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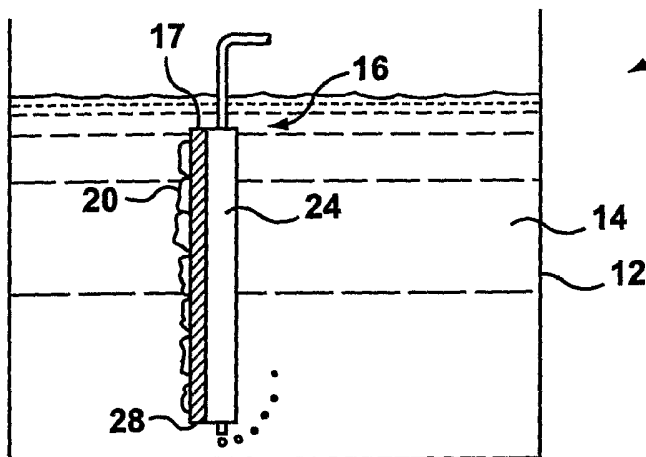
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(54) Title: MEMBRANE MODULE FOR GAS TRANSFER AND MEMBRANE SUPPORTED BIOFILM PROCESS



(57) Abstract: A membrane module apparatus to transfer a gas to or from a liquid has a sheet having at least one gas transfer surface. The gas transfer surface is in flow communication with a header through a gas channel. The module may be used to support a biofilm on the gas transfer surface. A plurality of sheets or portions of sheets may be separated by spacers.

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Title: Membrane Module for Gas Transfer and Membrane Supported Biofilm Process

Field of the invention

[0001] This invention relates to membrane modules to transfer a gas to or from another gas or a liquid for purposes, for example, such as waste water
5 treatment.

Background of the invention

[0002] Recently, development work has been done on a membrane supported bioreactor concept. For example, US Patent Nos. 4,181,604 and 4,746,435 describe a process for treating wastewater by supplying oxygen
10 from one side of a gas-permeable membrane to micro-organisms growing on the other side of the membrane. Hollow fibers with porous walls were used as the membrane. In US Patent No. 5,116,506, a gas permeable membrane divides a reactor vessel into a liquid compartment and a gas compartment. A biofilm is grown on the gas permeable membrane on the liquid side of the
15 membrane. Oxygen and alternate gases pass through the membrane to the bacteria growing on the liquid side of the membrane.

Summary of the invention

[0003] It is an object of the invention to improve on the prior art. It is another object of the present invention to provide a membrane module to
20 transfer a gas to or from another gas or a liquid. The following summary provides an introduction to the invention which may reside in a combination or sub-combination of features provided in this summary or in other parts of this document.

[0004] According to one aspect of the present invention, membrane
25 modules of various configurations are described. The modules generally include one or more membranes in a planar or sheet form having an inlet for gas at one edge and/or an outlet for gas at another edge. The planar form may be a continuous surface or a fabric or other structure made up of hollow fibers. The planar or sheet form has a gas transfer surface. A gas channel is

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connected in flow communication between the gas transfer surface and the inlet or outlet.

[0005] In the various embodiments, headers are attached to one or both of these edges to form modules of various configurations. In some
5 embodiments, the modules are further assembled into cassettes. Within a cassette, the planar or sheet forms may be separated by spaces of various configurations. The modules are adapted to support a biofilm on the membrane surface but some or all of the embodiments may also be used for other purposes.

10 **Brief description of the drawings**

[0006] For a better understanding of the present invention and to show more clearly how it may be carried into effect, reference will now be made by way of example, to the accompanying drawings that show embodiments of the present invention, and in which:

15 [0007] Figure 1 is a front view of one embodiment of a bioreactor apparatus according to the present invention;

[0008] Figure 2 is an enlarged detailed view of a portion of the apparatus of Figure 1;

20 [0009] Figure 3 is a perspective view of one embodiment of a growth support sheet according to the present invention;

[0010] Figure 4 is a detailed view of a portion of the sheet of Figure 3;

[0011] Figure 5 is an enlarged cross-sectional view of a fiber of the sheet of Figure 3;

25 [0012] Figure 6 is one embodiment of a membrane module for the apparatus of Figure 1;

[0013] Figure 7 is a cross sectional view of a portion of the module of Figure 6;

[0014] Figure 8 is a cross-sectional view of a portion of the module of Figure 6 taken along the lines 8-8;

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[0015] Figure 9 is cross-sectional view of a portion of the module of Figure 6 taken along the lines 9-9;

[0016] Figure 10 is a perspective view of the module of Figure 6 having alternative spacing structure;

5 **[0017]** Figure 11 is a detailed perspective view of a portion of the spacing structure of Figure 10;

[0018] Figure 12 is a perspective view of an alternative spacing structure to that of Figure 11;

10 **[0019]** Figure 13 is a perspective view of another alternative spacing structure for the module of Figure 6;

[0020] Figure 14 is front view of a plurality of the modules of Figure 6 shown in a vertically stacked arrangement;

[0021] Figure 15 is a perspective view of a plurality of the modules of Figure 6 shown in a horizontally stacked arrangement;

15 **[0022]** Figure 16 is another embodiment of a membrane module for the apparatus of Figure 1;

[0023] Figure 17 is an enlarged side view of a portion of the module of Figure 16;

20 **[0024]** Figure 18 is a schematic illustration of the module of Figure 16 during a drain cycle;

[0025] Figure 19 is an alternate configuration of the membrane module of Figure 16;

[0026] Figure 20 is a top view another embodiment of a membrane module for the apparatus of Figure 1, having a spiral configuration;

25 **[0027]** Figure 21 is a top view of the module of Figure 20 in an unwound state;

[0028] Figure 22 is a perspective view of the module of Figure 20;

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[0029] Figure 23 is a top view of an alternate configuration of the module of Figure 20, having adjacent central headers;

[0030] Figures 24 and 25 show the module of Figure 23 in an unwound and folded state, respectively;

5 [0031] Figure 26 shows modules according to Figure 23 installed in a tank.

[0032] Figures 27, 28 and 29 shown an unfolded element, folded element and wound element respectively of a square spiral embodiment.

10 [0033] Figures 30, 31 and 32 show alternate embodiments of wound modules.

[0034] Figure 33 shows a single sheet module.

[0035] Figures 34 and 35 show a closed and unfolded view of a header on the module of Figure 33 respectively.

15 [0036] Figures 36 and 37 show elevation and plan views respectively of the module of Figure 33 installed.

[0037] Figure 38 shows an alternate embodiment of a single sheet module.

[0038] Figures 39 and 40 show details of the headers of the module of Figure 38.

20 [0039] Figure 41 shows an isometric view of an embodiment using a fabric having open portions.

Detailed description of the invention

25 [0040] A bioreactor having a membrane supported biofilm according to the present invention is shown generally at reference character 10 in Figure 1 and Figure 2. The bioreactor 10 has a tank 12 containing tank water 14. A biomass or biofilm growth support element 16 is provided in the tank water 14, having a gas permeable membrane portion 17 with a support surface 18 on which microorganisms or biomass 20 can grow.

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[0041] The membrane portion 17 of the biomass growth support element 16 has a gas interface surface 22 provided opposite the support surface 18. The gas interface surface 22 is open to an air channel 24 with which the growth support element 16 is provided. Gas, such as oxygen or components of air, can diffuse through the membrane portion 17 of the growth support element 16 from the air channel 24 to the support surface 18, and thereby supply oxygen to the biomass 20. Excess gases, if any, may be released to the tank water 14 or ducted back to the atmosphere. The biomass growth support element 16 may optionally have two or more support surfaces 18 and support a biomass 20 on both sides, rather than only on one side as shown.

[0042] The growth support elements 16 can be provided in the form of sheets 28, each sheet 28 providing one or more membrane portions 17 with support surfaces 18 and air channels 24.

[0043] Referring now to Figure 3, the sheets 28 can be in the form of a textile sheet 30, constructed of, for example, but not limited to, a set of hollow fibers 32 extending in one direction, and a set of inert fibers 34 extending in a direction transverse to the first set. The sheet 30 may support a layer of biomass 20 on two sides. The sheet 30 has opposed active edges 33 defined by open ends of the hollow fibers 32, and inert edges 35 extending between the active edges 33. Inert edges 35 may have inert fibres 34 folded back to make the adjacent inert fibre 34 or may be confined by a strip of hot melt glue, a hem, or additional lines of stitching or mechanical clips to prevent fraying or unraveling. In making the sheet 30, it can be that two or more adjacent hollow fibers 32 are formed of a single continuous fiber that is folded back on itself at a fold portion 37. The fold portion 37 of the hollow fibers 32 can be severed or punctured to generate the active edges 33. Optionally, the sheet 30 may have hollow fibers 32 running in both directions such that all four of its edges are active edges 33.

[0044] The inert fibers 34 can be interconnected with the hollow fibers 32 by means of, for example, but not limited to, various types of knitting,

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stitching, or weaving so that a cohesive textile sheet 30 is provided. In the embodiment illustrated, the hollow fibers 32 and inert fibers 34 are interconnected by weaving, as best seen in Figure 4. The fibers 32, 34 are generally parallel and extend directly between the edges 33, 35, but other configurations may also be used.

[0045] As best seen in Figure 5, the hollow fibers 32 have tubular walls 36 that provide the sheet 30 with membrane portions 17. The interior of each hollow fiber 32 defines a lumen 38 that provides the air channel 24 for the sheet 30. The hollow fibers 32 can be made from polymethyl pentene (PMP), which has a high diffusion coefficient for oxygen. The PMP fibers may have dense but gas permeable walls. The hollow fibers 32 may also be made of other substances such as silicone or polyolefins such as PE or PP, also having dense walls or a dense layer, or from hydrophobic materials such as chemically treated PP or PE which has been stretched to create microporous walls, or other substances which are permeable to gases but non-welting and impermeable to liquid water. A sheet construction is described in US Provisional Patent Application Serial Number 60/447,025, filed on February 13, 2003. The entire text of 60/447,025 is incorporated herein by this reference to it. Sheets 30 can also be planar structures such as those shown in U.S. Pat. No. 6,558,549. The entire text of U.S. Pat. No. 6,558,549 is incorporated herein by this reference to it

[0046] The sheets 28, 30 can be configured in modules, each module providing a header to supply air or other gas to the gas channels 24. The modules can have more than one sheet 28, 30. The sheets 28, 30 in a module can be of a generally flat, planar configuration, or can be in other configurations, such as, for example, but not limited to, spiral configurations.

