flow channels B in the transition zone E2, and exits from the flow channels B back into the annular flow channel 13 in the transition zone E1.

[0040] An alternative embodiment, illustrated in FIG. 7, includes a radially expanded section 21 of the cylinder 3. In this embodiment, the fluid flow 19 exits the flow channels B in the zone C of the corrugated separator sheet 2 rather than in the zone E1, and flows into an annular flow channel 14 formed by the expanded section 21 and the cylinder 4. It should be understood that the alternative embodiment shown in FIG. 7 can be applied in a similar manner to the inlet end of the flow channels B.

[0041] In one embodiment, the shape of the convolutions in the zones D1 and D2 is as shown in the section view of FIG. 8. The convolutions in these zones have been folded over into a flattened portion 32 (i.e., corresponding to D1) and flattened into the cylinder 4, thereby sealing off the ends of the flow channels A. Regions E1 and D1, and E2 and D2, include convolutions bent in a direction transverse to the longitudinal direction in which the convolutions extend, the convolutions overlapping adjacent convolutions in the first and second flattened regions D1 and D2.

[0042] The flattened portion 32 is positioned adjacent a crest of the corrugated separator sheet 2. As can be seen, with reference to Fig. 5, positioning the flattened portion 32 adjacent one set of crests allows the flattened portion 32 to be secured to the cylinder 4 such that the set of crests do not interfere. In preferred embodiments, the flattened portion 32 is substantially flush with the set of crests such that the flattened portion 32 and set of crests engage the cylinder 4 together. With reference to Figs. 4-5, a second flattened portion (i.e., corresponding to D2) is also positioned adjacent and flush with the set of crests and secured to the first cylinder 4 in the same way as the first flattened portion 32. In other embodiments, the second flattened portion may be positioned adjacent and/or flush with the opposite set of crests and secured to second cylinder 3, or another barrier.

[0043] A process for forming a primary surface annular heat exchanger according to the embodiments shown in FIGs. 4, 5 and 8 will now be described with reference to FIGs. 9-12. As best seen in FIGs. 9 and 10, a corrugated separator sheet 2 is formed into a closed loop by engaging a convolution 9a located at a first longitudinal edge of the corrugated separator sheet into a convolution 9b located at a second longitudinal edge of the corrugated separator. In some preferable embodiments, the engagement between the convolutions 9a and 9b is secured by creating a metallurgical bond, such as by autogenous welding.

[0044] In some embodiments of the invention, the corrugated separarator sheet is next slid over a cylinder 24, the cylinder 24 having an outer diameter that is approximately equal to the outer diameter of the inner cylinder 4 of the primary surface annular heat exchanger. In a prefereable embodiment the width of the corrugated separator sheet is selected such that after engagement of the convolutions 9a and 9b, the corrugated separator sheet will not fit over the cylinder 24 in a free state. Since the nature of the convolutions allow for relatively easy expansion of the corrugated separator sheet, a most preferable embodiment would size the width of the corrugated separator sheet so that a slight stretching of the convolutions of the corrugated separator sheet occurs as it is placed over the cylinder 24, thereby ensuring uniform contact between the plurality of crests 9 and the cylinder 24.

[0045] In some embodiments of the invention, the corrugations in the zones D1 and D2 of the corrugated separator sheet 2 are flattened in a process illustrated in FIGs. 11 and 12. In such a process, a first wheel 22 of a diameter substantially smaller than the diameter of the cylinder 24 is positioned to be tangent to and in contact with the inner surface of the cylinder 24, so that the axis 26 of the wheel 22 and the axis 25 of the cylinder 24 are parallel to one another and define a plane 28, the plane 28 being the plane common to both axes 25 and 26. A second wheel 23 is positioned such that the axis 27 of the second wheel 23 is parallel to the axes 25 and 26 of the first wheel 22 and the cylinder 24, and is located in the plane 28. The second wheel 23 is furthermore positioned so that the tangent distance H1 between the wheels 22 and 23 is less than the sum of the convolution height H2 of the corrugated separator 2 and the thickness T1 of the cylinder 24. The wheels 22 and 23 are made to rotate about their respective axes 26 and 27, the wheel 22 rotating in a first direction indicated by the arrow 29 and the wheel 23 rotating in a second direction indicated by the arrow 30, said directions being opposite of one another, thereby causing the cylinder 24 to rotate about its own axis 25 in a direction indicated by the arrow 31. The rotation of the cylinder 24 causes

successive convolutions of the corrugated separator to be compressed as they pass under the wheel 23, thereby forming the flattened zone D1 or D2 of the corrugated separator, the amount of compression being determined by the tangential spacing H1. The width of the wheel 23 and the axial location of the corrugated separator relative to the wheel 23 can be selected in order to control the width of the flattened zone D1 or D2 of the corrugated separator.

[0046] In some embodiments, it may be preferable for the cylinder 24 to make multiple complete revolutions about its axis 25 and to successively decrease the spacing H1 while the cylinder 24 is revolving in order to flatten the convolutions in a more controlled manner.

[0047] In some embodiments of the invention multiple pairs of the wheels 22 and 23 are used to flatten the convolutions at both ends of the corrugated separator 2 in the same operation.

[0048] In some embodiments of the invention the corrugated separator is removed from the cylinder 24 and is assembled over the cylinder 4. In some other embodiments the cylinder 24 may actually be the cylinder 4.

[0049] In some embodiments of the invention the flattened zones D1 and D2 are bonded to the cylinder 4 by welding, brazing, gluing, or other bonding processes known to those skilled in the art.

[0050] It should be understood that the embodiments described above and illustrated in the figures are presented by way of example only and are not intended as a limitation upon the concepts and principles of the present invention. As such, it will be appreciated by one having ordinary skill in the art that various changes are possible.

CLAIMS

What is claimed is:

1. A heat exchanger comprising:

a corrugated separator having a surface positioned along a heat exchange fluid flow path, opposite ends of the separator having flattened corrugations;

a barrier positioned adjacent the surface; and

a plurality of flow channels in the heat exchange fluid flow path at least partially defined by the surface and the barrier;

wherein the flattened corrugations are secured to the barrier.

