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(54) **Title:** FLOW DISTRIBUTOR FOR A STACK ASSEMBLY

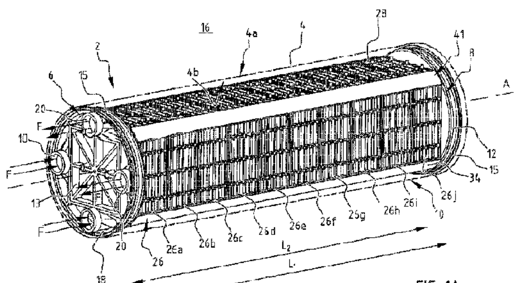

FIG. 1A

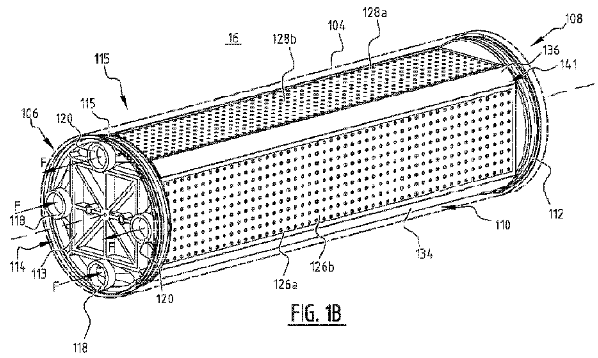

FIG. 1B

(57) **Abstract:** The invention relates to a flow distributor for a membrane stack of a stack assembly, the flow distributor comprising a housing comprising an inner space, wherein the inner space is operatively connectable to a number of flow openings of a membrane slack, and a plurality of flow distributor elements, wherein the plurality of flow distributor elements is at least partially positioned in the inner space and fill at least part of the inner space, and wherein the flow distributor is configured to be positioned in a fluid flow path of a stack assembly such that a flow of fluid at least partially flows through the plurality of flow distributor elements, and wherein the fluid flow path extends from at least one feed opening towards at least one discharge opening. The invention further relates to a stack assembly comprising a flow distributor, a flow distributor element, a method for manufacturing a stack assembly comprising a flow distributor and a method for generating energy and/or desalinating a fluid.

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FLOW DISTRIBUTOR FOR A STACK ASSEMBLY

The invention relates to a flow distributor for a membrane stack of a stack assembly, a stack assembly having such a flow distributor, an element for such a flow distributor, a method for manufacturing a flow distributor for a stack assembly and a method for generating energy and/or desalinating fluid.

Fluid flow distributors for stack assemblies are known from practice and are configured for guiding a fluid flow to and/or from a membrane stack, for example for an electro-dialysis (ED)device or reverse electro-dialysis (RED) device. Known flow distributors often comprise a housing having an inner or housing space that is operatively connectable to a membrane stack. This may for example be a plate-like structure having an inner space that is positioned adjacent the flow openings of a membrane stack, yet may also be a housing having an inner space in which a membrane stack is positioned and in which a flow of fluid is provided to (and from) a side of the membrane stack.

The flow distributor, and most notably the inner space thereof, is used to distribute the flow of fluid over the flow openings of the membrane stack. To establish a good performance of the membrane stack, a substantially uniform distribution of the fluid flow over the membrane cells is required. This can be achieved by increasing the volume of the inner space to reduce flow speed and flow resistance.

A disadvantage of known flow distributors having an increased volume is that the increased volume also leads to an increase in parasitic (ionic) short-cut currents, which in turn results in a reduction of the performance of the membrane stack and the stack assembly as a whole. This is especially true for electro-membrane processes such as RED and ED. To reduce the parasitic (ionic) short-cut currents, a low volume of the inner space is required. Therefore, an improved flow distributor is required that provides a highly uniform fluid flow distribution and simultaneously reduces the volume of the inner space to reduce parasitic (ionic) short-cut currents. The invention is therefore aimed at providing a flow distributor that obviates or at least reduces these disadvantages.

To that end, the invention comprises a flow distributor for a membrane stack of a stack assembly, the flow distributor comprising:

- a housing comprising an inner space, wherein the inner space is operatively connectable to a number of flow openings of a membrane stack; and
- a plurality of flow distributor elements, wherein the plurality of flow distributor elements is at least partially positioned in the inner space and fill at least part of the inner space; and

wherein the flow distributor is configured to be positioned in a fluid flow path of a stack assembly such that a flow of fluid at least partially flows through the plurality of flow distributor elements, and wherein the fluid flow path extends from at least one feed opening towards at least one discharge opening.

An advantage of the flow distributor according to the invention is that a more uniform distribution of the fluid over the flow openings of the membrane cells of the membrane stack is achieved.

In addition, the presence of the flow distributor elements according to the invention simultaneously provides a relatively low volume of the inner space, which reduces parasitic (ionic) short-cut currents. The relatively low volume of the inner space is mainly due to the fact that the plurality of flow distributor elements acts as a collection of individual elements that is shapable in multiple forms. It is noted that the collection as such comprises separate or individual elements that are mechanically unconnected and thus are able to move and settle with respect to each other. This flexibility or shapeability allows the plurality of flow distributor elements to conform to the shape of the inner space of the flow distributor.

Experiments have shown that the presence of flow distributor elements result in a reduction of the inner space volume with around 40 – 74%. It is believed that with particular forms and/or shapes and/or distribution, the reduction may be as high as 91%. The reduction of the inner space volume is for the purpose of the invention also referred to as packing density. In that respect, it is found that the reduction of the inner space depends on the distribution of the flow distributor elements in the inner space. A random distribution results in a lower reduction or packing density (i.e. around 40 – 60%), whereas a more uniform distribution (i.e. packing) of the flow distributor elements in the inner space may lead to a reduction or packing density of 60 – 74%. In all cases, the reduction of the inner space volume leads to a significant reduction of the amount of parasitic (ionic) short-cut currents.

As such, the flow distributor according the invention combines a highly uniform flow distribution over the membrane stack with a significant reduction of the parasitic (ionic) short-cut currents in the membrane assembly.

Another advantage of the flow distributor according to the invention is that the plurality of flow distributor elements may simultaneously be used for filtering the fluid flow before it enters the membrane stack. The plurality of flow distributor elements and the configuration of the flow distributor elements in the flow distributor may result in pollution/polluting elements attaching to the flow distributor elements or being contained in spaces between the flow distributor elements, rather than entering the membrane stack. The flow distributor elements may, as part of a process with the stack assembly, be regularly replaced to enhance a filtering function of the flow distributor. Additionally, cleaning-in-place (CIP) may be used.

As already briefly referred to above, it should be noted that the plurality of flow distributor elements is a collection of separate or individual flow distributor elements that is removably provided in the housing of the flow distributor. Moreover, the flow distributor elements are not mechanically (thus fixedly) connected or provided in the inner space, yet are a collection of loose elements that is provided to the inner space (and may be removed therefrom). In other words, the mere fact that the plurality of flow distributors according to the invention comprises a plurality of loose elements makes that it differs significantly from the known flow distributors. It is (highly) modular and flexible, because any quantity above two distributor elements already provides a measure of flow distribution. In practice, it would be preferred to provide a relatively large number of flow distributor elements in the inner space of the flow distributor to achieve a high packing density.

Moreover, an advantage of providing separate or loose flow distributor elements is that the flexibility with regard to its application is increased. Although each separate flow distributor element has a more or less fixed shape, the plurality of flow distributor elements as collection does not have a fixed shape, since the individual elements can be moved and/or shifted with regard to each other to (snugly) fit into any (existing) inner space of a manifold or flow distributor. This is not possible using the known flow distributors which have a fixed structure.

Due to the fact that the flow distributor elements are not mechanically or chemically connected (i.e. are loose elements), the elements can be easily removed from and/or replaced in the inner space of the flow distributor.

In an embodiment, the flow distributor is operatively connected with a gas supply device, such as an air pump, wherein, in use of the flow distributor, a gas and/or fluid is supplied to the flow distributor such that the flow of gas and/or fluid is supplied to the plurality of flow distributor elements.

The flow distributor may, especially when used to capture and/or immobilize pollution for the purpose of removing it, be connected to a gas supply device to provide the flow distributor elements in the form of a fluidized bed. This may be advantageous to provide enhanced cleaning and can for example be at least periodically be performed to clean the stack assembly or at least the flow distributor thereof. However, it is also possible to realize a fluidized state of the flow distributor elements by using the fluid flow that is provided to the stack assembly.