[0047] Referring now to Figure 6, a first embodiment of a module constructed of the sheet 30 is shown at 100. The module 100 has a plurality of sheets 30 extending between two parallel headers 102a and 102b. In Figure 6, the module 100 is designed to have about 12 sheets 30, three of which have been illustrated and identified as sheets 30a, 30b, and 30c. The

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headers 102 may be oriented generally vertically when installed in the tank 12. The header 102a is a gas delivery header, and the header 102b is a gas exhaust header. In some embodiments, the gas exhaust header 102b may be replaced by a dead end header holding one set of ends of the hollow fibers 32 closed or the gas exhaust header 102b may be omitted with one set of ends of the hollow fibers 32 optionally loose or positionally restrained and either closed or open.

[0048] The sheets 30 are oriented such that the hollow fibers 32 extend between the headers 102. In this configuration, the hollow fibers 32 may be oriented generally horizontally in use, although they may not follow a straight line across the horizon depending on the method used to make the fabric. The inert fibers 34 may be oriented generally vertically when the module 100 is installed in the tank 12. As best seen in Figure 7, the headers 102 each have an internal chamber 104, and the ends of the fibers 32 (defining the active edge 33) are potted in the headers 102 so that the lumens 38 of the fibers 32 are in flow communication with the chambers 104 of the headers 102. Ports 106 can be provided in the headers 102, extending through the housing of the headers 102 to the chambers 104.

[0049] Spacers 110 may be provided between adjacent sheets 30 in the module 100. As best seen in Figure 8, in the embodiment illustrated, each spacer 110 has a base portion 112 that is generally square-shaped with connection means 114 extending from either side of the base 112 so that adjacent spacers 110 can be connected together in a snap-fit arrangement. The connection means 114 can comprise a recess 116 with a retaining lip 118 on one side of the base portion 112, and axially extending fingers 120 with transverse protrusions 122 on the other side of the base portion 112, to engage the lip 118. Alternately spacers 110 may be made of simple blocks or buttons glued to the sheets 30. As a further alternate embodiment, spacers 110' can be provided having a central through-hole 12' through which a retaining rod 123 can be inserted (see Figure 6). The ends of the rod 123 can be bent or capped to hold a set of adjacent spacers 10' together. Further

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alternatively, the headers 102 may be held apart by a restraining structure and the sheets 30 tensioned so that they stay apart without the aid of spacers. The sheets 30 may be tensioned, for example, by increasing the space between the headers 102 or by heat shrinking the sheets 30 between headers
5 102 spaced at a fixed distance.

[0050] The spacers 110 can be further provided with an abutment surface 124 to keep the base portions 112 of adjacent spacers 110 from contacting each other when assembled, or in other words, to maintain a gap
10 125 to accommodate the hollow fibers 32 extending between adjacent spacers 110 without being pinched or crushed flat. The spacers 110 can be constructed of an injection molded polymer material.

[0051] To install the spacers 110, the fingers 120 of one spacer 110 can be forced between the weaved hollow fibers 32 and inert fibers 34 of the sheet 30, and then into the recess 116 of an adjacent spacer 110 to snap the
15 spacers together. When assembling the adjacent spacers 110, care should be taken to clear any hollow fibers 32 off of the abutment surface 124 before snapping the spacers 110 together. One or more hollow fibers 32 can be inserted in the recess 126 between the fingers 120 so that any hollow fibers 32 between the two fingers 120 will not be pinched. Alternatively, the spacers
20 110 can be configured to connect to each other outside the edges 35 of the sheets 30.

[0052] The spacers 110 can be attached spaced in a row along the lower inert edges 35 of the sheets 30. By providing a row of spacers 110 adjacent the bottom of the sheets 30 in the module 100, the lower inert edges
25 35 of the sheets can be maintained in spaced apart relation, and upwardly directed currents in the tank water 14 may be sufficient to maintain the spacing and/or to control sludge build-up across adjacent sheets 30 upward of the lower edges 35. Maintaining a space between adjacent sheets 30 is useful as it inhibits the biofilm 20 of one sheet 30 from merging with the
30 biofilm 20 of an adjacent sheet 30 and allows entry of air bubbles which can be used to remove excess biofilm 20.

[0053] The module 100 can have an additional row of spacers 110 along the upper inert edges 35 of the sheets 30. Spacers 110 can also be provided between the upper and lower inert edges 35 of the sheets 30. By aligning the spacers 110 in rows and columns, the spacers 110 can be provided in a grid pattern.

[0054] As an example, a module 100 having six sheets 30 pulled taut between the headers 102a and 102b was provided. Each sheet 30 had a length of 1-5 m (extending between the headers 102a and 102b) and a height of 0.5 m. Rows of spacers 110' were provided along the lower edge of the parallel sheets 30, at 20 cm intervals between the headers 102a and 102b. Each row of spacers 110' included five spacers 110', each of the five spacers 110' being positioned between two adjacent sheets 30. Each spacer 110' was 15 mm x 15 mm x 6 mm thick. The lower edges 35 of the sheets 30 were hemmed to prevent unraveling, and a rod 123 was pressed through the hemmed portion (and through the holes 121 in the spacers 110') and the ends of the rod 123 were bent over to secure the spacers 110' in position. Aeration was applied from below the module 100 at a rate of 0.8 SCFM, per foot of module length, with satisfactory results.

[0055] Referring now to Figure 9, the spacing between the fibers 32 at the fiber ends potted in the header can be reduced. For example, the ends of the fibers 32 can converge towards a narrower header 102. This can reduce the size of the headers 102, which can improve circulation fluid flow characteristics in the tank 12 around the headers 102, and can reduce costs by, for example, reducing the volume of potting resin in the header 102. An offset block 108 can be provided adjacent one or both sides of the narrowed header 102 so that multiple modules 100 can be packed together in side-by-side arrangements (see also Figure 15). The offset block 108 may connect to side plates 109 to keep tank water from reaching an area of un-spaced sheets 30.

[0056] Referring now to Figures 10 and 11, as an alternative to one or more of the rows of spacers 110, the module 100 can be provided with fluid

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permeable spacing strips 150. In the embodiment illustrated, the spacing strips 150 are provided adjacent the lower and upper inert edges of the sheets 30. Each spacing strip 150 comprises a length of a flow permeable spacing structure 154 extending between the headers 102. The spacing strips 150 have opposed ends 152 that are secured to the headers 102. The ends 152 can be potted in the headers 102.

[0057] The spacing strips 150 have sufficient compressive stiffness to maintain the desired spacing between adjacent sheets 30 in the module 100, yet are porous or otherwise minimally obstructing to tank water 14 circulating in the tank 12 in a generally upward direction, through the spacing strip 150, between adjacent sheets 30.

[0058] As best seen in an embodiment illustrated in Figure 11, the flow-permeable spacing structure 154 can comprise a lattice arrangement of plastic segments 156 providing a generally hollow elongate structure with a rectangular cross-section. The spacing structure 154 may also be a rigid plastic mesh of a configuration and construction as used as a spacer for spiral wound reverse osmosis modules. In embodiment illustrated in Figure 12, the flow-permeable spacing structure 154 of the spacing strip 150 comprises a length of plastic 158 having vertical through-holes 160 along its length. The spacing structure 150 can be formed of, for example, but not limited to, an injection-molded polymer. The spacing strips 150 can present side surfaces 151 to which the sheets 30 can be adhered.

[0059] Referring now to Figure 13, another alternative spacing structure 170 can be provided for the module 100. The spacing structure 170 comprises a substantially rigid band folded over to form a thin clip that can be secured to the sheet 30 adjacent the inert edges 35. The spacing structure 170 can be provided with horizontally outwardly protruding ridges 172 extending from one or both sides of the structure 170, at discrete points along its length. The ridges 172 can abut the spacing structures 170 attached to adjacent sheets 30 in the module 100, so that the desired gap is maintained

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between the sheets 30. Circulation currents in the tank water 14 can flow between the ridges 172 and adjacent spacing structures 170.

[0060] Referring now to Figures 14 and 15, the modules 100 can be conveniently stacked vertically and/or horizontally (side-by-side) to provide a reactor cube or cluster that efficiently uses the available space in the tank 12. The headers 102 may be provided with snap-fitting male and female elements in the ports 106 so that vertically adjacent headers 102 are releasably attached to each other (Figure 14). A duct 107 can extend across and be releasably attached to the upper ports 106 of a side-by-side stack of modules 100 (Figure 15). The modules 100 may rest on blocks on the bottom of a tank 12. Solid plates (not shown), for example of PVC, may be placed between horizontally adjacent headers 102 and attached to at least one, and optionally both headers 102 of a module 100. The plates may be shared between and attached to each of a pair of adjacent headers 102 or attached only to one header 102. By any of these methods, modules 100 or sets of modules 100 attached to each may have their headers 102 spaced by the plates. The modules 100, or sets of modules 100, may be placed in an oven to shrink and tension the sheets 30 which may remove the need for spacers 110.

[0061] A second module embodiment is shown generally at 200 in Figure 16. The module 200 has a single header 202 that may be oriented horizontally when installed in the tank 12.

[0062] Sheets 30 extend upwardly from the header 202, and the sheets 30 are oriented such that the hollow fibers 32 extend generally vertically and the inert fibers 34 extend generally horizontally. The lower active edges 33 of the sheets 30 are potted in the header 202.

[0063] In the embodiment illustrated, the upper active edges 33 of the sheets 30 extend above the surface of the tank water 14 in the tank 12, and are open to atmosphere. Alternately, the upper active edges 33 may be sealed shut to produce a dead end module. An optional cap 205 may be provided adjacent the upper ends of the hollow fibers 32 to protect the upper ends from intrusion of dirt or debris, and prevent the fabric sheet 30 from

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unraveling. The cap 205 can be buoyant to support the upper active edge 33 of the sheets 30 above the surface of the tank water 14. Alternatively, the upper edges 33 of the sheets 30 can be below the surface of the tank water 14 if the gas pressure in the lumens 38 is sufficient to prevent water intrusion.

5 **[0064]** As best seen in Figures 16 and 17, in the embodiment illustrated, the cap 205 is in the form of an elongate tubular member 207 that is clipped on to, and extends horizontally in use along, the upper active edges 33 of the sheets 30. The tubular member 207 has a width 209 (or diameter) such that the outer surfaces of caps 205 of adjacent sheets 30 abut each
10 other and thereby assist in maintaining a desired gap 211 between adjacent sheets 30 in the module 200.