2. The heat exchanger of claim 1, wherein the heat exchange fluid flow path is a first heat exchange fluid flow path, wherein the surface is a first surface, wherein the barrier is a first barrier and wherein the plurality of flow channels are a first plurality of flow channels, wherein the corrugated separator further includes a second surface positioned along a second heat exchange fluid flow path, the heat exchanger further comprising:

a second barrier positioned adjacent the second surface; and

a second plurality of flow channels in the second heat exchange fluid flow path bounded by the second surface and the second barrier;

wherein the first barrier and the second barrier are substantially concentric cylinders, and wherein the first barrier is located radially inward from the second barrier.

3. The heat exchanger of claim 2, wherein the corrugated separator includes a first flattened region adjacent a first end of the separator, a second flattened region adjacent a second end of the separator, a corrugated region between the first flattened region and the second flattened region, a first transition region connecting the first flattened region and a first end of the corrugated region, and a second transition region connecting the second flattened region and a second end of the corrugated region, and wherein the first barrier includes an inlet to the first heat exchange fluid flow path, the inlet being positioned proximate the first end of the corrugated region.

4. The heat exchanger of claim 3, wherein the inlet includes a plurality of trapezoid-shaped openings.

5. The heat exchanger of claim 3, wherein the first barrier includes an outlet from the first heat exchange fluid flow path, the outlet being positioned proximate the second end of the corrugated region.

6. The heat exchanger of claim 5, wherein the outlet includes a plurality of trapezoid-shaped openings.

7. The heat exchanger of claim 1, wherein the corrugated separator includes crests, wherein the crests are secured to the barrier by one of soldering, brazing, welding, adhesive bonding, and cohesive bonding.

8. The heat exchanger of claim 1, wherein the corrugated separator is formed into a substantially cylindrical shape.

9. The heat exchanger of claim 8, wherein the corrugated separator includes corrugations extending in a direction substantially parallel to a central axis of the substantially cylindrical shape.

10. The heat exchanger of claim 1, wherein the corrugated separator includes a longitudinal direction in which the corrugations extend, wherein the corrugated separator includes a first flattened region adjacent a first longitudinal end of the separator, a second flattened region adjacent a second longitudinal end of the separator, a corrugated region between the first flattened region and the second flattened region, a first transition region connecting the first flattened region and a first end of the corrugated region, and a second transition region connecting the second flattened region and a second end of the corrugated region, and wherein the first transition region and the first flattened region include corrugations bent in a direction transverse to the longitudinal direction, the corrugations overlapping adjacent corrugations in the first flattened region.

11. The heat exchanger of claim 1, wherein the flattened corrugations secured to the barrier substantially seal off the heat exchange fluid flow path.

12. The heat exchanger of claim 1, wherein the corrugations include a plurality of peaks and troughs, and wherein the flattened corrugations are located adjacent one of the peaks and the troughs.

13. A method of making a heat exchanger, the method comprising the acts of:

providing a corrugated separator sheet having corrugations extending in a longitudinal direction;

flattening the corrugations into flattened portions positioned at first and second longitudinal ends of the corrugated separator sheet;

positioning the corrugated separator sheet adjacent a non-corrugated barrier to create a heat exchange flow path between the corrugated separator sheet and the non-corrugated barrier; and

securing the flattened portions to a surface of the non-corrugated barrier.

14. The method of claim 13, further comprising:

forming the corrugated separator sheet into a corrugated cylinder by joining a first corrugation located at a first edge oriented parallel to the corrugations and a second corrugation located at a second edge oriented parallel to the corrugations.

15. The method of claim 13, wherein the act of flattening further comprises:

positioning the corrugated separator sheet adjacent a sleeve such that crests of the corrugated separator sheet engage the sleeve;

positioning the corrugated separator sheet and sleeve between two wheels spaced apart a distance smaller than a height of the corrugations;

rotating the two wheels in opposite directions to feed the corrugated separator sheet and sleeve between the two wheels, thereby forming one of the flattened portions flush with the crests.

16. The method of claim 13, wherein the sleeve is substantially cylindrical.

17. The method of claim 13, wherein the non-corrugated barrier is a first non-corrugated barrier, the method further comprising:

positioning the corrugated separator sheet between the first non-corrugated barrier and a second non-corrugated barrier to define a first heat exchange fluid flow path on a first side of the corrugated separator sheet and a second heat exchange fluid flow path on a second side of the corrugated separator sheet.

18. The method of claim 17, wherein positioning the corrugated separator sheet between the first non-corrugated barrier and a second non-corrugated barrier includes positioning the corrugated separator sheet in a substantially cylindrical space.

19. The method of claim 17, further comprising:

providing an inlet to the first heat exchange fluid flow path, the inlet being positioned proximate a first end of the corrugations; and

providing an outlet to the first heat exchange fluid flow path, the outlet being positioned proximate a second end of the corrugations;

wherein the acts of providing an inlet and providing an outlet include creating apertures in one of the non-corrugated barriers.

20. The method of claim 19, wherein the act of creating apertures includes creating apertures in the non-corrugated barrier to which the flattened portions are secured.

21. The method of claim 13, further comprising securing crests of the corrugated separator sheet to the non-corrugated barrier.

22. A corrugated separator sheet for a heat exchanger, the corrugated separator sheet comprising:

a plurality of corrugations extending parallel to one another in a longitudinal direction, the corrugations having a plurality of peaks and a plurality of troughs opposite the plurality of peaks; and

a flattened region proximate a longitudinal end of the separator sheet;

wherein the flattened region is adjacent the plurality of peaks.

23. The corrugated separator sheet of claim 22, wherein the flattened region is substantially flush with the plurality of peaks.

24. The corrugated separator sheet of claim 22, wherein the corrugated separator sheet is cylindrical.

25. The corrugated separator sheet of claim 22, wherein the flattened region is a first flattened region, and wherein the longitudinal end is a first longitudinal end, further comprising a second flattened region proximate a second longitudinal end of the separator sheet, wherein the second flattened region is adjacent one of the plurality of peaks and the plurality of troughs.