It should be noted that a flow distributor is often also referred to a fluid flow distributor and/or manifold. For the purpose of the application, these terms are considered to be similar and interchangeable. A flow distributor, fluid flow distributor and/or manifold is a device that is configured for guiding and/or holding and/or transferring a fluid and forms part of a fluid flow path in the stack assembly.

It is furthermore noted that a flow distributor according to the invention is a flow distributing unit providing a fluid flow path between a main flow opening and flow openings in a membrane stack. This means that the housing of the flow distributor for the stack assembly may comprise a separate physical housing, such as a manifold (housing), yet may also be an integrally formed housing of a part of the stack assembly, such a channel or opening that extends in a membrane stack and which forms the (main) fluid flow distribution channel for the fluid flow that is to be provided to the membrane stack. In this case, the inner space is formed by the channel itself and the housing is formed by the channel wall, which is formed by the membranes in the membrane stack. In other words, for the purpose of the invention, a (feed/discharge) fluid path that extends through a side edge and/or corner of the membrane stack in known membrane stacks is also considered to be a flow distributor. In that respect, it is preferably that the plurality of flow distributor elements is positioned between the main flow opening and the flow openings of the membrane stack to provide maximum effect. Due to the (preferably) relatively small size of the flow distributor elements, they can be applied in various known stack assemblies. Size should be construed as diameter and/or length and/or width. This includes manifolds formed as a solid frame or the abovementioned manifolds that comprise a (feed/discharge) fluid flow path in the membrane stack.

It is also noted that to the purpose of the invention, the terms membrane cell, cell, cell pair and/or membrane compartment are considered to have a similar meaning and can thus interchangeably be used in the application.

It is furthermore noted that the flow distributor elements are, as also follows from the description, particles that are packed in the inner space without applying any (mechanical or chemical) connection means. In other words, the inner space is filled with loose particles, wherein preferably the particles are of a specific shape and size that depends on the application. The term flow distributor element for the purpose of the invention is similar to the word particle and these terms may be used interchangeably in the application.

In an embodiment according to the invention, the packing density of the plurality of flow distributor elements in the inner space is in the range of 40% – 91%, and more preferably in the range of in the range of 40% – 75%.

An advantage of a packing density in the abovementioned range is that it combines a highly uniform flow distribution over the membrane stack with a significant reduction of the parasitic (ionic) short-cut currents in the membrane assembly. It is noted in this respect that the packing density is the reduction of the inner space due to the (combined) volume of the flow distributor elements. In other words, in a simplified equation it follows that:

$$\text{Packing Density } (\%) = \frac{\text{Volume } (\textit{flow distributor elements})}{\text{Volume } (\textit{inner space})}$$

In an embodiment according to the invention, the housing may further comprise a main flow opening and a number of membrane flow openings that are positioned adjacent openings of an associated membrane stack, wherein the main flow opening is configured to provide a feed flow to the inner space and the number of membrane flow openings is configured for providing a fluid flow to the membrane stack and/or membrane cells in the membrane stack, or wherein the number of membrane flow openings is configured for providing a discharge fluid flow from the membrane stack and/or membrane cells in the membrane stack to the inner space and the main flow opening is configured to discharge a fluid flow from the inner space.

The flow distributor according to the invention may be a manifold in a stack assembly. This for example may be manifold having an inlet and an inlet channel that extends along a number of manifold outlet openings that are positioned adjacent the membrane stack. The inner space of the manifold, which is formed by the inlet channel may be filled with a plurality of flow distributor elements. An advantage of such a configuration is that the manifold, the plurality of flow distributor elements and the membrane stack may be formed as an integral unit that is placeable in a housing of the stack assembly.

In a different embodiment, the membrane assembly comprises a housing having an inner space, such as a tube or pipe-like structure, and an enclosing structure enclosing the membrane stack, wherein flow compartments are formed between an inner wall of the membrane assembly housing and an outer side of the enclosing structure, and wherein the flow compartments form the flow distributor, wherein the flow distributor elements are positioned in the flow compartments.

This allows the plurality of flow distributor elements to be used to provide a uniform flow to the membrane stack (through openings in the enclosing structure) and reduce parasitic (ionic) short-cut currents without being directly adjacent with or abutting onto the membrane stack. An advantage thereof is that the plurality of flow distributor elements can easily be exchanged from the flow compartments without damaging the membranes in the membrane stack, since they are spatially separated from the membrane stack by the enclosing structure. This allows the plurality of flow distributor elements to be used for cleaning the fluid flow and, when polluted, to be easily removed from the flow compartments to be replaced with new, fresh elements.

In an embodiment according to the invention, the plurality of flow distributor elements may be positioned at or near at least a part of a number of flow openings of a membrane stack.

Positioning the plurality of flow distributor elements at or near the flow openings has the advantage that the flow of fluid is forced to flow between the elements to enter the flow openings. As a result, the flow is substantially in the same plane, i.e. substantially parallel to, the flow openings that emanate in the membrane compartment between the membranes through which the flow of fluid is to flow. This configuration leads to a more uniform flow distribution and therewith increases the performance of a stack assembly in which it is used. In addition or alternatively, it may also reduce entry and/or exit losses. This embodiment may for example be used to refit known membrane stacks having a feed channel extending in and/or through the membrane stack. In an embodiment, the plurality of flow distributor elements is provided in an insert, preferably a specially adapted insert, that is insertable in the feed channel of a (known) membrane stack, wherein the insert is at least partially filled with flow distributor elements. The use of inserts may be especially useful in modifying existing stacks. An additional advantage is that, when an insert having relatively smooth side edges/walls is used, the friction losses of the fluid flow may be reduced along the side walls of the existing flow channels.

In an embodiment according to the invention, the flow distributor elements may be provided with a coating.

An advantage of applying a coating to the elements is that the elements may be used to increase the filtering capabilities of the elements in order to more efficiently filter the fluid flow in the manifold. The coating may additionally or alternatively also be used to provide other characteristics such as an improved fluid flow and/or a reduction of the ionic conductivity in the fluid flow distributor to reduce short-cut currents.

In an embodiment according to the invention, the plurality of flow distributor elements may comprise a first plurality of flow distributor elements having a first size and a second plurality of flow distributor elements having a second size, wherein the first size and the second size are different.

An advantage is that the flow distributor elements of different sizes may be chosen to perform different functions. This may for example mean that the larger elements are specifically configured for filtering and/or cleaning the fluid flow, whereas the smaller flow distributor elements are specifically configured for evenly dividing the flow of fluid over the flow openings of the membrane stack. In addition, having a relatively small size near the membrane stack openings and larger sized flow distributor elements further away from the membrane stack openings is that the volume is (optimally) reduced near the membrane stack to attain a more evenly/uniformly distributed flow, whereas the larger sized flow distributor elements provide a large volume reduction, while simultaneously reducing the pressure drop compared to the smaller sized flow distributor elements. As a result, a more efficient use can be made of the flow distributor elements. Furthermore, a more effective reduction of ionic short-cut currents is achieved. The use of different sizes of elements is especially useful if the membrane stack has relatively rough edges, which allows the small particles to snugly fit against the membrane stack.

Another advantage of providing flow distributor elements having different sizes is that a similar or improved effect can be achieved using a lower amount of flow distributor elements. The size of the flow distributor elements is preferably chosen such that larger flow distributor elements are positioned near the main flow opening of the flow distributor and smaller flow distributor elements are positioned near or at the flow openings in the membrane stack. By choosing this configuration, the flow is evenly divided over the flow openings of the membrane stack, while reducing the number of flow distributor elements that is required. This embodiment is especially useful in stack assemblies with separate flow compartments and/or relatively large flow compartments in the manifold.

It is noted that it is also possible to provide elements having more than two different sizes, i.e. three, four or even more. It may also concern elements that have different sizes which all fall within a predetermined range.

In an embodiment according to the invention, the flow distributor elements may be provided with at least two groups of elements, wherein a first group of elements is manufactured from a first material and a second group of elements is manufactured from a second material, wherein the materials may cooperate to provide the elements of the groups of elements with a static electric charge.

By providing flow distributor elements with a static charge, the flow distributor elements are provided with enhanced filtering properties.