[0065] To facilitate holding the upper active edges 33 of the sheets 30 above the surface of the tank water 14, the module 200 can be provided with hooks 213 extending upwards from the upper edges 33 of the sheets 30.
15 Suspending means 215, such as, for example, but not limited to, a cable or rod, can engage the hooks 213 to support the upper edges 33 of the sheets 30. The hooks 213 can extend from the caps 205.

[0066] Referring now to Figure 19, the single header module 200 can be configured to have the header 202 at the upper end of the sheets, with the
20 sheets 30 extending vertically downward from the header 30 when installed in the tank 12. Weights 221 can be attached to the lower active edges 33 of the sheets 30 to maintain the vertical orientation of the hollow fibers 32. This may be particularly necessary where the sheets 30 are buoyant.

[0067] The lower edges 33 of the sheets 30 may be left open to release
25 excess gas supplied to the fibers and/or to vent any gasses that may have diffused from the biomass 20 into the lumens 38. The tank water 14 adjacent the open ends may provide some back pressure to the gas in the hollow fibers 32 which may encourage greater transfer of oxygen through the membrane portions 17. Alternately, a single sheet header as shown for other
30 embodiments may be used to collect gases at the lower end of the sheets 30 and connected to a tube to release those gases above the water surface.

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[0068] As a further alternative, the module 200 can be provided with hollow fibers 32 oriented in a U-shaped configuration, such that the second end of the hollow fibers 32 are supported above the surface of the tank water, adjacent the header 202, and the central section of each fiber is secured to a lower portion of the tank 12, or weighted down.

[0069] A third module embodiment 300, having sheets configured in a spiral arrangement, is shown in Figure 20. The module 300 is formed of at least one sheet 30 having hollow fibers 32 extending between opposed headers 302a and 302b, and a spacing structure 310 provided adjacent the sheets 30 (Figure 21). In the embodiment illustrated, the spacing structure 310 comprises a corrugated layer provided adjacent the sheet 30, providing vertical channels 331 through which tank water 14 can circulate when the module 300 is installed in the tank 12. Other spacing structures 310 may also be used, such as a rigid plastic mesh, for example, of the configuration and construction of spacers for spiral wound reverse osmosis modules. The corrugated layer 310 can be made of an extruded plastic.

[0070] Referring to Figures 20 and 22, the spiral configuration of the module 300 can be provided by winding one of the headers 302 with its attached one or more sheets 30 and corrugated layers 310 around the other header 302 in spirals of increasing radius. The wound bundle can be inserted into a generally cylindrical tank or cage 321 to hold the sheets/layers in the spiral configuration. The module 300 according to this configuration has one header (302a) extending generally along the axis of the spiral module 300, and the second header (302b) disposed adjacent the outer periphery of the spiral.

[0071] It can be advantageous (for piping and/or other reasons) to provide the delivery and exhaust headers 302a and 302b in closer proximity to one another. Such an arrangement is shown in the module 300 in Figure 23, where the two headers 302a and 302b extend adjacent each other generally along the axis of the spiral module 300. This module can be formed by providing sheets 30 spacing structures 310 between the headers 302a and

302b (Figure 24), and folding the sheet layers in half so that the headers 302a and 302b are adjacent each other (Figure 25). The folded portion of the sheet is then wound around both headers 302a and 302b in spirals of increasing radius. In the embodiment illustrated, the module 300 has a single sheet 30
5 extending between the headers 302, sandwiched by a spacing structure (corrugated layer) 310 on either side. The corrugated layer 310 itself is only about the half the actual desired spacing width, since the layer 310 will generally be doubled (two layers 310 side-by-side) when the module 300 is configured in the spiral arrangement (Figure 23).

10 **[0072]** The spacing structure 310 need not be in the form of a corrugated layer, but can take the form of, for example, but not limited to, sheets 30 having lateral protrusions extending from the surface of the sheets 30. The protrusions can be formed from the sheets 30 by pressing or embossing, or the protrusions can be separately attached buttons that are
15 adhered to the surface of the sheets. As a further alternative spacing structure 310, the sheets 30 can be provided with a stiffness that can urge the sheets 30 to unwind from the confined spiral form. To obtain the desired stiffness, horizontal stiffener elements can be secured to the sheets 30. Alternatively, the hollow fibers can be constructed to have an inherent
20 stiffness that may provide sufficient unwinding force without the addition of separate stiffener elements. As a result of the unwinding force, each spiral portion of the sheets 30 in the module 300 can space itself evenly apart from adjacent spiral portions, thus providing the desired gap.

[0073] As best seen in Figure 26, the modules 300 can be packed in
25 the tank 12 to provide a reactor. The modules 300 can be packed in rows, and the upper ends of the delivery headers 302a in each row can be attached to a single channel gas delivery manifold 335, which can in turn be connected to a supply main 337. A module 300 may also be placed inside of a hollow pipe which functions as a container for a reactor.

30 **[0074]** The upper ends of the exhaust headers 302b can exhaust to atmosphere. Alternatively, the manifolds 335 can be dual channel manifolds

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having a delivery conduit 335a and an exhaust conduit 335b. The headers 302a and 302b can be connected to the conduits 335a and 335b, respectively.

[0075] As best seen in Figure 27, the sheets 30 (and layers 310 in the embodiment illustrated) of the modules 300 can be wound in a generally square spiral rather than a circular spiral to increase the packing density of the modules 300 in the tank 12. To facilitate forming a square spiral in the embodiment illustrated, corner elements 350 are provided along the length of the corrugated layer 310 on one side of the sheet 30, at selected locations along the length of the layer 310 (Figure 29). The locations for the corner elements 350 are selected so that when the module 300 is folded over (Figure 29) and wrapped into a spiral (Figure 27), the corner elements 350 are aligned at desired corner locations of the spiral. The sheet 30 and layers 310 of the spiral module 300 can follow the contour of the corner elements 350 to assist in forming a square shaped spiral. The corner elements 350 can be formed of, for example, but not limited to, an extruded right angle bracket that extends the height of the module 300. Alternately, the corner elements 350 can be inserted as the sheets 30 are being wound.

[0076] Alternate spiral designs for the module 300 are also possible. As an example, module 300 as illustrated in Figure 30 has a single central gas delivery header 302a disposed as a hub with a plurality of sheets 30 and exhaust header 302b extending radially outwardly from the header 302a. The sheets 30 with exhaust headers 302b can be wound together around the header 302a to form a spiral configuration (Figure 31). Any suitable spacing structure 310 (not illustrated) can be provided between the wound sheets 30 to provide a desired spacing between the sheets 30.

[0077] Another spiral configuration for the module 300, best seen in Figure 32, has the sheet 30 extending between the headers 302a and 302b. A portion of the sheet 30 is wound around the header 302b, and another portion of the sheet 30 is wound around the header 302a, thereby forming a double spiral configuration.

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[0078] Referring now to Figure 33, another embodiment of a module 400 has a sheet 30 with a fixed width 401 and a continuous length extending transverse to the width 401. The hollow fibers 32 extend along the width 401 of the sheet 30, and are oriented in the weft direction. The inert fibers 34 are oriented in the warp direction. By being formed with a continuous length, the sheet 30 can be customized to have a length fit for any particular size of tank 12.

[0079] The module 400 has headers 402 in the form of ducts that extend continuously along the length of the sheet 30. More particularly, a gas delivery duct 402a and a gas exhaust duct 402b extend along opposite active edges 33 of the sheet 30. The headers or ducts 402 are also formed of a continuous length, and can be, for example, an extruded polymer material.

[0080] Further details of the ducts 402 can be seen in Figures 34 and 35. The duct 402 can be an extrusion having two concave shell portions 433 and 435, which can be positioned opposite each other to form a hollow interior cavity 437. The shells 433, 435 can be positioned along the active edge 33 of the sheet 30 so that the open ends of the hollow fibers 32 are inside the cavity 437. A sealant bead 441 can be applied between the edges of the shells 433, 435 adjacent the sheet 30 to seal the duct 402. The shells 433, 435 can also be sealed opposite the sheet 30, or that side can be provided with a hinge portion 439 so that the duct 402 has just the one seam along the sheet 30.

[0081] In use, the modules 400 are oriented in the tank 12 such that the ducts 402 are oriented vertically as shown in Figures 36 and 37. The length of the module 400 can conveniently be cut to fit the height of the tank 12. Multiple modules 400 can be arranged side-by-side within the tank 12, and the ducts 402 can have a width 443 such that the ducts 402 of adjacent modules 400 abut to maintain a desired gap between the sheets 30 (Figure 37). Feed and exhaust mains 452a and 452b, respectively, can be provided for attachment to the headers 402a and 402b. The bottom of the sheet 30 may be weighted or otherwise biased towards or attached to the bottom of a tank 12. Lower ends of the ducts 402 are sealed closed.

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[0082] Referring now to Figure 38, a modified module 500 is similar to module 400 but has the sheet 30 formed with the hollow fibers 32 extending along a continuous length in the warp direction. Gas delivery and exhaust headers 502a, 502b extend along the width 501 of the module 500, spaced
5 apart from each other periodically along the length of the module 500. The distance between the headers 502a, 502b can be determined based on a number of process factors such as the pressure drop per unit length of hollow fiber 32. Lower ends of the headers 502 may be sealed. Upper ends of headers 502 may be connected to larger exhaust or inlet pipes. The module
10 500 may be folded in a Z-pattern such that feed headers 502a form a line and exhaust headers 502b form a second line to facilitate connection to larger feed or exhaust pipes.

[0083] The headers 502 can be of two-piece construction having two concave shell portions 533 and 535 positioned opposite each other to form a
15 hollow interior cavity 537. The shells 533, 535 are on opposite sides of the hollow fibers 32, which extend perpendicularly and continuously between the shells 533, 535 (Figure 39). A sealant bead 541 can be applied between the edges of the shells 533, 535 adjacent the sheet 30 to seal the edges against the sheet 30. A hollow cylindrical punch can then be pressed through the
20 length of the cavity 537 to cut open the ends of the hollow fibers 32 so that the hollow fibers 32 are in flow communication with the headers 502.