26. The corrugated separator sheet of claim 25, wherein the first flattened region is secured to a first cylindrical barrier and the plurality of troughs are positioned adjacent a second cylindrical barrier, wherein a first flow path is defined between the corrugated separator sheet and the first cylindrical barrier and a second flow path is defined between the corrugated separator sheet and the second cylindrical barrier.

27. The corrugated separator sheet of claim 26, wherein the second flattened region is adjacent the plurality of peaks, wherein the second flattened region is secured to the first cylindrical barrier.

28. The corrugated separator sheet of claim 26, further comprising a corrugated region between the first flattened region and the second flattened region, a first transition region connecting the first flattened region and a first end of the corrugated region, and a second transition region connecting the second flattened region and a second end of the corrugated region, wherein the first cylindrical barrier includes an inlet to the first flow path, the inlet being positioned proximate the first end of the corrugated region.

29. The corrugated separator sheet of claim 22, wherein the flattened region is a first flattened region and the longitudinal end is a first longitudinal end, the corrugated separator sheet further comprising:

a second flattened region adjacent a second longitudinal end of the separator sheet;

a corrugated region between the first flattened region and the second flattened region;

a first transition region connecting the first flattened region and a first end of the corrugated region; and

a second transition region connecting the second flattened region and a second end of the corrugated region;

wherein the first transition region and the first flattened region include corrugations bent in a direction transverse to the longitudinal direction, the corrugations overlapping adjacent corrugations in the first flattened region.