It may alternatively also possible to provide a single group of flow distributor elements, wherein each flow distributor element in the group of flow distributor elements is manufactured from two different materials, wherein the two materials are chosen to cooperate with each to create a static electric charge, and wherein, in use of the flow distributor, the flow distributor elements cooperate to generate a static electric charge.

Preferably, the static electric charge is generated by moving the flow distributor elements against each other, although other suitable charge generations processes may also be used.

In an embodiment according to the invention, the flow distributor elements may be manufactured from a non-ion-conducting and/or non-electrically conducting material.

An advantage of using non-ion-conducting and/or non-electrically conducting material for the flow distributor elements is that it reduces (ionic) short-cut currents in the manifold, which increases the performance of the stack assembly and the membrane stack.

In an embodiment according to the invention, the flow distributor elements may be manufactured from glass, plastic, including PE, PP, PVC, PET, PC, PS, an elastomer, including rubber and silicons, a ceramic including alumina and silica-dioxide, carbon, graphite, an ion exchange resin or a combination of these materials. However, it should be noted that other suitable materials, for example PTFE and PVDF are also possible. In addition and/or alternatively, the material may be chosen to be an absorptive and/or catalytic material.

In an embodiment according to the invention, the flow distributor elements may have a size in the range of 10 μm – 100 mm, and preferably in the range of 0.1 mm – 75 mm, and more preferably in the range of 0.5 mm – 50 mm.

In an embodiment according to the invention, the flow distributor elements may have a size that is substantially smaller than a size of the flow distributor inner space, wherein preferably a ratio between the flow distributor element size S_E and the inner space I_S is in the range of $I_S/S_E > 1$, preferably in the range of $I_S/S_E > 4$, wherein S_E and I_S are a length and/or a width and/or a diameter.

Alternatively, in an embodiment, the flow distributor elements may even have a size that is considerably smaller than a size of the flow distributor inner space, in which a ratio between the flow distributor element size S_E and the inner space I_S is in the range of $I_S/S_E > 8$.

In an embodiment according to the invention, the flow distributor elements are made of a material that is compressible under pressure.

Providing compressible flow distributor elements has the advantage that the flow paths in the flow distributor can be adapted by adapting the pressure in the flow distributor without having to replace the flow distributor elements in the flow distributor.

Another advantage is that, by compressing the elements, the effective volume of the flow distributor inner space can be even further reduced. Examples of such materials are elastomers, including rubber and silicon and compressible types of plastic for example PS or PU.

In an embodiment according to the invention, the flow distributor elements may be made of a material that is substantially incompressible.

Providing incompressible flow distributor elements has the advantage that the flow distributor elements can be used under a wide range of pressures without changing the properties of the manifold. Examples of such materials are glass, plastic, including PE, PP, PVC, PET, PC.

In an embodiment according to the invention, the flow distributor elements may comprise elongated elements, and preferably may comprise elongated cylindrical elements.

An advantage of providing elongated flow distributor elements (i.e. having a length that is larger than a width or diameter) is that the elements can easily be positioned and/or removed and, in addition, can be easily uniformly distributed to reduce the volume of the inner space. This embodiment is for example useful in known stack assemblies in which the flow distributor is formed by a channel in the membrane stack, since the elongated flow distributor elements can easily be positioned and/or inserted in the flow channel of the flow distributor.

Furthermore, especially when using elongated cylindrical flow distributor elements, the elements can be substantially uniformly divided in the inner space and a high reduction of inner space volume can be achieved. This results in a significant reduction of ionic short-cut currents, while simultaneously achieving a uniform flow having a relatively low pressure drop in the channels formed by use of the elements.

Yet another advantage is that the elongated elements easily be fitted in an inner space. The elongated elements may be solid elements or hollow elements having a closed inner space. Preferably, the elongated elements have a length that is substantially equal to the height of the membrane stack with which they are used and/or a length that is substantially equal to the length/height of the inner space in which they are used.

In an embodiment according to the invention, the flow distributor elements may have a substantially spherical shape and/or substantially ellipsoid shape.

An advantage of a spherical or ellipsoid shape is that the elements, when packed together in a space, automatically provide openings or voids that form a fluid flow path (i.e. channels) for the fluid flow. Another advantage is that the spherical and/or ellipsoid shape, especially when the flow distributor elements are used for filtering, makes it easier to remove the flow distributor elements from the flow distributor and replace them with fresh (unpolluted) flow distributor elements. In addition, the flow distributor elements according to this embodiment can be advantageously used to be fluidized to achieve a cleaning-in-place (CIP) mode of operation of the stack assembly. Furthermore, spherical-shaped and/or ellipsoid-shaped distributor elements, due to the shape, are also subject to settling in snugly during placement.

It should be noted that the distributor elements may also have a different shape, including, but not limited to (hollow) tubes, rods, tetrahedron-shaped, cylindrically shaped, cube-shaped, hexagonally and/or rectangally shaped elements, as well as dimer-shaped elements, rings, flakes, fibers and/or wires. The choice for a specific shape or form depends inter alia on the application in which it is used and/or costs and/or weight.

In an embodiment the elements may be hollow elements having an inner space.

An advantage of using hollow elements is that it reduces weight and (manufacturing) costs of the elements, wherein the hollow elements have a closed inner space..

In an embodiment, the elements may have an element outer surface that is adapted to the type of fluid to be used. The outer surface of the elements may be adapted to the fluid flow pollution level and/or the type of fluid to be used, in that the outer surface may be a substantially smooth outer surface having a low friction coefficient or may be a rough or roughened outer surface having a relatively high coefficient of friction. It may even be possible to have an outer surface having both smooth and rough or roughened parts.

The invention also relates to a stack assembly for a membrane stack, the stack assembly comprising:

- a membrane stack having a number of membranes;

- a flow distributor comprising a plurality of flow distributor elements; and
- a flow path configured for guiding a fluid flow through the membrane stack of the stack assembly, wherein the flow path extends from a feed opening to a discharge opening, wherein, viewed from the feed opening in the direction of the flow path, the flow path includes a number of upstream flow openings in the membrane stack, the membranes, a number of downstream flow openings, and the discharge opening;

wherein the plurality of flow distributor elements is positioned in at least part of the fluid flow path between the feed opening and the number of upstream flow openings and/or between the number of downstream flow openings and the discharge opening, such that a flow of fluid that is fed to the stack assembly passes through the flow distributor.

The stack assembly according to the invention has similar effects and advantages as the abovementioned flow distributor according to the invention.

It is noted that the stack assembly according to the invention may also be a reversible stack assembly. In such a reversible stack assembly the flow direction can be reversed during and/or between operations by switching the feed and discharge flow to the stack assembly. Such reversible stack assemblies fall within the scope of the invention as well.

An advantage of the stack assembly according to the invention is that the use of the flow distributor elements provides a relatively simple and cost-effective manner for providing an evenly distributed flow to the flow openings of the membrane stack.

Another advantage is that the flow distributor elements simultaneously may provide other benefits including filtering of the fluid flow through the stack assembly, therewith reducing the risk of fouling and/or damaging of the membrane stack.

Yet another advantage of the stack assembly according to the invention is that it also, especially in electro-membrane processes, leads to a reduction of (parasitic) ionic short-cut currents (and thus enhanced performance).

In an embodiment of the stack assembly according to the invention, the stack assembly may comprise a flow distributor according to the invention, wherein the flow path may extend at least partially through the manifold, and wherein the plurality of elements may be positioned in the manifold.

It is noted that the stack assembly according to the invention can be used in a wide variety of processes including reverse electro-dialysis (RED), electro-dialysis (ED), energy storage, preferably using a combination of RED and ED, EDR, and can be used in fuel cell applications, flow batteries and/or filtration devices.

The invention also relates to a flow distributor element, wherein a plurality of flow distributor elements is configured to be positioned in an inner space of a flow distributor for filling at least part of the inner space and/or is configured to be positioned in at least part of a fluid flow path that extends between a fluid feed opening of a stack assembly and an associated number of upstream flow openings of a membrane stack and/or between a number of downstream flow openings of a membrane stack and an associated discharge opening of a stack assembly, such that a flow of fluid that flows through the stack assembly passes through the plurality of flow distributor elements.

The flow distributor element according to the invention has similar effects and advantages as the abovementioned flow distributor and stack assembly according to the invention.