[0084] Referring now to Figure 41, another module embodiment 600 has sheets 30 with pattern weaving extending between headers 602. The pattern weaved sheets 30 have alternating loosely weaved zones 631 and
25 tightly weaved zones 633. The modules 600 may be oriented flat (i.e. in a substantially horizontal plane) when installed in the tank 12. Multiple modules 600 can be stacked on top of each other to form a reactor cluster. Adjacent modules can have loose and tight weave zones 631, 633 in reverse locations so that the loose weave zones 631 in one module is sandwiched by tight
30 weave zones 633 of adjacent modules. This arrangement can provide a sinuous flow path for circulation currents in the tank water 14. Alternatively,

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the loose and tight weave zones 631, 633 of adjacent modules 600 can be in vertical alignment so that the aligned loose weave zones 633 provide vertical flow paths that are generally straight. The sheets 30 of this embodiment may be closely spaced, for example less than 4 mm or less than 2 mm spacing, or
5 be adjacent each other, or separated only by the potting materials. Other modules may have a larger spacing, for example between 2 mm and 20 mm or between 4 mm and 12 mm.

[0085] While preferred embodiments of the invention have been described herein in detail, it is to be understood that this description is by way
10 of example only, and is not intended to be limiting. Other embodiments may be made or performed within the scope of the invention which is defined by the following claims.

Claims:

We claim:

1. A membrane module apparatus to transfer a gas to or from another gas or a liquid, the apparatus comprising:
 - a) a sheet having at least one gas transfer surface;
 - b) a gas channel in flow communication with the gas transfer surface; and
 - c) a header in flow communication with the gas channel.
2. The apparatus according to claim 1, wherein the sheet is a textile sheet comprising hollow fibers.
3. The apparatus according to claim 2, wherein the walls of the hollow fibers comprise the gas transfer surface.
4. The apparatus according to claim 2 or 3, wherein the hollow fibers are constructed of a thermoplastic polymer.
5. The apparatus according to claim 2, wherein the sheet further comprises inert fibers.
6. The apparatus according to claim 5, wherein the hollow fibers and inert fibers are knitted, weaved, or stitched together to form the sheet.
7. The apparatus according to claim 1, comprising a gas delivery header and a gas exhaust header.
8. The apparatus according to claim 7, wherein the hollow fibers extend between and are in fluid communication with the gas delivery header and gas exhaust header.
9. The apparatus according to claim 1 comprising two headers and a plurality of generally parallel sheets extending between the two headers.

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10. The apparatus according to claim 9 further comprising spacers between adjacent parallel sheets.

11. The apparatus according to claim 10 wherein the spacers comprise a spacer block positioned between adjacent sheets.

12. The apparatus according to claim 9 wherein the headers pull each sheet taut so that adjacent sheets remain spaced apart from each other.

13. The apparatus according to claim 10 wherein the spacers comprise fluid permeable spacing strips positioned between adjacent sheets.

14. The apparatus according to claim 13 wherein the spacing strips comprise a flow permeable spacing structure.

15. The apparatus according to claim 14 wherein the spacing structure extends between the two headers.

16. The apparatus according to claim 14 wherein the spacing structure comprises a lattice arrangement of plastic segments.

17. The apparatus according to claim 14 wherein the spacing structure comprises a length of plastic having through holes spaced apart along its length.

18. The apparatus according to claim 10 wherein the spacers comprise substantially rigid clips attached along an edge of the sheets.

19. The apparatus according to claim 18 further comprising a series of clips held along the lower edges of the sheets.

20. The apparatus according to claim 18 wherein the clips have outwardly protruding ridges.

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21. The apparatus according to claim 1 comprising two headers and at least one sheet extending between the two headers, wherein at least a portion of the sheet is wound to overlap itself.
22. The apparatus according to claim 21 further comprising a spacer for spacing apart adjacent overlapping portions of the spirally wound portion of the sheet.
23. The apparatus according to claim 22, wherein the spacing means comprises a corrugated layer positioned between adjacent overlapping portions of the spirally wound portion of the sheet.
24. The apparatus according to claim 23, wherein the corrugated layer extends between two headers.
25. The apparatus according to claim 22, wherein the spacer comprises lateral protrusions extending from the surface of the at least one sheet.
26. The apparatus according to claim 25, wherein the lateral protrusions are formed by embossing the sheet
27. The apparatus according to claim 25, wherein the lateral protrusions comprise separately attached buttons.
28. The apparatus according to claim 22 further comprising biasing means urging the wound sheet to unwind
29. The apparatus according to claim 28, wherein the biasing means comprises a stiffener element secured to the at least one sheet
30. The apparatus according to claim 1 comprising a first header, a plurality of second headers, and at least one sheet extending between the first header and each of the second headers.

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31. The apparatus according to claim 30 wherein the second headers are arranged generally along a circle having the first header at its axis.

32. The apparatus according to claim 31 wherein the sheets extend generally radially between the first and second headers.

33. The apparatus according to claim 31 wherein the sheets extend in a curved, spiral configuration between the first and second headers.

34. The apparatus according to claim 1 wherein each sheet extends between opposed headers that extend continuously along the length of the sheet.

35. The apparatus according to claim 34 wherein the headers have a width adapted to space apart the sheets of adjacent modules stacked together in a tank.

36. The apparatus according to claim 21 wherein the two headers are adjacent each other.

37. A plurality of the apparatus of claim 1 assembled into a cassette.

38. A cassette comprising a plurality of the apparatus of claim 1 stacked vertically, wherein the header of a lower apparatus is connected to the header of an upper apparatus.

39. A cassette comprising a plurality of the apparatus of claim 1 wherein the headers are connected in parallel to a gas conduit.

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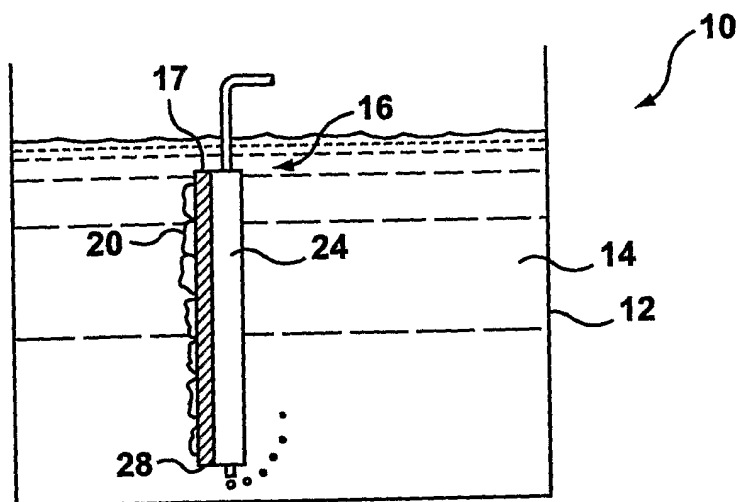