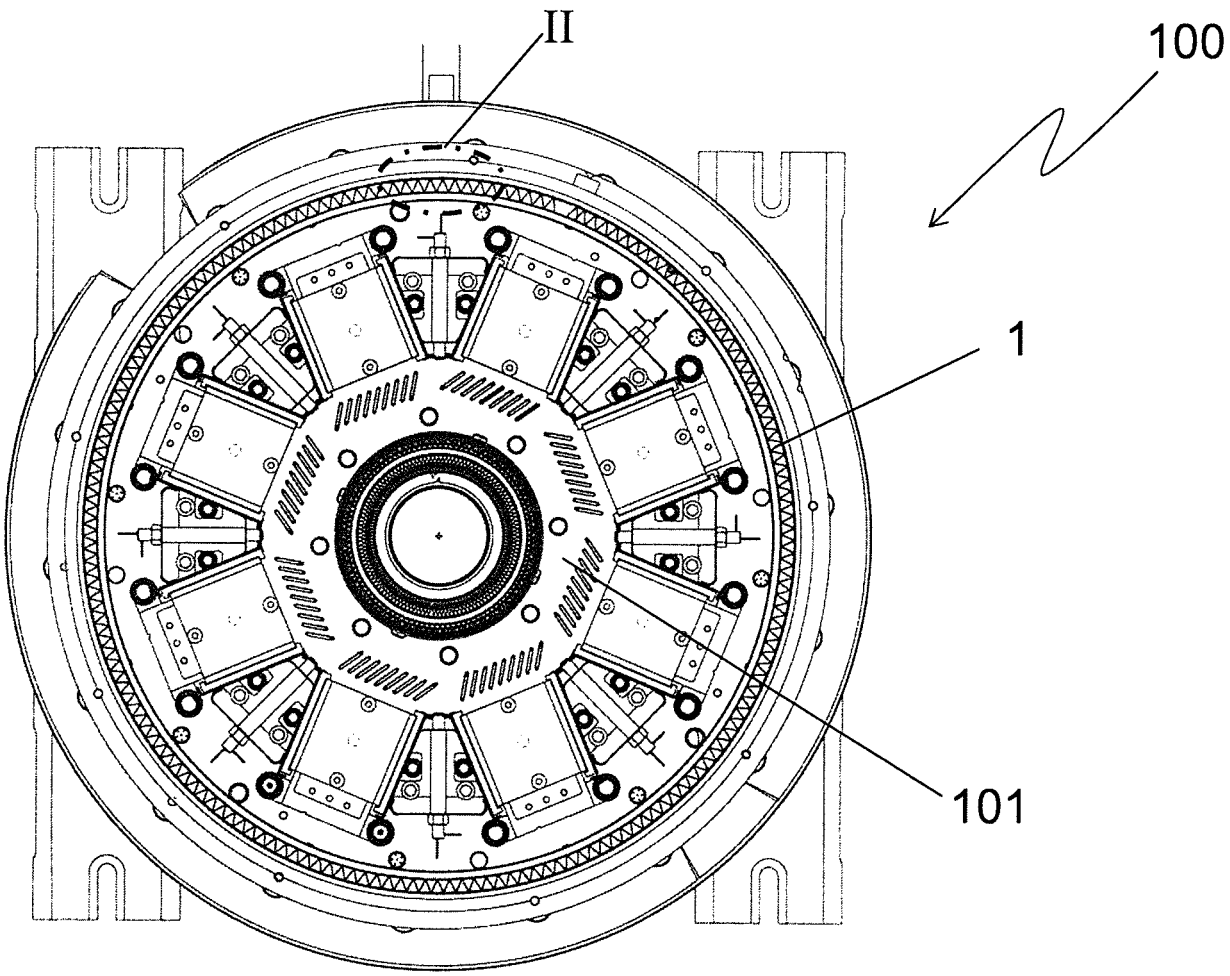


Fig. 1

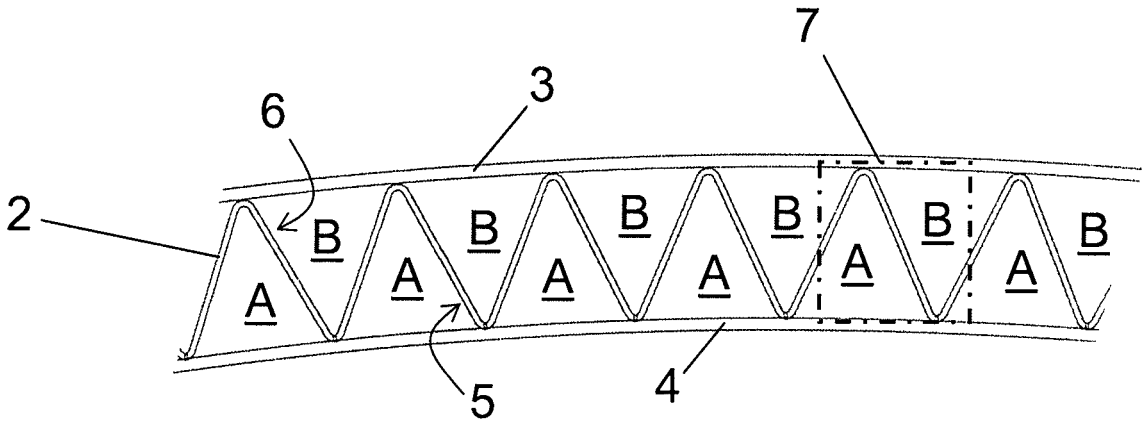


Fig. 2

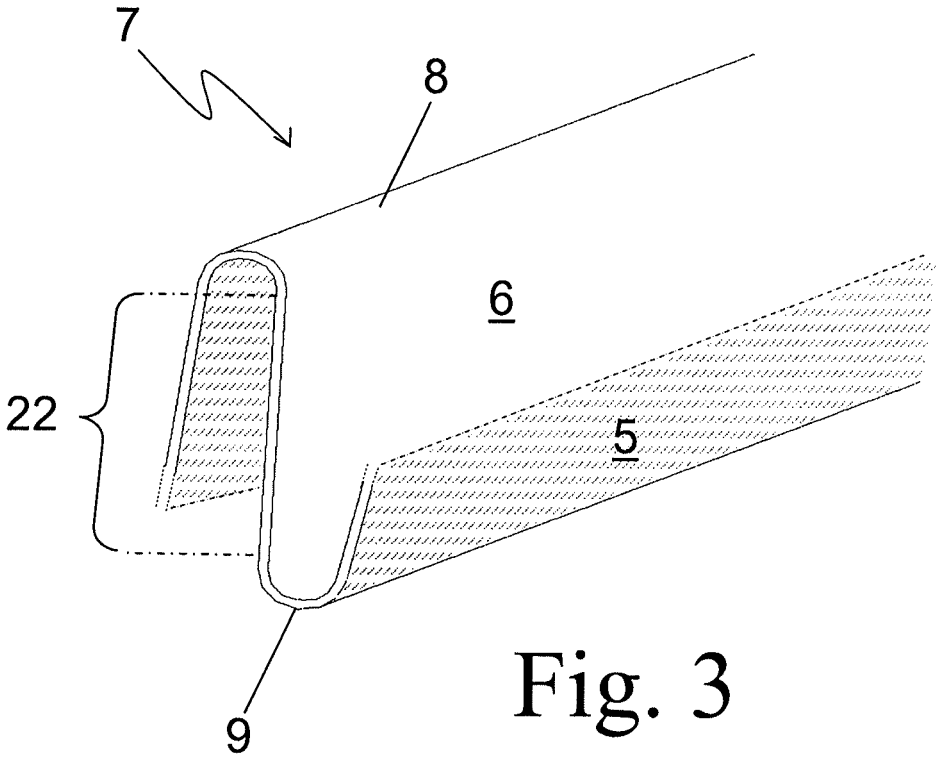