It is noted that the flow distributor element can be used in a wide variety of (membrane) cell applications, which include fuel cells, CDI stacks and/or filtration devices in which the elements have a function to distribute flow and/or reduce ionic short-cut currents. It may also be used for filtering a fluid and/or (catalytically) remove/transform pollutants. Especially flow distributor elements comprising catalytic materials and/or materials having absorptive properties may advantageously be used to improve the quality of the feedstream to enhance overall performance.

The invention also relates to a method for generating energy and/or desalisation of a fluid, the method comprising the steps of:

- providing a stack assembly according to the invention;
- feeding a flow of fluid to the feed opening of the stack assembly;
- discharging the flow of fluid from the discharge opening of the stack assembly;

wherein, the flow of fluid, during operation is guided through the plurality of flow distributor elements before entering the membrane stack and/or after exiting the membrane stack.

The method for generating energy and/or desalination of a fluid has similar effects and advantages as the abovementioned manifold, stack assembly and flow distributor according to the invention. A method for generating energy using a stack assembly according to the invention (and especially the flow distributor therein) has the advantage that the performance of such a process is relatively high due to the fact that the stack assembly reduces ionic short-cut currents, increases uniform flow distribution over the membranes in the membrane stack and is relatively easy to disassemble for cleaning purposes. Such a process comprises for example reverse electro-dialysis (RED), which may also be combined with an electro-dialysis (ED) process, which allows the stack assembly to be used for energy storage.

In an embodiment of the method according to the invention, wherein the electro-membrane process is a process for desalinating a fluid, wherein the step of providing a fluid flow to the stack assembly comprises providing at least a flow of brackish or salt water to the membrane stack, and the method additionally comprises the step of generating a (concentrated) salt water flow and a desalinated (i.e. diluate) water flow.

A method for generating energy using a stack assembly according to the invention has the advantage that the performance of such a process is relatively high due to the fact that the stack assembly reduces ionic short-cut currents, increases uniform flow distribution over the membranes in the membrane stack and is relatively easy to disassemble for cleaning purposes. Furthermore, a desalination process such as electro-dialysis (ED) may, as also mentioned above, be advantageously be combined with a reverse electro-dialysis (RED) process to allow the stack assembly to be used for energy storage.

In an embodiment of the method according to the invention, the method comprises the step of storing energy, wherein the method comprises the steps of performing an electro-dialysis (ED) process to store energy in the form of salt water and fresh water and performing a reverse electro-dialysis (RED) process for generating energy from the stored salt water and the fresh water; and alternating the previous steps to respectively store and retrieve energy from the stack assembly.

Due to the high performance of the stack assembly to the invention, the stack assembly can advantageously be used to store energy in an efficient and cost-effective way. The embodiment of the method according to the invention has a high efficiency and, consequently, low energy losses.

The invention also relates to a method for manufacturing a stack assembly comprising a flow distributor, the method comprising the steps of:

- providing a flow distributor comprising a plurality of flow distributor elements; and
- providing a membrane stack;
- providing a stack assembly having an inner space in which the membrane stack and the flow distributor are positionable, wherein the stack assembly is provided with a fluid flow path that extends from an inlet to an outlet and being configured to accommodate a fluid flow;
- inserting the membrane stack in the inner space of the stack assembly; and
- inserting the flow distributor in the fluid flow path between the inlet and the membrane stack and/or between the membrane stack and the outlet.

The method for manufacturing a stack assembly comprising a flow distributor has similar effects and advantages as the abovementioned flow distributor and stack assembly according to the invention and as the abovementioned method for generating energy and/or desalinating a fluid according to the invention.

Further advantages, features and details of the invention are elucidated on the basis of preferred embodiments thereof, wherein reference is made to the accompanying drawings, in which:

Figure 1A shows a perspective view of an example of a stack assembly according to the invention;

Figure 1B shows a perspective view of a second example of a stack assembly according to the invention;

Figure 2A shows a cross-sectional view of the stack assembly of figure 1A;

Figure 2B shows a cross-sectional view the stack assembly of figure 1B;

Figure 2C shows a cross-sectional view of a third example of a stack assembly according to the invention;

Figure 2D shows a cross-sectional view of a subsequent example of a stack assembly according to the invention;

Figure 3A shows a front view of the stack assembly of figure 1A with the end plate removed;

Figure 3B shows a front view of the stack assembly of figure 1B with the end plate removed;

Figure 3C shows a front view of the stack assembly of figure 2C with the end plate removed;

Figure 3D shows a cut-out view of an alternative connection between a sealing connector and two associated side plates;

Figure 3E shows a front view of the stack assembly of figure 2D with the end plate removed;

Figure 4A shows a perspective view of the stack assembly of figure 1B;

Figure 5 shows a detailed perspective of a cross-section of a fourth example of a stack assembly according to the invention;

Figure 6A shows an example of a membrane stack according to the invention; and

Figure 6B shows a detailed view of the membrane stack of figure 6A;

Figure 7A shows a second example of a membrane stack according to the invention; and

Figure 7B shows a detailed view of the membrane stack of figure 7A;

Figure 8A shows a perspective view of a flow guide of figure 6;

Figure 8B shows a side view of a flow guide of figure 6; and

Figure 9 shows schematic examples of flow distributor elements according to the invention.

An example of stack assembly 2 according to the invention (see figures 1A, 2A, 3A) comprises elongated tube 4 having outer wall 4a and inner wall 4b and length L1. Elongated tube 4 extends around central axis A from first end 6 to second end 8, which in this example are open ends, and therewith forms housing space 10. First end 6 and second 8 are sealingly closeable by respective end plates 12, 14, therewith sealingly closing housing space 10 from environment 16. End plates 12, 14 are in this example provided with flow openings 18, 20 for allowing a fluid flow into and out of housing space 10. Sealing 15 may be provided between end plates 12, 14 and the respective end 6, 8 of tube 4. Furthermore, in this example, end plate 12 is provided with electrode plate 13 having electrode 11.

Stack assembly 2 also comprises membrane stack 22 (see also figure 6a-b, 7a-b), which is formed by a number of membranes cells 24, 524 that are stacked on each other. Sides 22a, 22b, 22c, 22d of membrane stack 22 are provided with respective side plates 26, 28, 30, 32, which are in this example contiguous with membrane stack 22 and extend over the entire length L2 of membrane stack 22. Side plates 26, 28, 30, 32 are connected to each other through sealing connectors 34, 36, 38, 40 to form enclosing structure 41. Each side plate 26, 28, 30, 32 may be formed of a single plate, yet may also be formed from a number of plates that are positioned next to each other. In this example, side plate 26 includes a number of adjacent side plates 26a, 26b, 26c, 26d, 26e, 26f, 26g, 26h, 26i, 26j. Side plates 28, 30, 32 includes a number of respective adjacent side plates 28a – 28j, 30a – 30j, 32a – 32j .

Each sealing connector 34, 36, 38, 40 may be formed of a single sealing connector or may be formed of a number of sealing connectors that are positioned adjacent to each other when viewed along length L2.

Side plates 26, 28, 30, 32 and sealing connectors 34, 36, 38, 40 together form enclosing structure 41 to enclose and hold membrane stack 22. Enclosing structure 41 may be fixedly connected to membrane stack 22, yet may also be releasably connected to membrane stack 22. The latter can be performed by clamping membrane stack 22 and/or individual membrane cells 24 of membrane stack 22 in enclosing structure 41.

In an alternative example (see figure 3d), enclosing structure 41 may comprise a different connection between side plates 26, 28, 30, 32 and sealing connectors 34, 36, 38, 40 together form enclosing structure 41 to enclose and hold membrane stack 22. In this example, sealing connectors 34, 36, 38, 40 are relatively thin and side plates 26, 28, 30, 32 are provided at a relatively short distance from each other.

Enclosing structure 41 is configured to be slidingly insertable in elongated tube 4, such that sealing connectors 34, 36, 38, 40 are in sealing connection with inner wall 4b of external housing 4, which in this case is elongated tube 4.

When enclosing structure 41 and enclosed membrane stack 22 are inserted in elongated tube 4, the sealing connection between sealing connectors 34, 36, 38, 40 and inner wall 4b result in the formation of flow compartments 42, 44, 46, 48. In this example (see figure 3A) each flow compartment 42, 44, 46, 48 is delineated by two sealing connectors, one side plate and a part of inner wall 4b. For example, as can be seen in the figures 1A, 2A, 3A, flow compartment 42 is delineated by sealing connectors 34, 36, side plate 26 and a part of inner wall 4b.