FIG. 1

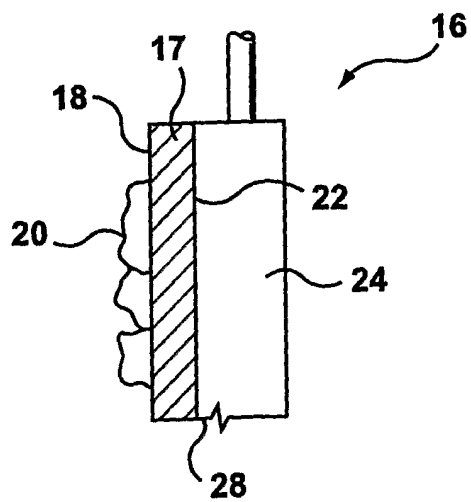


FIG. 2

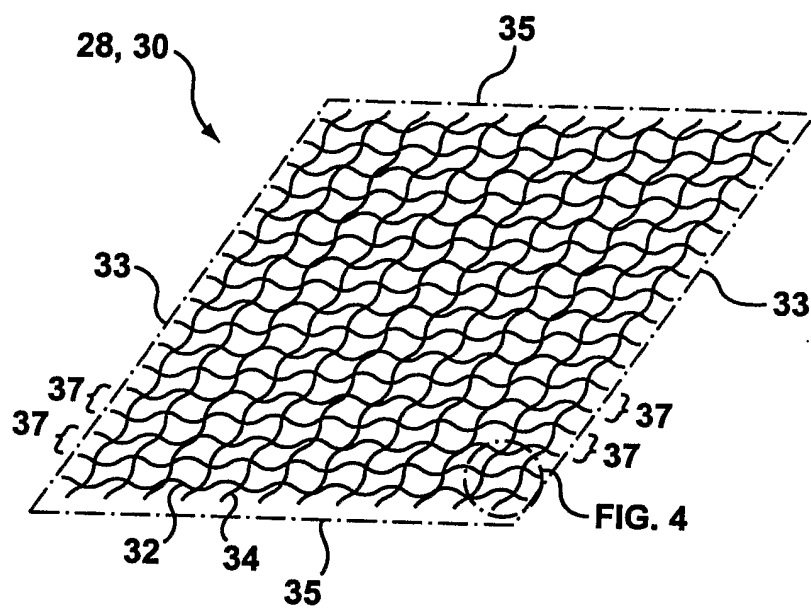


FIG. 3

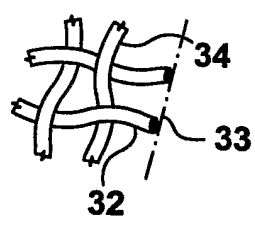


FIG. 4

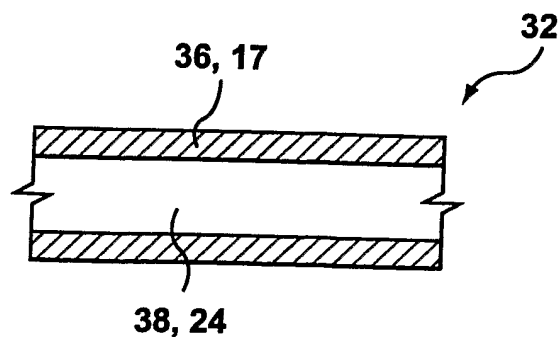


FIG. 5

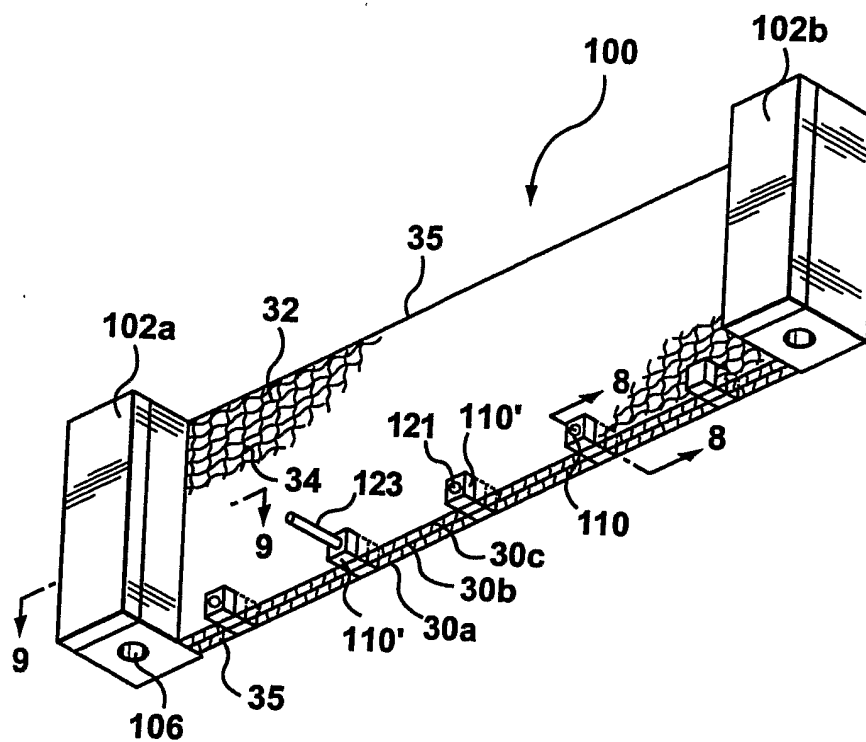


FIG. 6

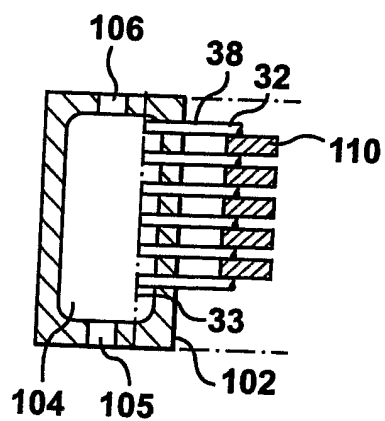


FIG. 7

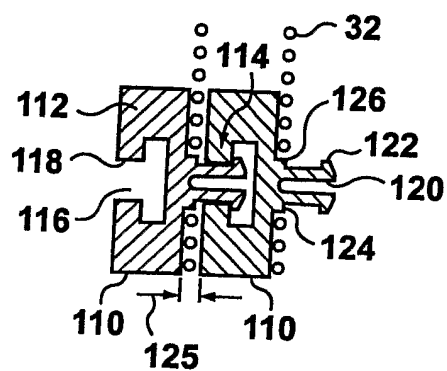


FIG. 8

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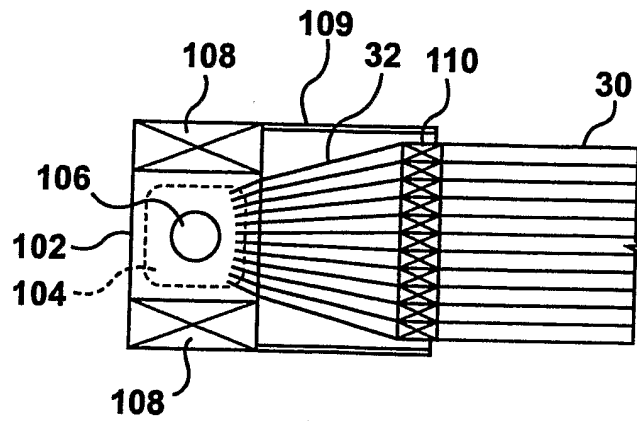