Fig. 3

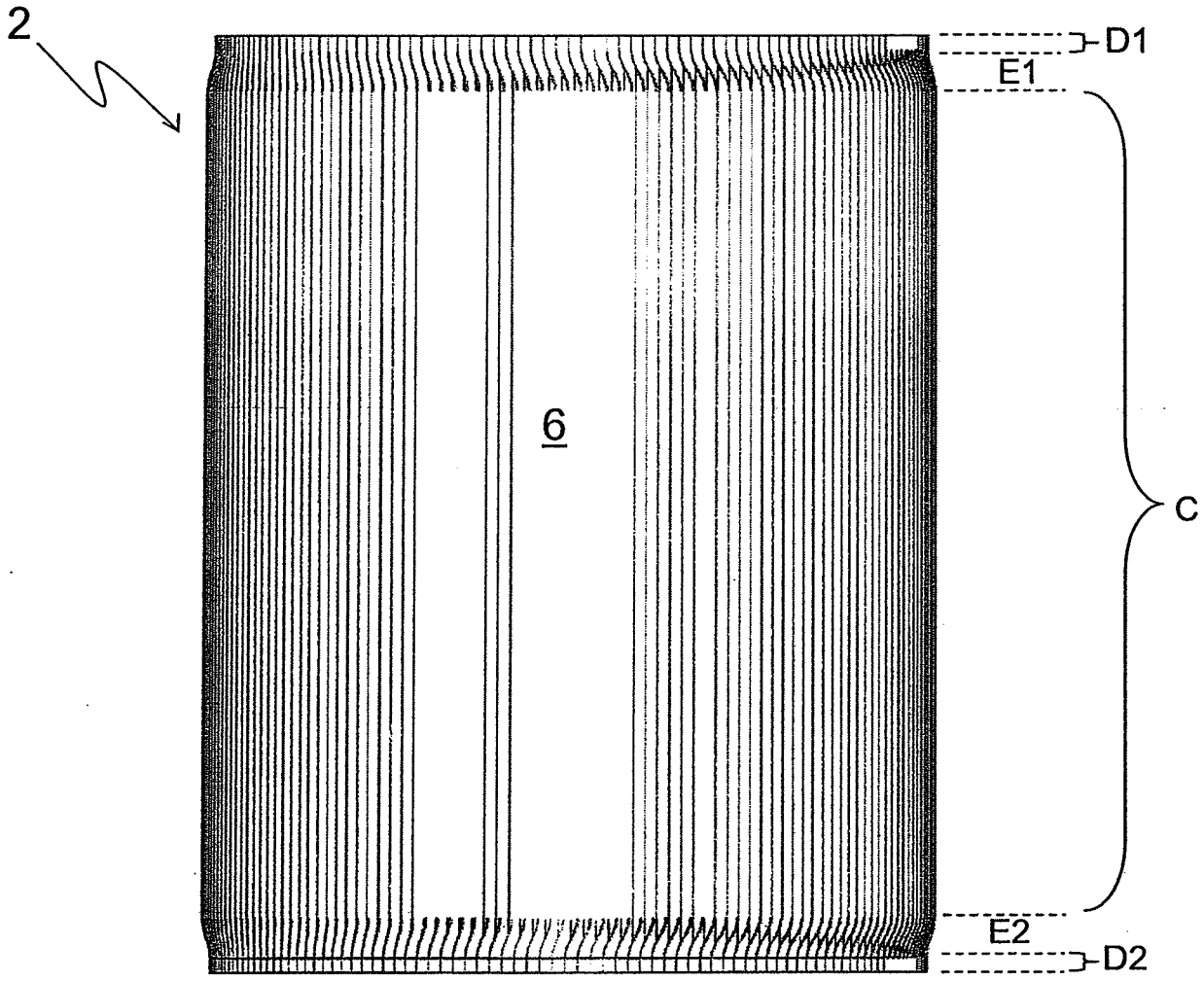


Fig. 4

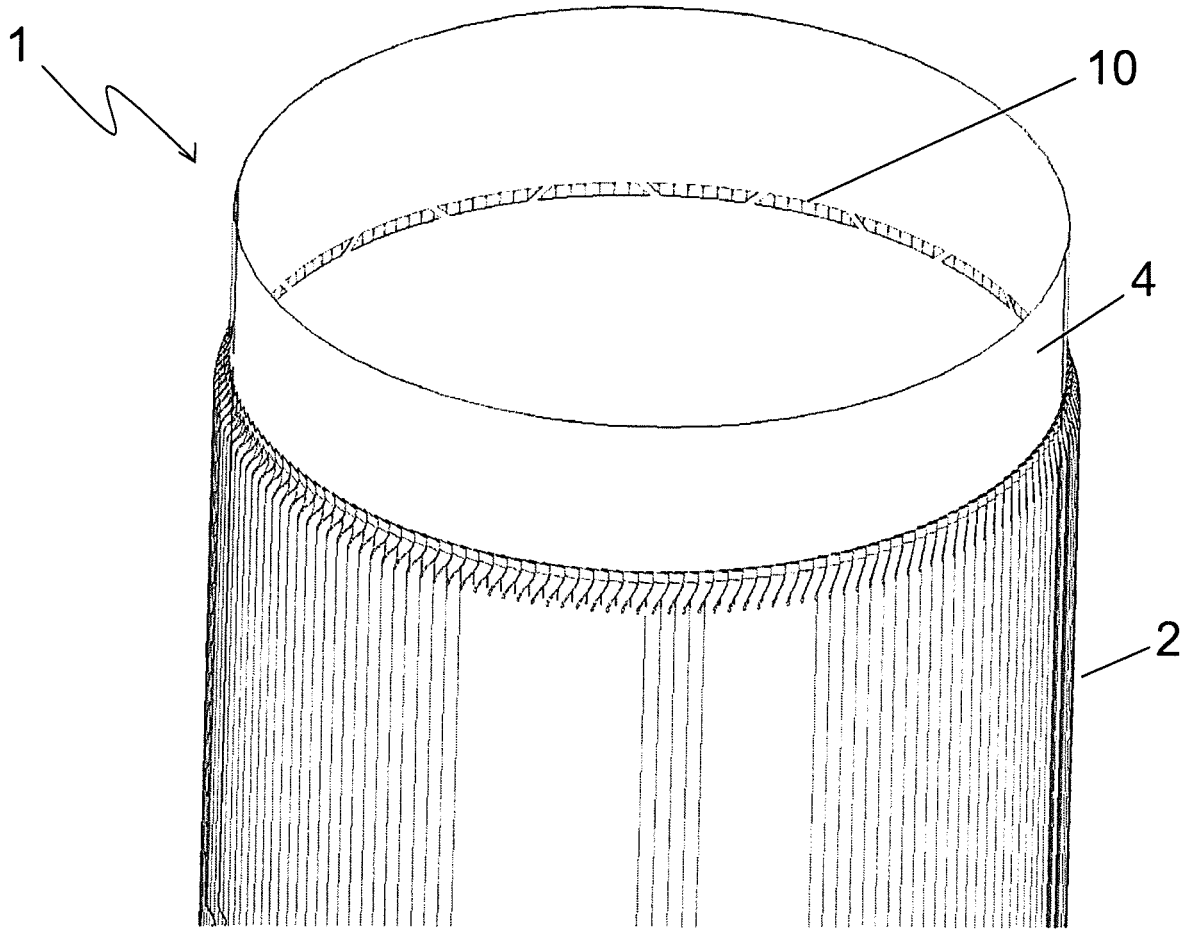