Side plates 26, 28, 30, 32 are provided with a number of flow openings 50, which regulate the flow of fluid from flow compartments 42, 44, 46, 48 to membrane cells 24 of membrane stack

22. In this example, a membrane cell 24, 524 is formed by an AEM and a CEM membrane which are positioned on top of each other. Each membrane cell 24, 524 is formed of two membranes, which are connected to each other on two opposite sides to form a membrane compartment (see figure 6a, 6b, 7a, 7b). In this example, the membranes of the membrane compartment are formed by substantially unprofiled membranes in conjunction with (conventional) spacers (wherein the spacers may in some embodiments also be omitted). Alternatively, profiled membranes may be used in conjunction with the flow guides according to the invention. A fluid is guidable from a first side to a second, opposite side (or vice versa) through membrane cell 24, 524. Preferably, the membrane cells are stacked alternatingly, such that a cross-flow stack 22 is realised.

A second example of stack assembly 102 according to the invention (see figures 1B, 2B, 3B, 4) comprises elongated tube 104 having outer wall 104a and inner wall 104b and length L1. Elongated tube 104 extends around central axis A from first end 106 to second end 108, which in this example are open ends, and therewith forms housing space 110. First end 106 and second 108 are sealingly closeable by respective end plates 112, 114, therewith sealingly closing housing space 110 from environment 16. End plates 112, 114 are in this example provided with flow openings 118, 120 for allowing a fluid flow into and out of housing space 110. Sealing 115 may be provided between end plates 112, 114 and the respective end 106, 108 of tube 104. Furthermore, end plate 114 is in this example provided with electrode plate 113, which is removably connected to end plate 114. Electrode plate 113 preferably includes at least one electrode 111. In addition, figure 4 clearly shows a closing/clamping ring 117 which is positioned between end plate 114 and tube 104. Clamping ring 117, which in this example is seeger ring 117, replaces the function of pull rods used in conventional membrane assemblies to hold the membrane stack together.
Stack assembly 102 also comprises membrane stack 22, which is formed by a number of membranes cells 24 that are stacked on each other (see also figure 6a, 6b). Sides 22a, 22b, 22c, 22d of membrane stack 22 are provided with respective side plates 126, 128, 130, 132, which are in this example contiguous with membrane stack 22 and extend over the entire length L2 of membrane stack 22. Side plates 126, 128, 130, 132 are in this example formed by frames 126a, 128a, 130a, 132a, each of which encloses associated porous layer 126b, 128b, 130b, 132b. Frames 126a, 128a, 130a, 132a are connected to each other through sealing connectors 134, 136, 138, 140 to form enclosing structure 141. Porous layers 126b, 128b, 130b, 132b may be configured to be adjacent and contiguous with membrane stack 22 (as shown in figure 2b), yet may also be slightly thinner than associated frames 126a, 128a, 130a, 132a such that an open space or chamber 133 is present between a porous layer 126b, 128b, 130b, 132b and the side of membrane stack 22 positioned within enclosing structure 141 (see figure 4). Chamber 133 may also be filled with flow distributor elements 264.

A third example of stack assembly 202 (see figures 2C, 3C) comprises elongated tube 204 having outer wall 204a and inner wall 204b and length L1. Elongated tube 204 extends around central axis A from first end 206 to second end 208, which in this example are open ends, and therewith forms housing space 210. First end 206 and second 208 are sealingly closeable by respective end plates 212, 214, therewith sealingly closing housing space 210 from environment 16. End plate 214 is in this example provided with flow openings 218, 220 for allowing a fluid flow into and out of housing space 210. A sealing may be provided between end plates 212, 214 and the respective end 206, 108 of tube 204. Furthermore, end plate 214 is provided with electrode plate 213, which is removably connected to end plate 214. Furthermore, membrane stack 22 is in this example fixated in elongated tube 204 by means of seeger ring 217.

Stack assembly 202 also comprises membrane stack 22, which is formed by a number of membranes cells 24 that are stacked on each other (see also figure 6). In this particular example (see figures 2C, 3C), membrane stack 22 is enclosed by side plates 226, 228, 230, 232 that comprises a frame 226a, 228a, 230a, 232a, wherein each frame 226a, 228a, 230a, 232a, is filled with flow distributor elements 264, which in this example are spherical plastic beads 264 or elongated cylindrical elements 264, wherein the elongated elements 264 preferably extend over substantially entire length L2. Flow distributor elements 264 are packed snugly and in a tight fit in each frame 226a, 228a, 230a, 232a, such that a plate-like structure is formed. This has the advantage that entire enclosing structure 241 including elements 264 can be removed from housing 204.

It is noted that stack assembly 202 can also be used in a configuration in which no frame 226a, 228a, 230a, 232a is applied (see figures 2D, 3E). In this particular example (of figures 2D, 3E), flow compartments 242, 244, 246, 248 are, preferably completely, filled with flow distributor elements 264, which in this example are spherical plastic beads 264. Spherical plastic beads 264 which fill flow compartments 242, 244, 246, 248 in this particular embodiment are packed snugly such that they extend from the side of membrane stack 22 up to inner housing wall 4b. Together with sealing connectors 234, 236, 238, 240 they form enclosing structure 241. Combinations of the abovementioned embodiments can however also be used, i.e. partially filled flow compartments 242, 244, 246, 248 with or without side plates. This means that in this particular example the connection between sealing connectors 234, 236, 238, 240 and flow distributor elements 264 which form enclosing structure 241 is not a fixed connection, yet a connection formed using the pressure of flow distributor elements 264 that are snugly fit together in flow compartments 242, 244, 246, 248.

Another example of stack assembly 302 (see figure 5) shows a cross-sectional view of elongated tube 304 having housing space 310 in which enclosing structure 314 is positioned. In this example, enclosing structure 314 includes sealing connectors 334, 336, 338, 340 and side plates 326, 328, 330, 332. Side plates 326, 328, 330, 332 in this example consist of a framework 326a, 328a, 330a, 332a, each framework 326a, 328a, 330a, 332a having a central opening in which respective layers of porous materials 326b, 328b, 330b, 332b are positioned. Furthermore, porous layers 326b, 328b, 330b, 332b are thinner than the corresponding frameworks 326a, 328a, 330a, 332a, in which they are positioned, therewith forming space or chamber 333 between porous layers 326b, 328b, 330b, 332b and the associated side of enclosed membrane stack 22. In this example, one of the chambers 133 is filled with flow distributor elements 364, which are in this case spherical beads 364. Although one or more chambers 133 may be kept open, in practice it is preferred that either none or all chambers 133 are filled with flow distributor elements 264. In addition, figure 5 shows flow compartments 342, 344, 346, 348 that extend between inner wall 304b of tube 304 and respective porous layers 326b, 328b, 330b, 332b.

In an example according to the invention, membrane cell 24 also comprises flow guides 51, which are positioned between adjacent membranes 54, 56 (see figures 6a, 6b, 8a, 8b). In this example, flow guide 51 has membrane support section 53 to which membrane 54 is attached. In this example, flow guide 51 has a length LF in the range of 20 – 5,000 mm. The width or depth D1 of flow guide 51 is in the range of 2 – 150 mm, whereas width (or depth) D2 of flow section 52 is in the range of 1 – 149 mm. Width D3 of membrane support section 53 is in this example in the range of 1 – 50 mm. Flow guide 51 in this example has total height H1 in the range of 0.015 – 4 mm. The height H3 of membrane support section 53 is substantially equal to a thickness T1 of the membrane 54 that is attached to it, such that flow section 52 of strip 51 is at similar level as upper side 54a of membrane 54 (see figure 6A, 6B). In this example, height H3 is in the range of 0.005 – 2 mm. Flow guide 51 is furthermore provided with projections 58, which extend to a height that is higher than the membrane surface 54a, when viewed from that surface 54a. Projections 58 in this example have a height in the range of 0.01 mm – 2 mm. Projections 58 thus form flow channels or openings 60a – 60d through which a fluid is guided from flow compartments 42, 44, 46, 48/142, 144, 146, 148/242, 244, 246, 248/342, 344, 346, 348 into membrane cell 24. In this example, flow openings 60 have width W1 in the range of 0.1 – 50 mm, which is in this example equal to the range of width W2 of projections 58. Flow guide 51 is also provided with flow guide connection sections 52a, which have width W3 of 2 – 150 mm.