FIG. 9

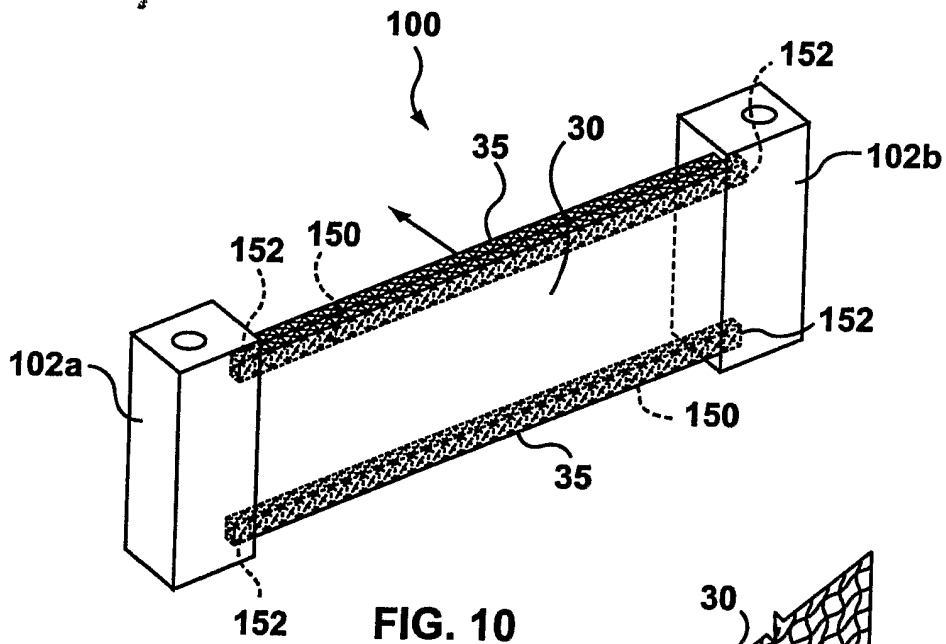


FIG. 10

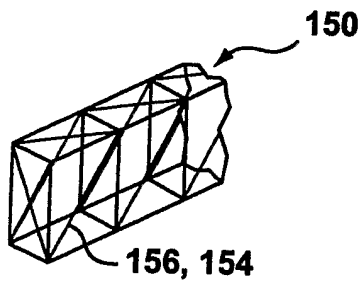


FIG. 11

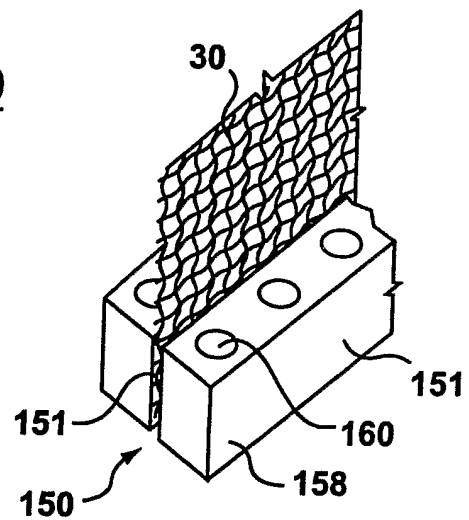


FIG. 12

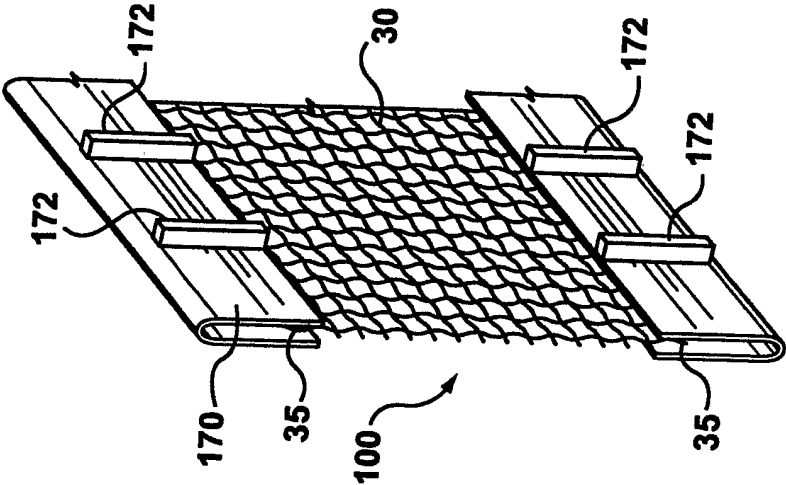


FIG. 13

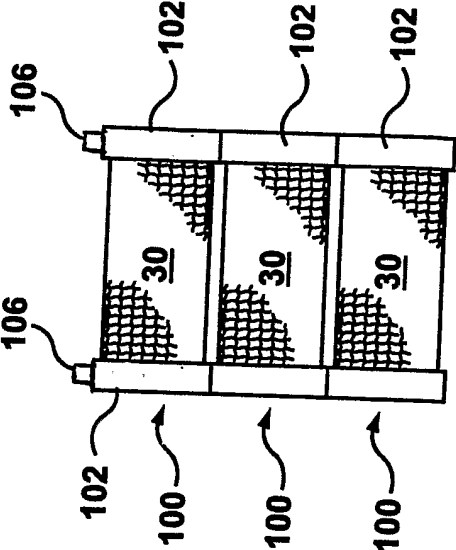


FIG. 14

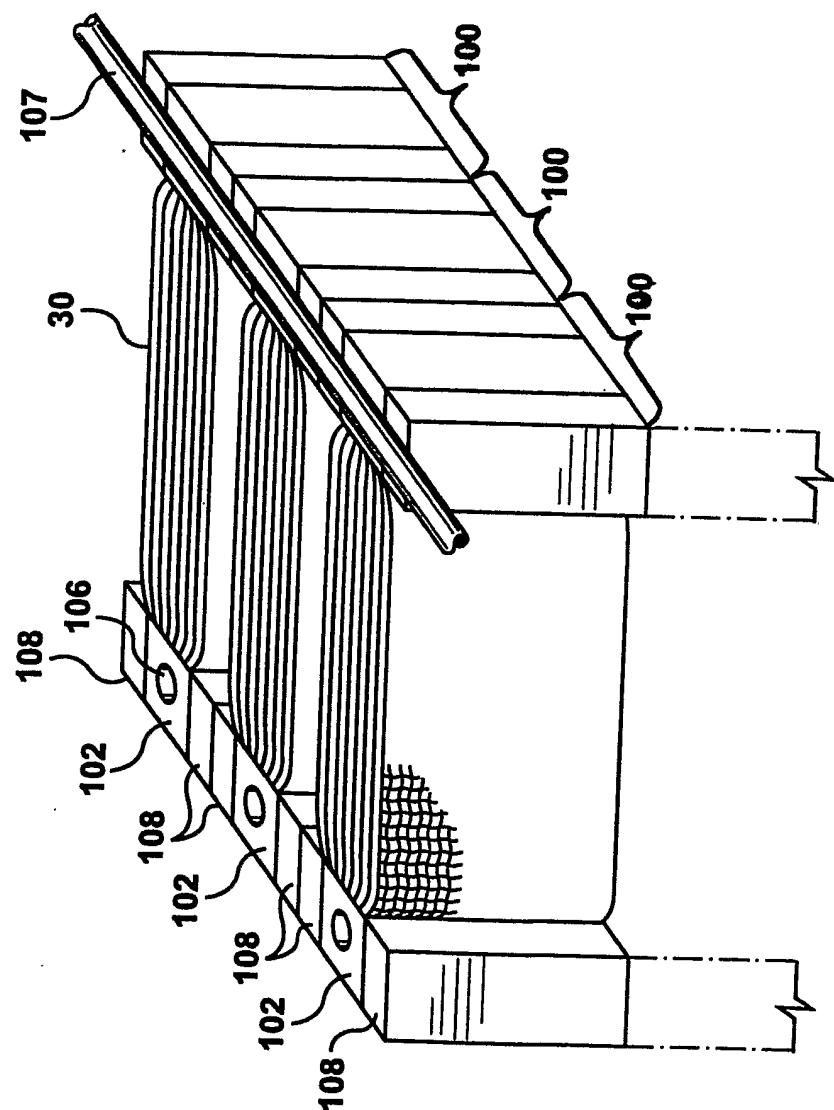


FIG. 15

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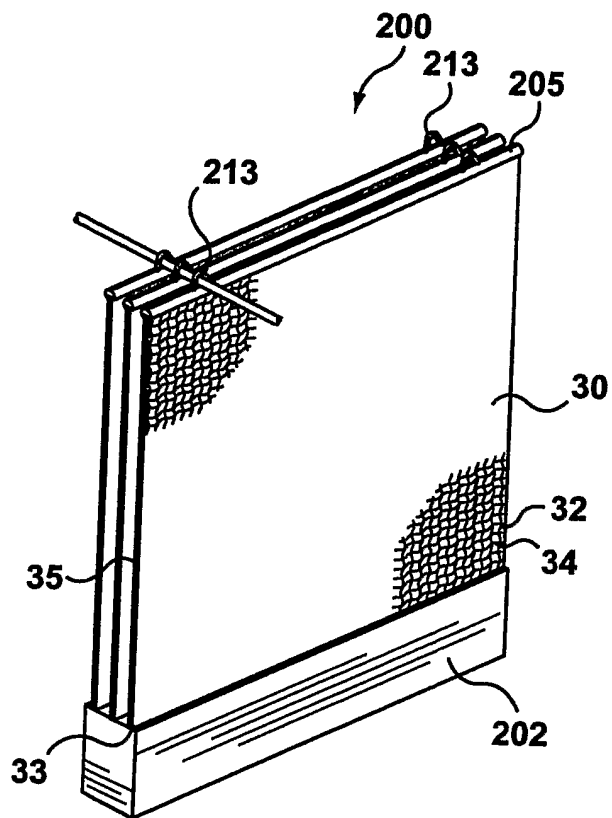


FIG. 16

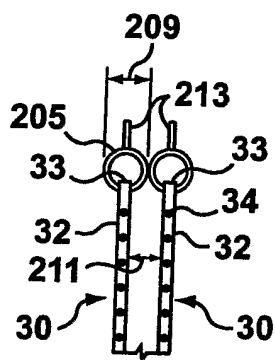


FIG. 17

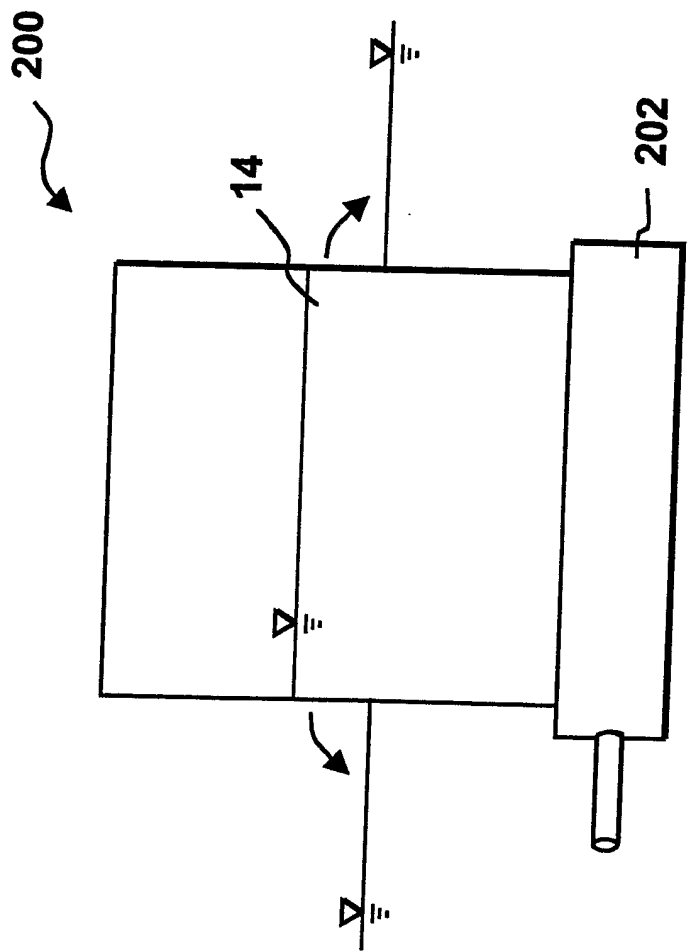


FIG. 18

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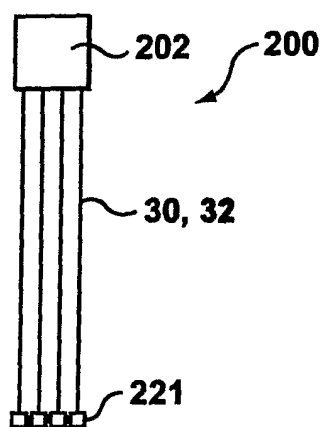


FIG. 19

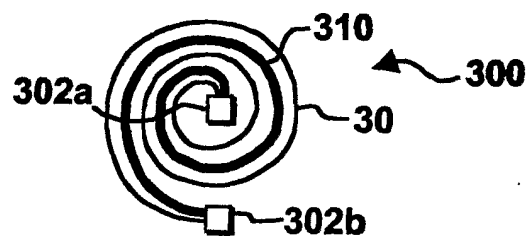


FIG. 20

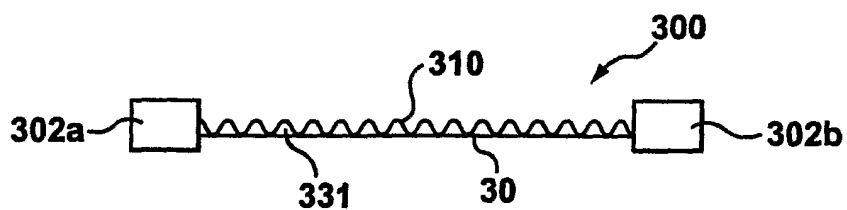


FIG. 21

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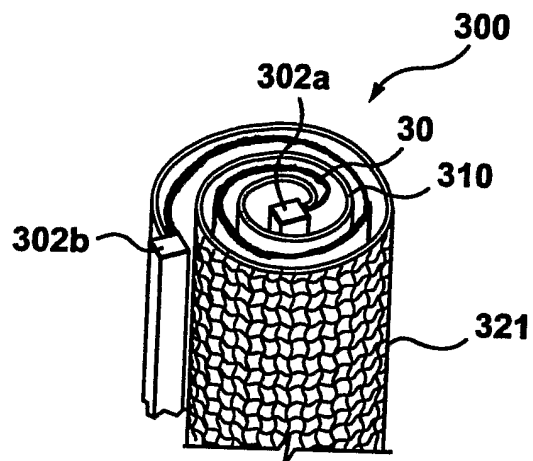