Fig. 5

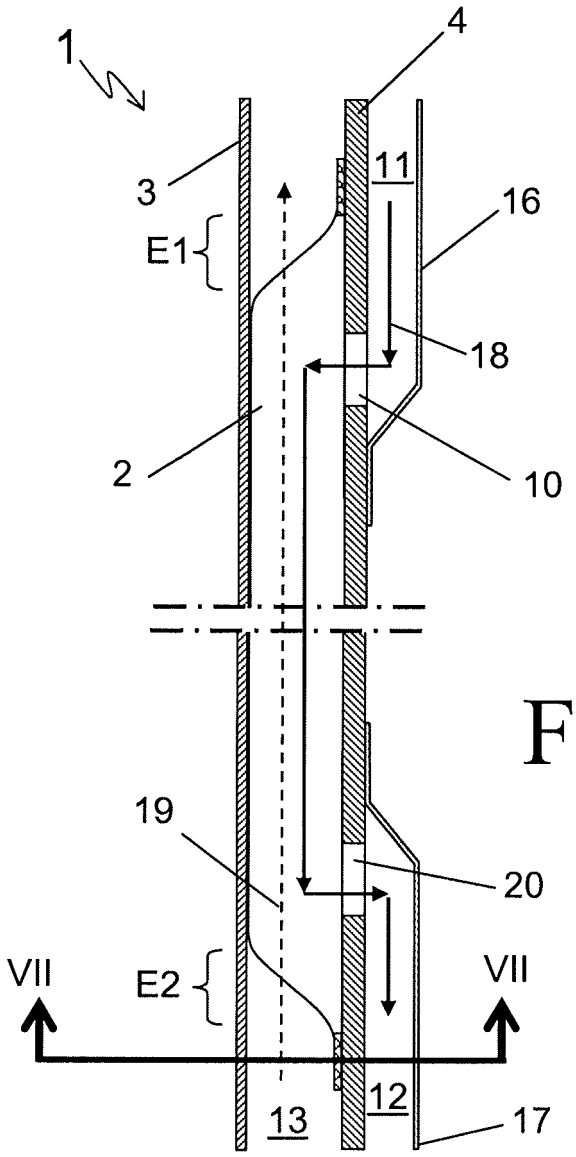


Fig. 6

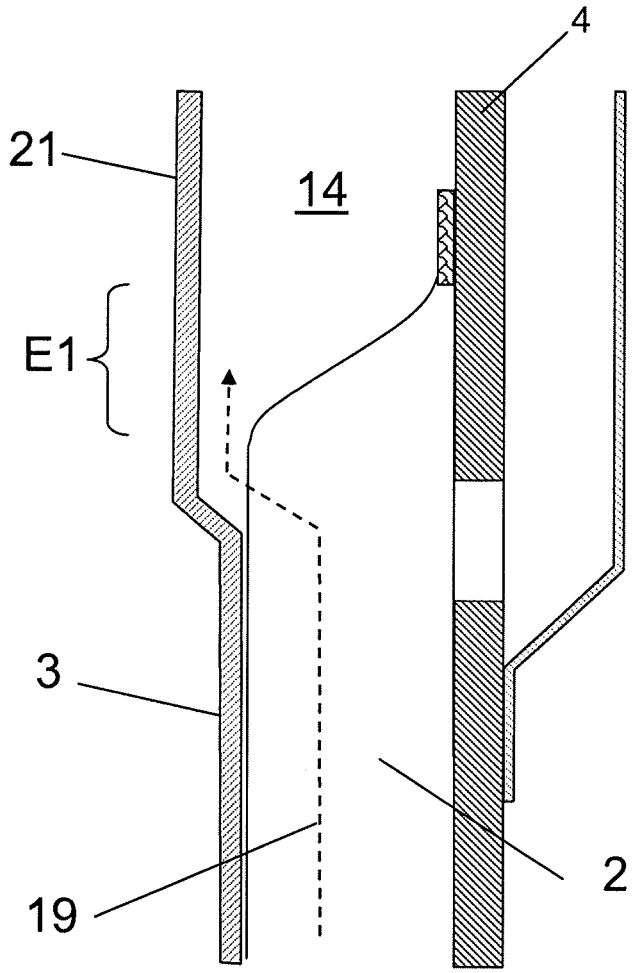


Fig. 7