In a second example of membrane stack 522, membrane stack 522 comprises flow guides 551, having flow section 552 and membrane support section 553 (see figures 7A, 7B). Membranes 554, 556 are both connected to membrane support section 553 of flow guide 551, whereas two different membranes are connected to a lower side of flow guide 551 near flow section 552. Flow section 552 extends between projections 558 that form channels from flow openings 560, 560a, 560b towards membrane cell 524.

Flow distributor elements 264 can be provided in different forms, shapes and/or sizes. Examples of shapes of flow distributor elements 264 are provided in figure 9. It is noted that a length of elongated cylindrical element 264d can be much larger than a diameter of elongated cylindrical element 264d.

In use of the assembly, a fluid flow is provided through opening 18 of end plate 12 into flow compartments 46, 48;146, 148;246, 24; 346, 348, which thus form feed flow compartments 46, 48;146, 148;246, 24; 346, 348. From feed flow compartments 46, 48;146, 148;246, 24; 346, 348 the fluid is divided over flow channels/openings 60b, 60c (not shown) by side plates 26, 28, 30, 32; 126, 128, 130, 132; 226, 228, 230, 232 and/or porous layers 126b, 128b, 130b, 132b; 326b, 328b, 330b, 332b and/or flow distributor elements 264 into membrane cells 24, which are stacked in a cross-flow configuration in this example. In membrane cells 24, a process, such as an ED or RED-process takes place, and the fluid flow exits membrane cells 24 through respective openings 60a, 60d (not shown) into flow compartments 42, 44; 142, 144; 242, 244; 342, 344. In this example, the fluid flows exit compartments 42, 44; 142, 144; 242, 244; 342, 344 through flow openings 20, 120, 220, 320 (not shown) in end plate 12, 112, 212, 312 (not shown).

It is noted that the fluid flow through compartments 242, 244, 246, 248 is divided more evenly by means of flow distributor elements 264, which is this example are provided as spherical plastic beads 264. It is noted that porous layers 126b, 128b, 130b, 132b; 326b, 328b, 330b, 332b may be used separately or in conjunction with flow distributor particles 264 (see for example figure 4). It is furthermore noted that both the porous layer 126b, 128b, 130b, 132b; 326b, 328b, 330b, 332b and/or the flow distributor particles 264 may also be used in known, existing stack assemblies and its use whether alone or in combination is therewith not restricted to the stack assembly according to the invention.

It is noted that the size and form of each of the flow openings 50 and/or the flow openings 60a – 60d (not shown) are preferably chosen to complement each other to achieve a evenly divided fluid flow over membrane cells 24. Additionally, sealings may be applied between side plates 26, 28, 30, 32 and sides 22a, 22b, 22c, 22d of membrane stack 22.

The present invention is by no means limited to the above described preferred embodiments thereof. The rights sought are defined by the following claims, within the scope of which many modifications can be envisaged.

Simulations and experiments were performed with regard to the flow distributor according to the invention, the setup and results of which are provided below.

In the experiments an in-house designed 10x10 cm^2 lab cross-flow stack was used. The stack was operated in reverse electrodialysis (RED) mode with 50 cells/cell pairs (i.e. N=50).

The membrane stack was placed in an inner space of an enclosing structure formed by side walls. The side walls were provided with a flow inlet and a flow outlet and the sides of the membrane stack were sealingly connected to the side walls to form different flow compartments. Each flow compartment formed a space that was delineated by the side wall, a side of the membrane stack and the sealing provided between the side of the membrane stack and the side wall. The flow compartment was filled with flow distributor elements according to the invention.

The stack comprised, side-plates, two end-plates including electrode compartments, extruded polypropylene (PP) net spacers (approximately 0.48 mm thick), ion exchange membranes (cation exchange membranes and anion exchange membranes) and platinum coated titanium mesh electrodes.

The electrode rinse solution consisted of 0.2 M $K_3Fe(CN)_6$, 0.2M $K_4Fe(CN)_6 \cdot 3H_2O$ and 0.25M NaCl and was recirculated through the electrode-compartment at a flow rate of 150 ml/minute. The feed solutions were made using NaCl and tap water. The Low feed solution had a salinity of 1g/l NaCL (conductivity of ~2.05 mS/cm) and the High feed solution had a salinity of 30.7 g/l (conductivity of ~46.7 mS/cm). The measurements were conducted at approximately 25 degrees °C using a potentiostat. A plastic netting was put in the connectors of the inlet/outlets of side-plate in order to prevent the particles to be removed from the inner space/flow compartment of the side-plates. The differential pressure meters were connected directly to the side-plates, measuring the differential pressure between the opposite flow compartments/side-plates.

The inner space surface area of the side-plates A was approximately 6.7x10 cm^2 (height x width cm^2). The volume of the inner space was approximately A x Δx cm^3, with Δx being defined as the thickness of the inner space between the side wall and the side plate.

In the various experiments and simulations, two parameters were varied. First of all, a base-line or reference was established using the flow compartment size Δx of 0.2 cm. The other experiments and simulations were performed using a Δx for the flow compartment of 1.0 cm.

The second parameter was the presence and the type of flow distributor elements that were used in the flow compartments. It was assumed that changing the thickness Δx, and thus the volume of the flow compartment would affect the ionic short-cut currents. An increasing Δx was assumed to lead to increasing ionic short-cut currents.

Furthermore, it was assumed that, at a given Δx, the ionic short-cut currents would be reduced by using the flow distributor elements, since the flow distributor elements would reduce the volume of the flow compartments.

Simulations

In addition to the experiments, simulations were performed using an in-house custom-made process model (that is a mathematical approximation of the lab-stack that was used for conducting the experiments). The results are provided in Table 1-2. The difference between the experiments and the simulations was that a co-flow configuration was used in the simulation.

However, it is known that this provided similar results as when a cross-flow configuration was used with these process conditions. For the simulations as presented in Table1-2, the same stack configuration and process conditions (such as conductivity and flow rate) were assumed as in the experiments. For the simulations as shown in Table 1 empty flow compartments and a flow velocity of 1.5 cm/s were assumed. For all simulations 25 degrees °C was used. The model doesn't take into account the shape and/or size and/or material type of distributor elements, thus the simulation results of EPS and glass beads are the same.

The model, within its limitations, gives a good indication what to expect, and trends of OCV and Pd yield (indicative for ionic shortcut current losses) can be predicted quite accurately (Table1-2). The model includes among others the Bruggeman equation (Eq.1) correcting conductivity in the flow distributor/manifolds. The model assumes 40% porosity of the (packed) bed of flow distributor elements, in these examples solid glass or Expanded polystyrene (EPS) beads. Thus a reduction of 60% of the inner space/flow compartment volume of the flow distributor in the side-plates.

The conductivity in porous medium can be calculated using the emperical Bruggeman equation: conductivity in porous medium = porosity$^{1.5}$ x conductivity pore phase, thus $\sigma_B = \varepsilon_p^{1.5} \sigma_p$ (Eq. 1).

The OCV and/or the power density yield (Pd-yield) is a good indicator of the amount of parasitic ionic shortcut currents. In Table 1 the simulation results are listed. If the Pd-yield is 100% that means no ionic shortcut current losses. From Table 1. the influence of Δx of the flow distributor/flow compartment on the ionic shortcut currents can be clearly seen; the larger Δx, the lower the OCV and Pd yield, and thus higher ionic shortcut current losses. Also the strongest decrease in Pd yield and OCV, in this example, is in approximately the first 2 mm.

It is known that a larger thickness Δx (and consequently the volume) of the flow compartment of the side-plates gives a more uniform flow distribution in the membrane stack, yet also increases the ionic short-cut currents. This is also observed in the results presented in table 1, in which it is clear that the open circuit voltage (OCV) and the Pd-yield reduce with increasing Δx.

Table 1. Simulations (1.5 cm/s; N=50)

ΔX (cm)	OCV (V)	Pd_ yield (%)
0.020	7.35	93.00
0.050	6.72	85.81
0.100	6.07	78.10
0.200	5.37	69.73
0.250	5.16	67.20

0.300	5.00	65.25
0.400	4.77	62.45
0.500	4.61	60.53
0.800	4.34	57.25
1.000	4.25	56.03

Experiment 1

In experiment 1, the experiment was performed using $\Delta x = 0.2$ cm and an empty flow compartment (i.e. without flow distributor elements). The results are shown in Table 2.