FIG. 22

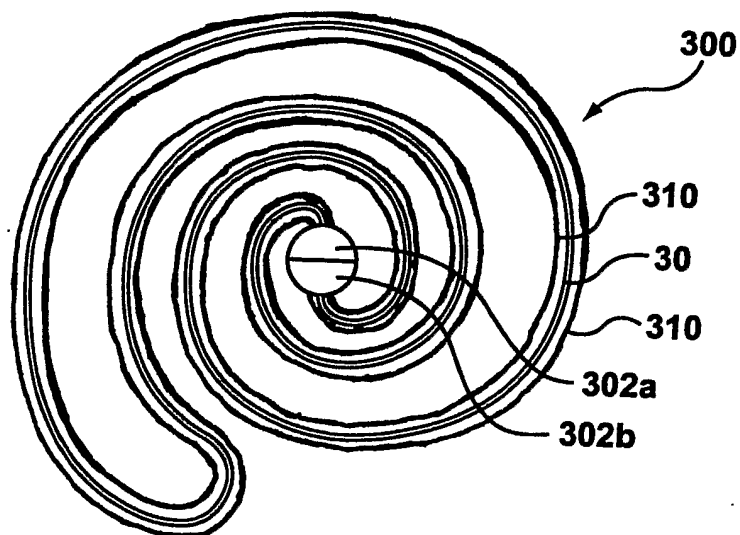


FIG. 23

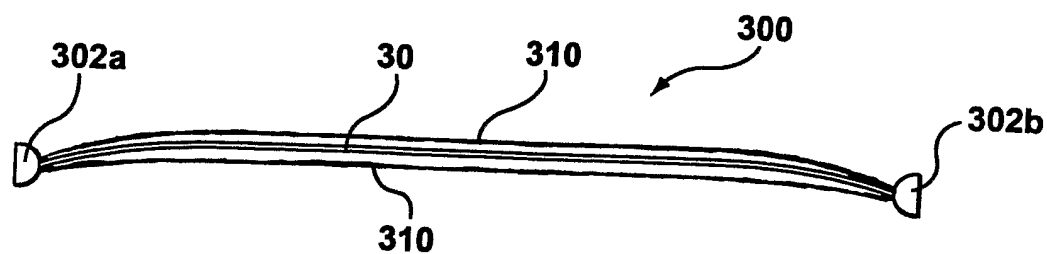


FIG. 24

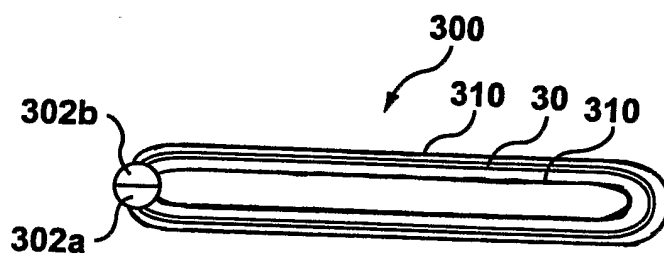


FIG. 25

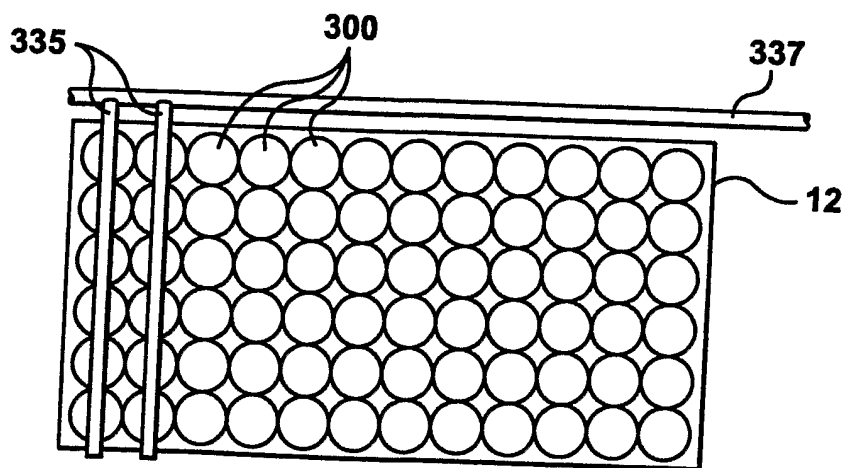


FIG. 26

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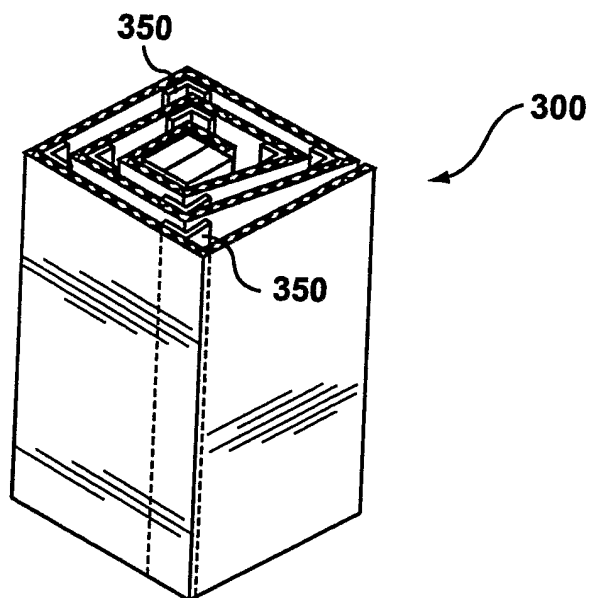