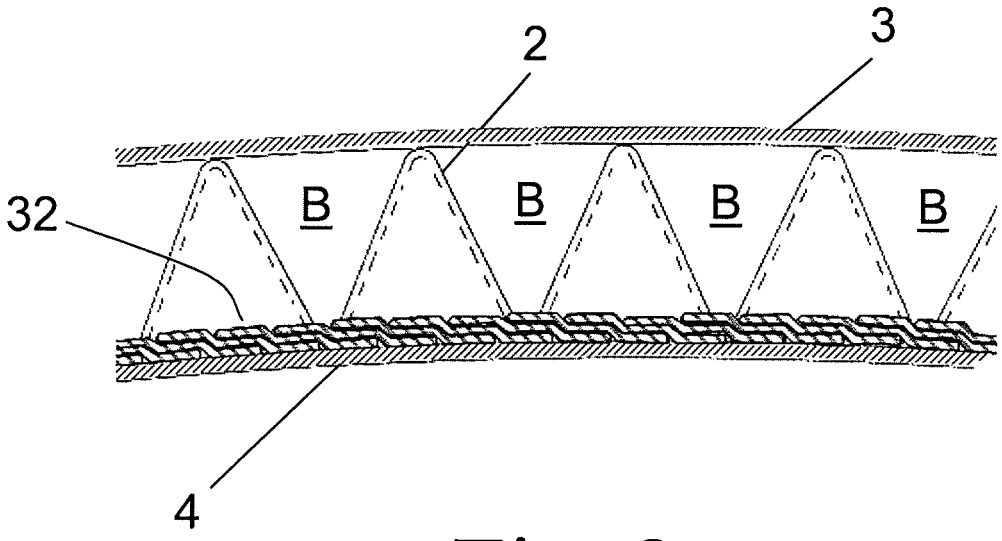


Fig. 8

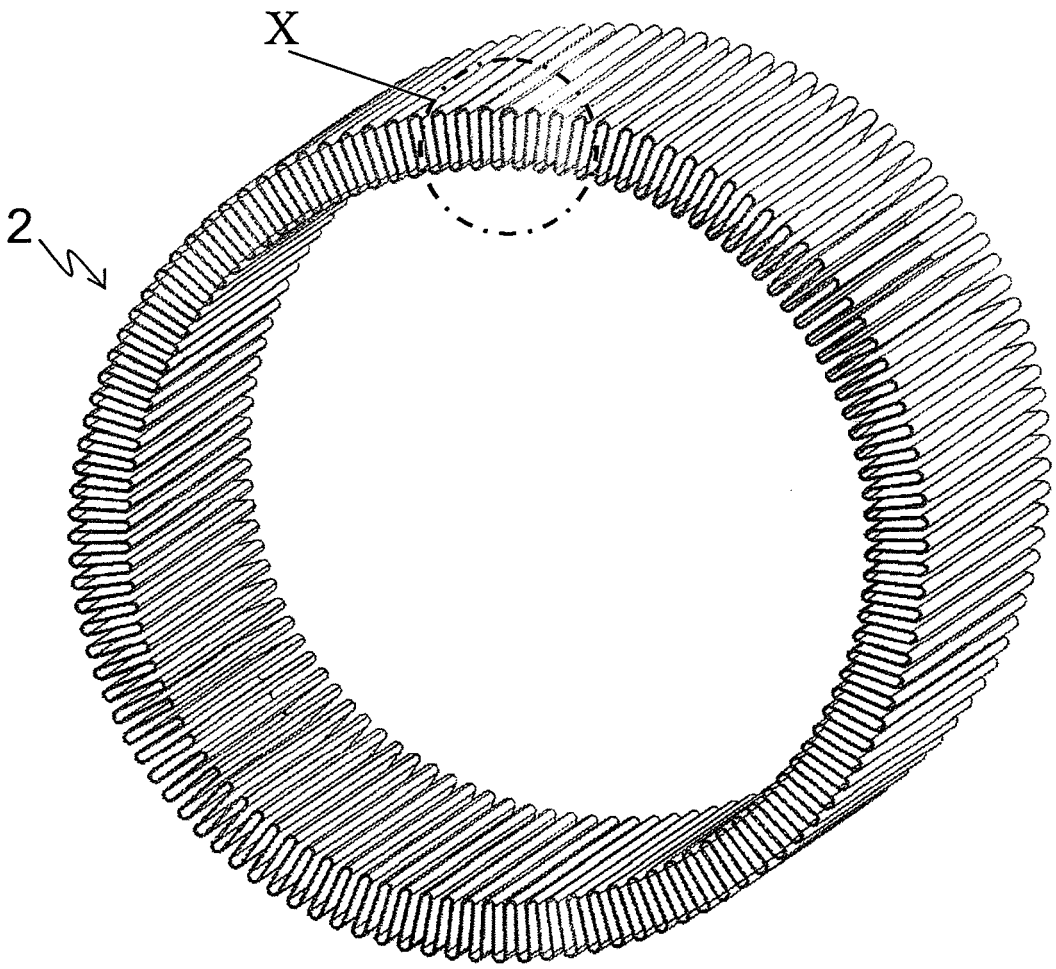


Fig. 9

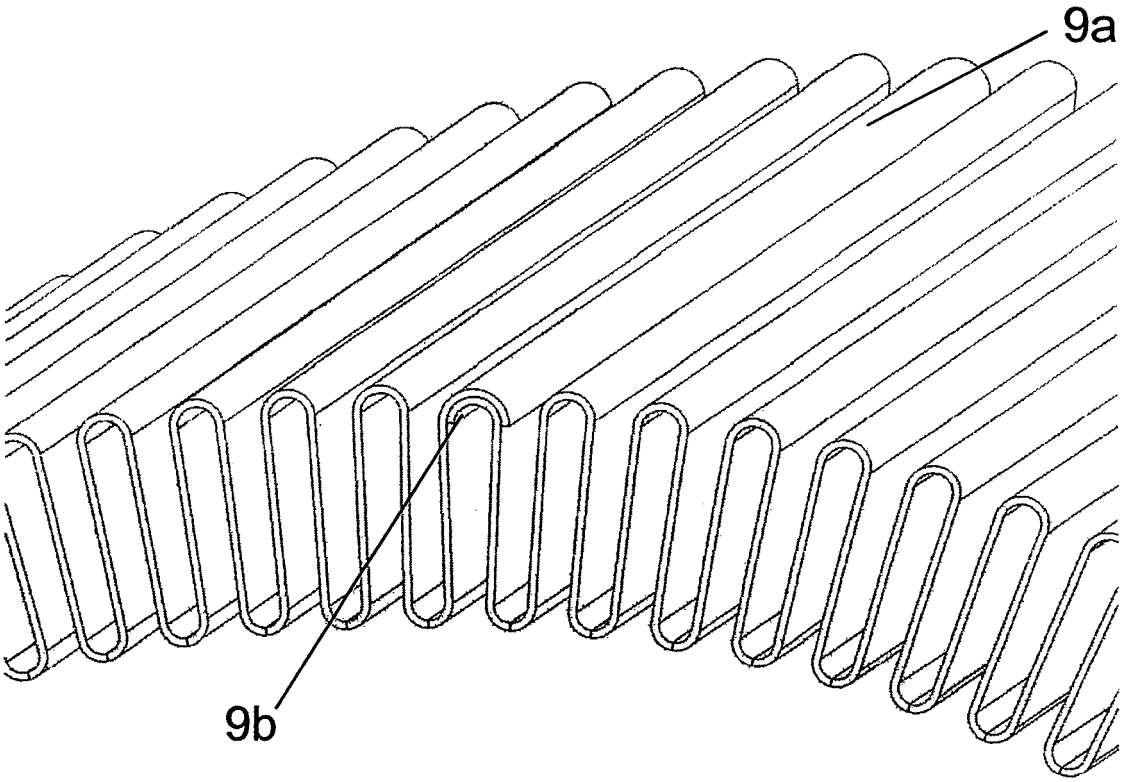