Table 2. (N=50)		Experiments					Model simulations		
Δx flow compartment (cm)	velocity (cm/s)	OCV (V)	Pd (W/m²)	$R_{internal}$ (ohm)	ΔP (Low) (mbar)	ΔP (High) (mbar)	OCV (V)	Pd (W/m²)	Pd_yield (%)
0.2 (Empty)	0.25	4.5	0.20	25.1	2	14	5.0	0.29	71.25
0.2 (Empty)	1.50	4.9	0.25	24.0	16	70	5.4	0.36	69.73
1.0 (Empty)	0.25	3.8	0.20	18.7	1	8	3.9	0.23	58.04
1.0 (Empty)	1.50	4.3	0.24	19.0	14	44	4.2	0.29	56.03
1.0 (Glass beads)	0.25	4.6	0.31	16.7	<=1	<=1	4.8	0.28	68.82
1.0 (Glass beads)	1.50	5.0	0.36	17.3	9	17	5.2	0.35	67.20
1.0 (EPS beads)	0.25	4.4	0.26	19.0	<=1	<=1	4.8	0.28	68.82
1.0 (EPS beads)	1.50	4.9	0.31	19.3	12	19	5.2	0.35	67.20

Experiment 2

In experiment 2, a similar set-up was used as in experiment 1, although Δx was now 1.0 cm. Experimental and simulation results are tabulated in Table 2.

Again, the OCV and Pd-yield give a clear indication of the amount of parasitic ionic shortcut currents. From the results in Table 2 it is clear that using the 1.0 cm thick flow compartments, a significant lower OCV is obtained than with the 0.2 cm flow compartment which indicate higher losses due to parasitic ionic shortcut currents. Also an ink injection test was performed (not shown) showing that the flow distribution in the empty flow compartment was not very homogeneous/uniform.

Experiment 3

In experiment 3, a similar set up was used as in experiment 2, although the flow compartments were now filled up with solid glass beads (Vitrosphere, approximately 1.1-2.5 mm diameter). Due to the use of a standard lab-stack that was not optimised for the use of flow distributor elements (for instance the position of opening to fill up the flow compartment was not optimised), a small part of the corner(s) of the flow compartments was not filled with the beads. The simulation and experimental results are shown in Table 2.

Comparing the results from experiment 2 and experiment 3, it can be clearly seen that filling up the flow compartments with glass beads, leads to a significantly improved performance. This can be deduced from the fact that the OCV was at least 17% higher and the Pd-yield was at least 49% higher, which is indicative that the ionic short cut losses are significantly reduced.

In an more optimised flow distributor/manifold system, with a better filled up flow compartment, an even better result may be obtained. Again, an ink injection test was performed (not shown), which showed that the flow distribution in the flow compartment of experiment 3 was more uniform than with the empty flow compartment in experiment 2. The net pressure drop even decreased slightly. This is probably attributed to better flow distribution and/or more effective elimination of trapped air in the spacers.

Experiment 4

In experiment 4, a similar setup was used as in experiment 3. although the glass beads were replaced with light expanded polystyrene beads (approximately 2-3 mm diameter). The results are shown in Table 2.

The results were similar with the results obtained with the glass beads in terms of performance. The EPS beads significantly improved the performance, leading to about 15% higher OCV and about 30% higher Pd-yield. The small difference compared to the results with glass beads are most likely due to the larger bead sizes and/or a slightly lower packing density.

An ink injection test was performed (not shown), which showed that the flow distribution in the flow compartment of experiment 4 was more uniform than with the empty flow compartment in experiment 2. A practical and economical advantage of EPS beads over glass beads is that EPS beads are cheaper and lighter, thus reducing costs and weight of the membrane assembly.

Comparing the pressure drops of experiments 1 – 4 (Table 2), it can be concluded that packing the flow compartment in the side-plates with flow distributor elements leads to a substantially equal or even slightly lower overall pressure drop. This is indicative of a better flow distribution and/or more efficient removal from air which might be trapped in the netting of the spacers.

Experiment 5

In order to show the influence of the distributor elements when packed in the flow compartments, some illustrative calculations were performed using the Ergun equation (Eq.2) often used to calculated the pressure drop ΔP in packed beds.

$$\Delta P = \frac{150\,\mu\,L}{D^2}\frac{(1-\epsilon)^2}{\epsilon^3}v + \frac{1.75\,L\,\rho}{D}\frac{(1-\epsilon)}{\epsilon^3}v^2 \quad \text{(Eq. 2)}$$

In equation 2, ΔP is pressure drop across (packed) bed (Pa); ε, void fraction/porosity of(packed) bed; μ, dynamic viscosity of fluid (Pa s); ρ, density fluid (kg/m3); L length (m) of (packed)bed; v superficial velocity fluid (m/s); D equivalent spherical diameter (m) of the distributor elements (in the experiment calculations spherical beads are assumed). Three different calculations were performed in this experiment.

Experiment 5.1

In experiment 5.1, the influence of distributor element size was evaluated. The conditions used for performing the experiment are substantially similar as experimental conditions used in the experiments with glass beads as provided above. Assuming a superficial flow velocity of 2.7 cm, an estimated bed height (the flow compartment in side-plate) of 6.7 cm, a void fraction of 0.4 (porosity 40%), dynamic viscoscity of 0.001 Pa S, density of 1000 kg/m3, the pressure drop was calculated according to Eq. 2 with two different glass bead diameters. With a glass bead diameter of 2.5 mm, the pressure drop is 5.6 mbar, which is rather low. With a glass bead diameter of 1.1 mm, the pressure drop would be 19.9 mbar, which is still rather low. This shows that there is an effect of size on the pressure drop in flow compartments packed with flow distributor elements. Thus, the size of distributor elements should be considered when designing. It should be noted that in a real stack the superficial flow velocity in the flow compartment is not constant due to the fact that the fluid flows into the membrane stack along the flow path. The fluid flow into the membrane stack results in the pressure drop in the flow compartments of a real stack under these conditions being substantially lower than these calculated values.

Experiment 5.2

Experiment 5.2 evaluated the effect of porosity: the settings are similar as experiment 5.1 with 2.5 mm glass beads, with the only difference the porosity, which is now set as 50%. Changing the porosity to 50% (void fraction of 0.5) will give a pressure drop of 2.2 mbar according to Eq.2. Changing the porosity to 35% will give a calculated pressure drop of 9.5 mbar.

Experiment 5.3

Experiment 5.3 evaluated the influence of superficial flow velocity: the settings are similar as calculation 1 with 2.5 mm glass beads, with the only difference the superficial flow velocity, which is now set at 5.4 cm/s. Increasing the velocity to 5.4 cm/s will give a calculated pressure drop of 17.7 mbar.

The present invention is by no means limited to the above described preferred embodiments thereof. The rights sought are defined by the following claims, within the scope of which many modifications can be envisaged.

CLAIMS

1. Flow distributor for a membrane stack of a stack assembly, the flow distributor comprising:
   - a housing comprising an inner space, wherein the inner space is operatively connectable to a number of flow openings of a membrane stack; and
   - a plurality of flow distributor elements, wherein the plurality of flow distributor elements is at least partially positioned in the inner space and fill at least part of the inner space; and

   wherein the flow distributor is configured to be positioned in a fluid flow path of a stack assembly such that a flow of fluid at least partially flows through the plurality of flow distributor elements, and wherein the fluid flow path extends from at least one feed opening towards at least one discharge opening.

2. Flow distributor according to claim 1, the housing further comprising:
   - a main flow opening; and
   - a number of membrane flow openings that are positioned adjacent openings of a membrane stack with which the flow distributor is associated;

   wherein the main flow opening is configured to provide a feed flow to the inner space and the number of membrane flow openings is configured for providing a fluid flow to the membrane stack and/or membrane cells in the membrane stack; and/or
   wherein the number of membrane flow openings is configured for providing a discharge fluid flow from the membrane stack and/or membrane cells in the membrane stack to the inner space and the main flow opening is configured to discharge a fluid flow from the inner space.

3. Flow distributor according to any one of the preceding claims, wherein the plurality of flow distributor elements is positioned at or near at least a part of a number of flow openings of a membrane stack.