FIG. 27

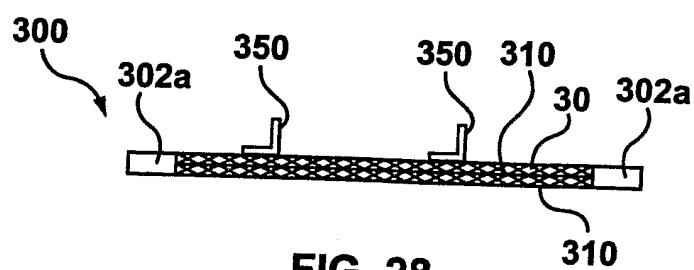


FIG. 28

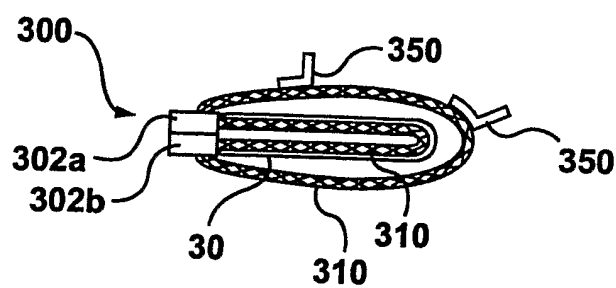


FIG. 29

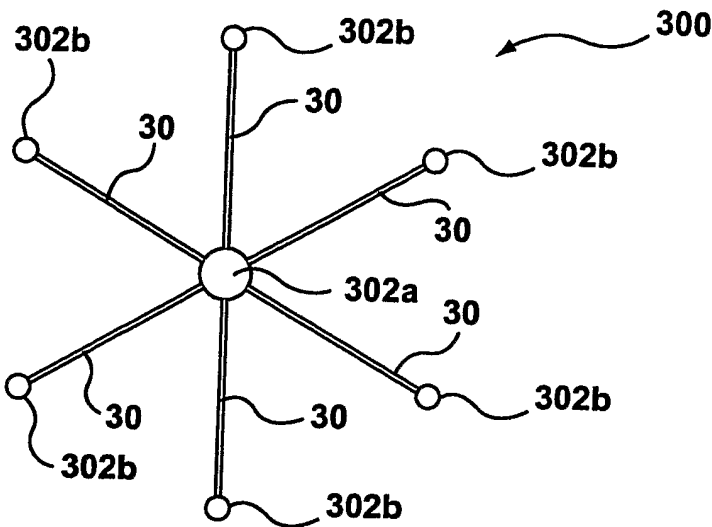


FIG. 30

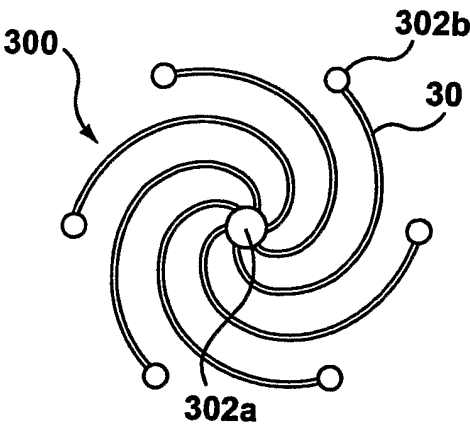


FIG. 31

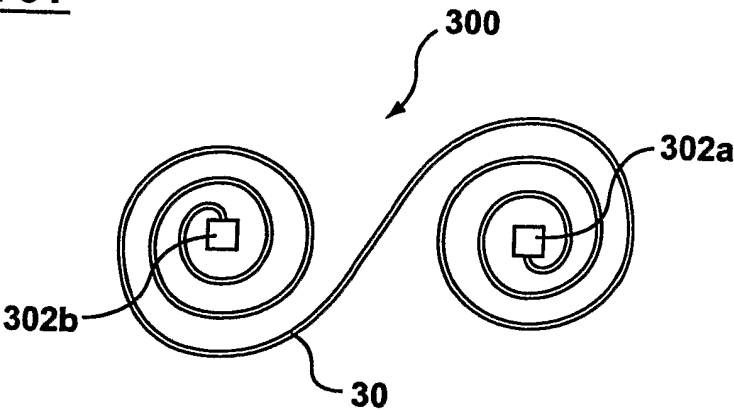
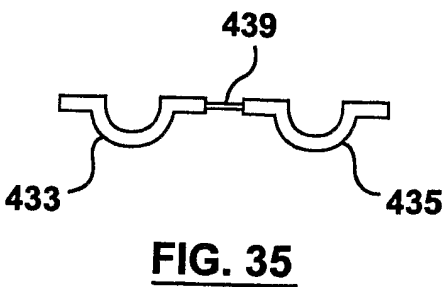
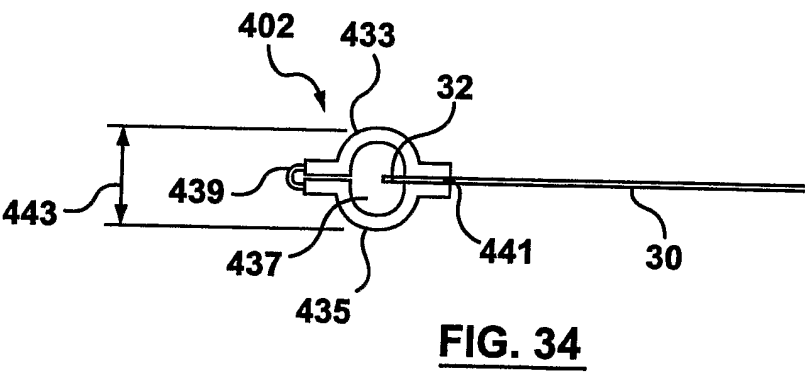
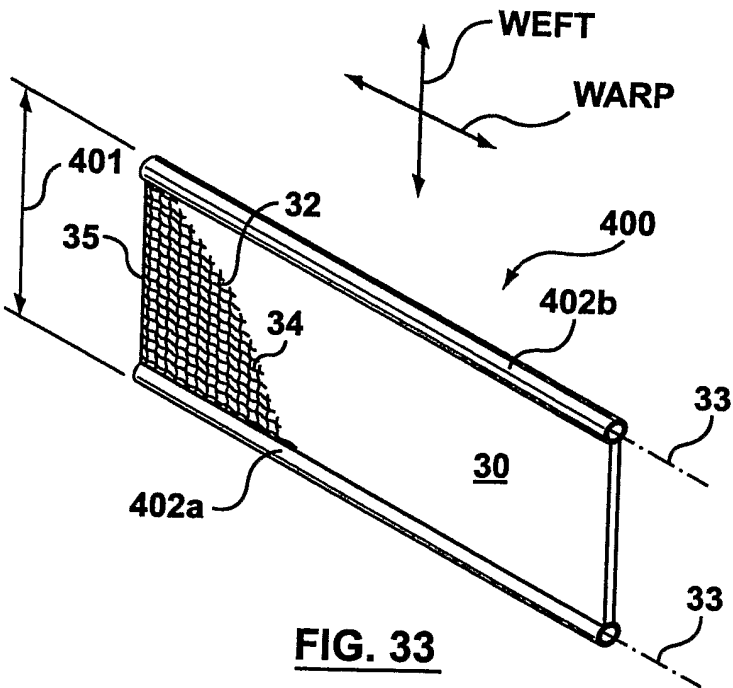
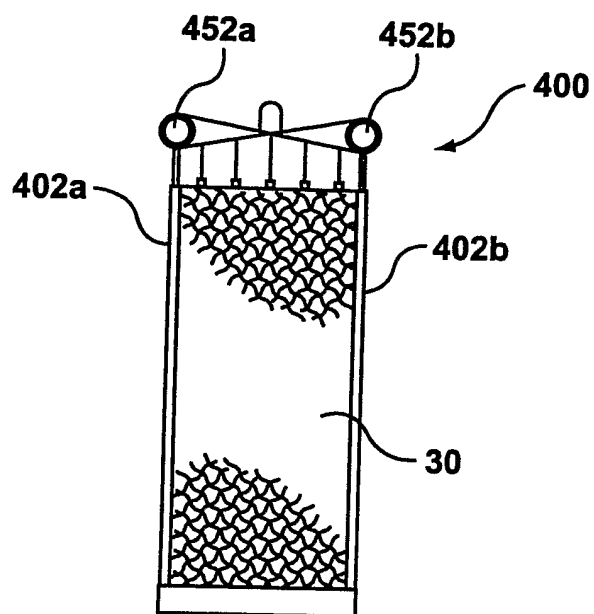
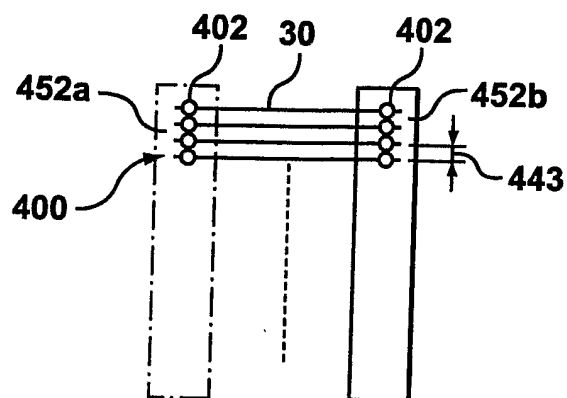
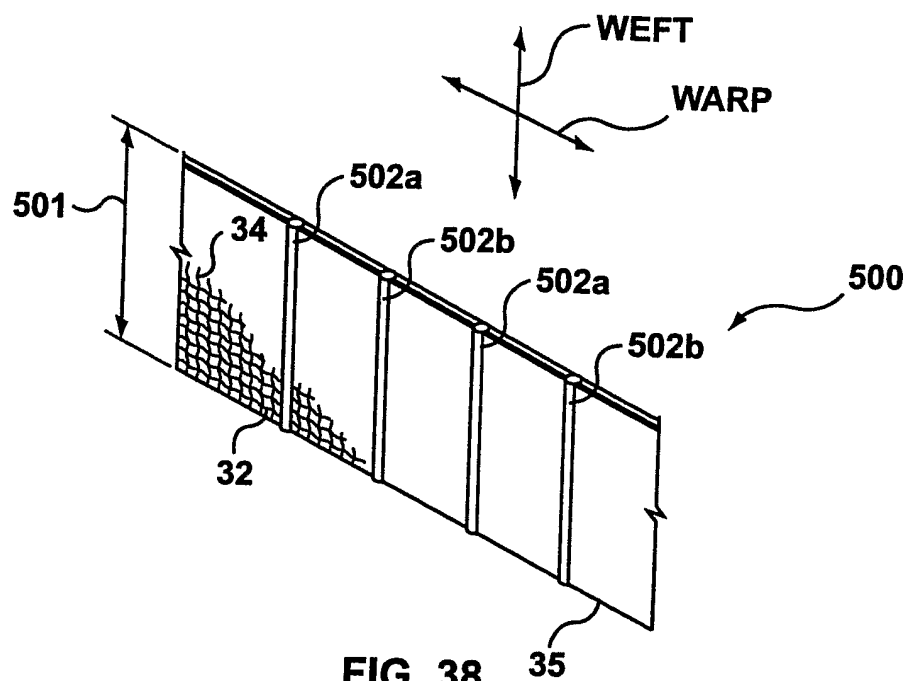
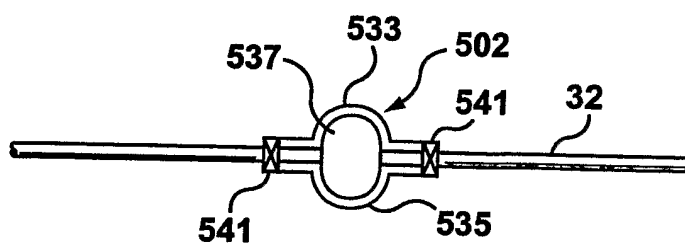
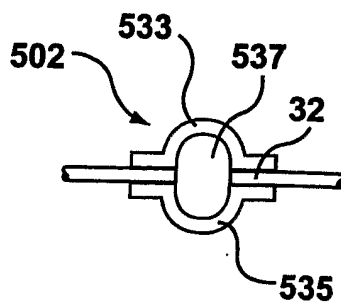


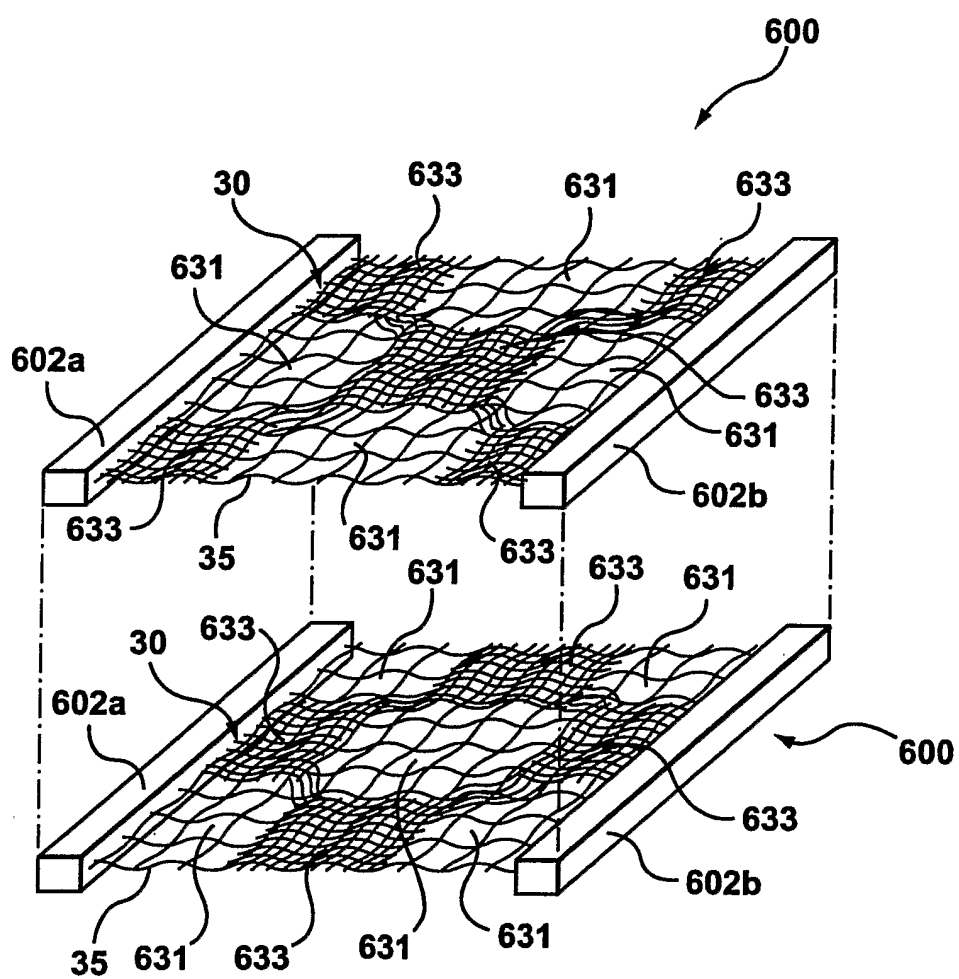
FIG. 32



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**FIG. 36****FIG. 37**

**FIG. 38****FIG. 39****FIG. 40**

**FIG. 41**

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2004/001496

A. CLASSIFICATION OF SUBJECT MATTER

According to International Patent Classification (IPC) Int. Cl 7 B01D-63/04

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int. Cl 7 B01D-63/04, B01D-63/08, B01D-63/10, B01D-63/14, C02F-3/30

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base, and, where practicable, search terms used)

CPD, USPTO, WEST, Esp@cenet

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US6309550 (Inversen et al) 30 October 2001	1 - 4, 7 - 8, 37 - 39
Y	see the whole document	5 and 6

Further documents are listed in the continuation of Box C.

Patent family members are listed in annex.

* Special categories of cited documents :	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance		
"E" earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means		
"P" document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international-type search
16 November 2004 (16-11-2004)

Date of mailing of the international-type search report
07 January 2005 (07-01-2005)

Name and mailing address of the ISA/
Commissioner of Patents
Canadian Patent Office - PCT
Ottawa/Gatineau K1A 0C9
Facsimile No. 1-819-953-9358

Authorized officer
Mark Hantke (819) 953-5773

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2004/001496

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CA2005959 (Glassford) 20 June 1990 see the whole document	1, 7 - 10
X	US6558549 (Cote et al) 06 May 2003 see the whole document	1, 9, 21 - 29, 37 - 39
Y		9 - 20, 30 - 36
Y	CA2182915 (Aleiy et al) 12 February 1997 see claim 1	5, 6
Y	CA2102156 (Huang et al) 01 July 1004 see claim 1	5, 6
Y	CA2356316 (Kovar et al) 17 August 2000 see claim 1	9 - 20, 30 - 36
Y	CA2100002 (Hopkins) 11 February 1994 see claim 1, and Figures 1 - 8	9 - 20, 30 - 36

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2004/001496

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2004/001496

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons :

- 1 ☐ Claims Nos. :
because they relate to subject matter not required to be searched by this Authority; namely:

- 2 ☐ Claims Nos. :
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically :

- 3 ☐ Claims Nos. :
because they are dependant claims and are not drafted in accordance with the second and third sentences of Rule

Box III Observation where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows :

Claim 1 is known from US6309550 or US6558549, therefore there is no single general inventive concept to link the following groups of claims;

- claims 2 to 6 are directed to woven sheet of hollow fibres
- claims 7, 8, 34 and 35 are directed to sheets having delivery and exhaust headers
- claims 9 to 20 are directed to a plurality of parallel sheets
- claims 21 to 33 and 36 are directed to spiral wound sheet
- claims 37 to 39 are directed to a cassette of a plurality of membrane modules

- 1 ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

- 2 ☒ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

- 3 ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos. :

- 4 ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos. :

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.