Fig. 10

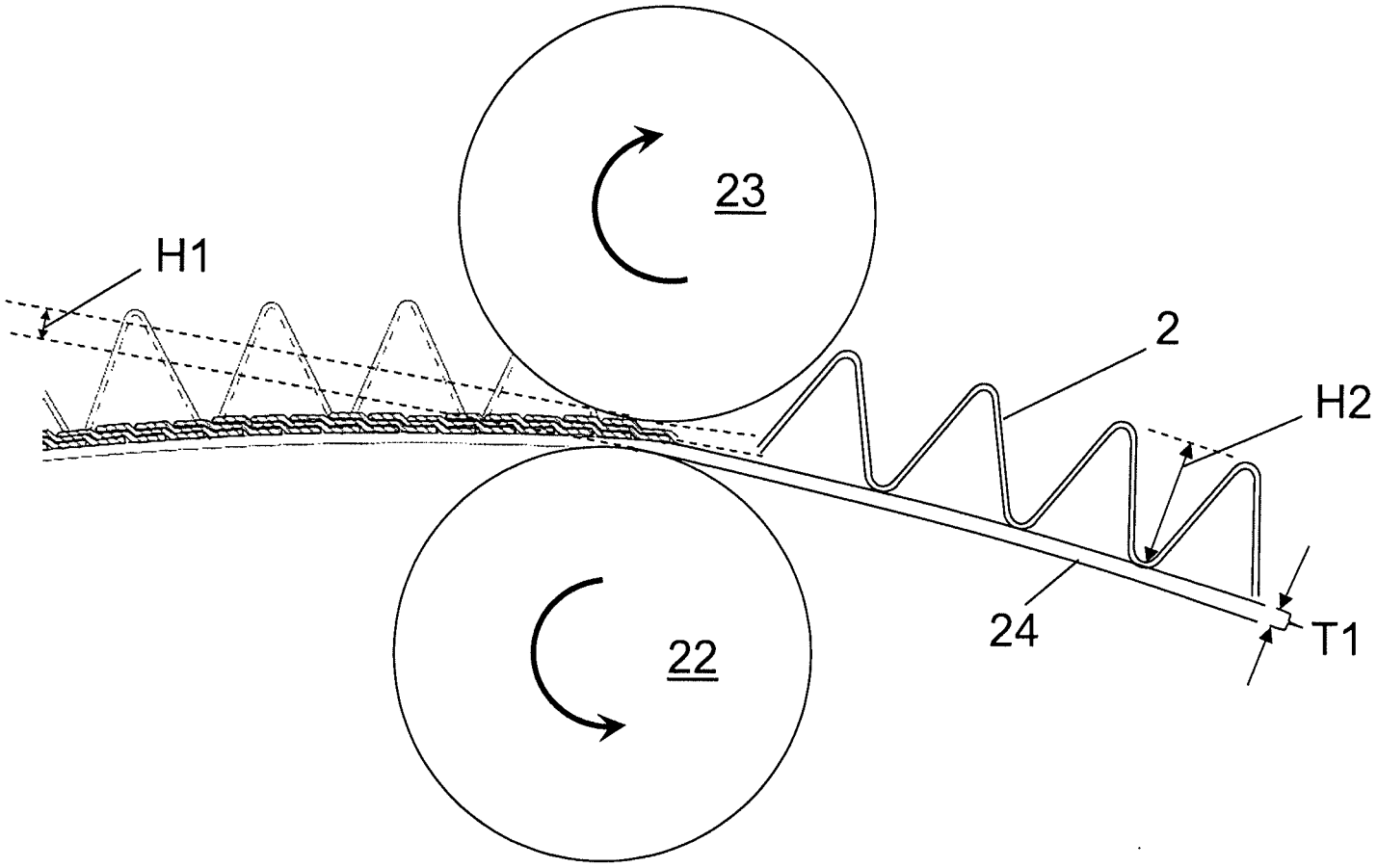


Fig. 11

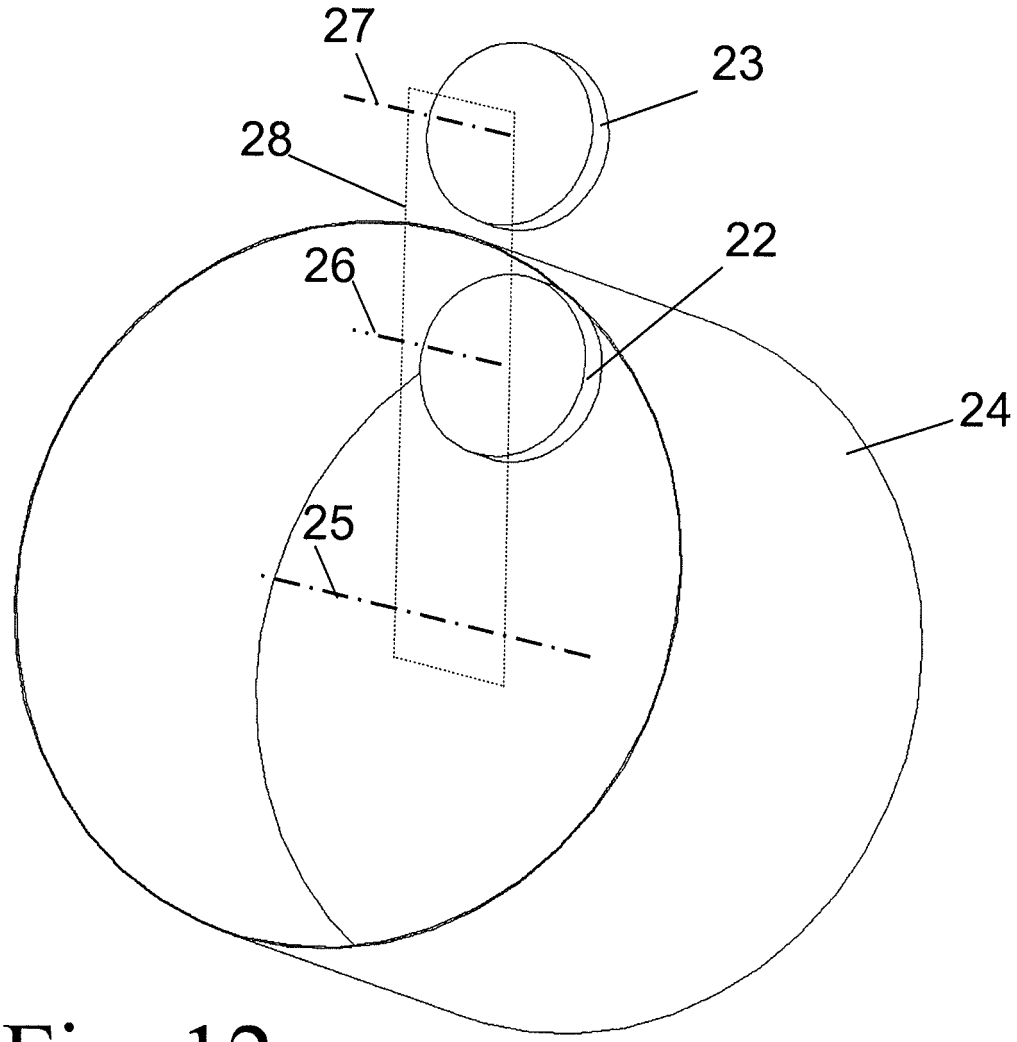


Fig. 12