4. Flow distributor according to any one of the preceding claims, wherein the flow distributor elements are provided with a coating, preferably a (nano)coating with hydrophilic or hydrophobic properties.

5. Flow distributor according to any one of the preceding claims, wherein the plurality of flow distributor elements comprises a first plurality of flow distributor elements having a first size and a second plurality of flow distributor elements having a second size, wherein the first size and the second size are different.

6. Flow distributor according to any one of the preceding claims, wherein the flow distributor elements are provided with at least two groups of elements, wherein a first group of elements is manufactured from a first material and a second group of elements is manufactured from a second material, wherein the materials cooperate to provide the elements of the groups of elements with a static electric charge.

7. Flow distributor according to any one of the preceding claims, wherein the flow distributor elements are manufactured from a non-ionically conducting and/or non-electrically conducting material.

8. Flow distributor according to any one of the preceding claims, wherein the elements are manufactured from glass, wood, plastic, including PE, PP, PVC, PET, PC, PS, PTFE, PVDF, an elastomer, including rubber and silicons, a ceramic including alumina-oxide and silica-dioxide, carbon, graphite, an ion exchange resin or a combination of these materials.

9. Flow distributor according to any one of the preceding claims, wherein the flow distributor elements have a size in the range of 10 micrometer – 100 millimeter, and preferably in the range of 0.1 mm – 75 mm, and more preferably in the range of 0.5 mm – 50 mm.

10. Flow distributor according to any one of the preceding claims, wherein the flow distributor elements are made of a material that is compressible under pressure.

11. Flow distributor according to any one of the claims 1 – 9, wherein the flow distributor elements are made of a material that is substantially incompressible.

12. Flow distributor according to any one of the preceding claims, wherein the flow distributor elements have substantially spherical shape and/or ellipsoid shape.

13. Flow distributor according to any one of the preceding claims, wherein the flow distributor elements comprise elongated elements, and preferably comprise elongated cylindrical elements.

14. Stack assembly for a membrane stack, the stack assembly comprising:
    - a membrane stack having a number of membranes;
    - a flow distributor comprising a plurality of flow distributor elements; and

- a flow path configured for guiding a fluid flow through the membrane stack of the stack assembly, wherein the flow path extends from at least one feed opening to at least one discharge opening, wherein, viewed from the at least one feed opening in a downstream direction of the flow path, the flow path includes a number of upstream flow openings in the membrane stack, the membranes, a number of downstream flow openings, and the at least one discharge opening;

wherein the plurality of flow distributor elements is positioned in at least part of the fluid flow path between the feed opening and the number of upstream flow openings and/or between the number of downstream flow openings and the discharge opening, such that a flow of fluid that is fed to the stack assembly passes through the flow distributor.

15. Stack assembly according to claim 14, the stack assembly comprising a flow distributor according to any one of the claims 1 – 13, wherein the flow path extends at least partially through the flow distributor, and wherein the plurality of flow distributor elements is positioned in the flow distributor.

16. Flow distributor element, configured to be included in a plurality of flow distributor elements that is positioned in an inner space of a flow distributor for filling at least part of the inner space and/or is configured to be included in a plurality of flow distributor elements that is positioned in at least part of a fluid flow path that extends between a fluid feed opening of a stack assembly and an associated number of upstream flow openings of a membrane stack and/or between a number of downstream flow openings of a membrane stack and an associated discharge opening of a stack assembly, such that a flow of fluid that flows through the stack assembly passes through the plurality of flow distributor elements.

17. Method for generating energy and/or desalinating a fluid, the method comprising the steps of:
- providing a stack assembly according to any one of the claims 14 – 15;
- feeding a flow of fluid to the feed opening of the stack assembly; and
- discharging the flow of fluid from the discharge opening of the stack assembly;

wherein, the flow of fluid, during operation is guided through the plurality of flow distributor elements before entering the membrane stack and/or after exiting the membrane stack.

18. Method for manufacturing a stack assembly comprising a flow distributor, the method comprising the steps of:
- providing a flow distributor comprising a plurality of flow distributor elements;
- providing a membrane stack;

- providing a stack assembly having an inner space in which the membrane stack and the flow distributor elements are positionable, wherein the stack assembly is provided with a fluid flow path that extends from an inlet to an outlet and being configured to accommodate a fluid flow;
- inserting the membrane stack in the inner space of the stack assembly; and
- inserting the flow distributor in the fluid flow path between the inlet and the membrane stack and/or between the membrane stack and the outlet.

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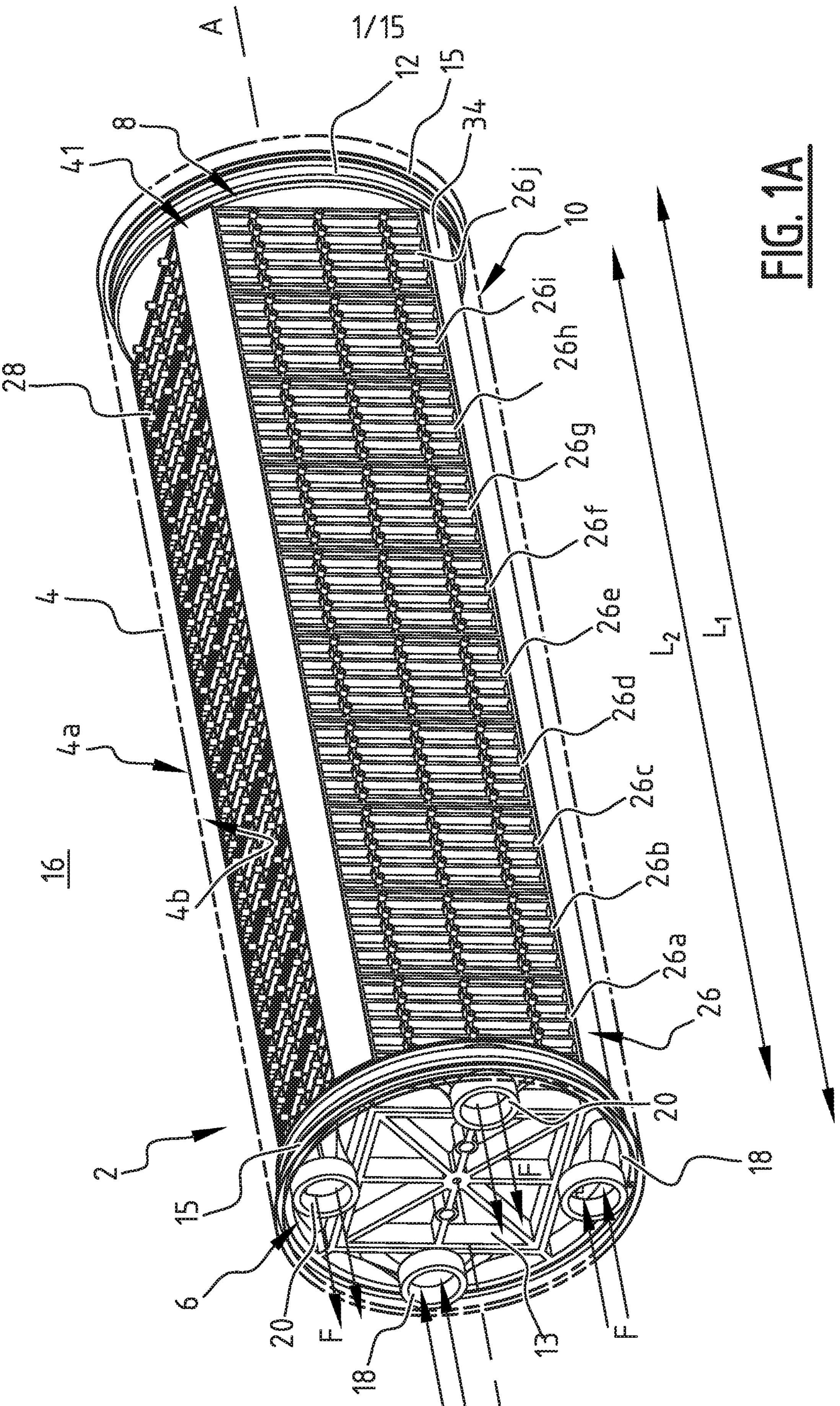
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F

FIG. 1A

2/15

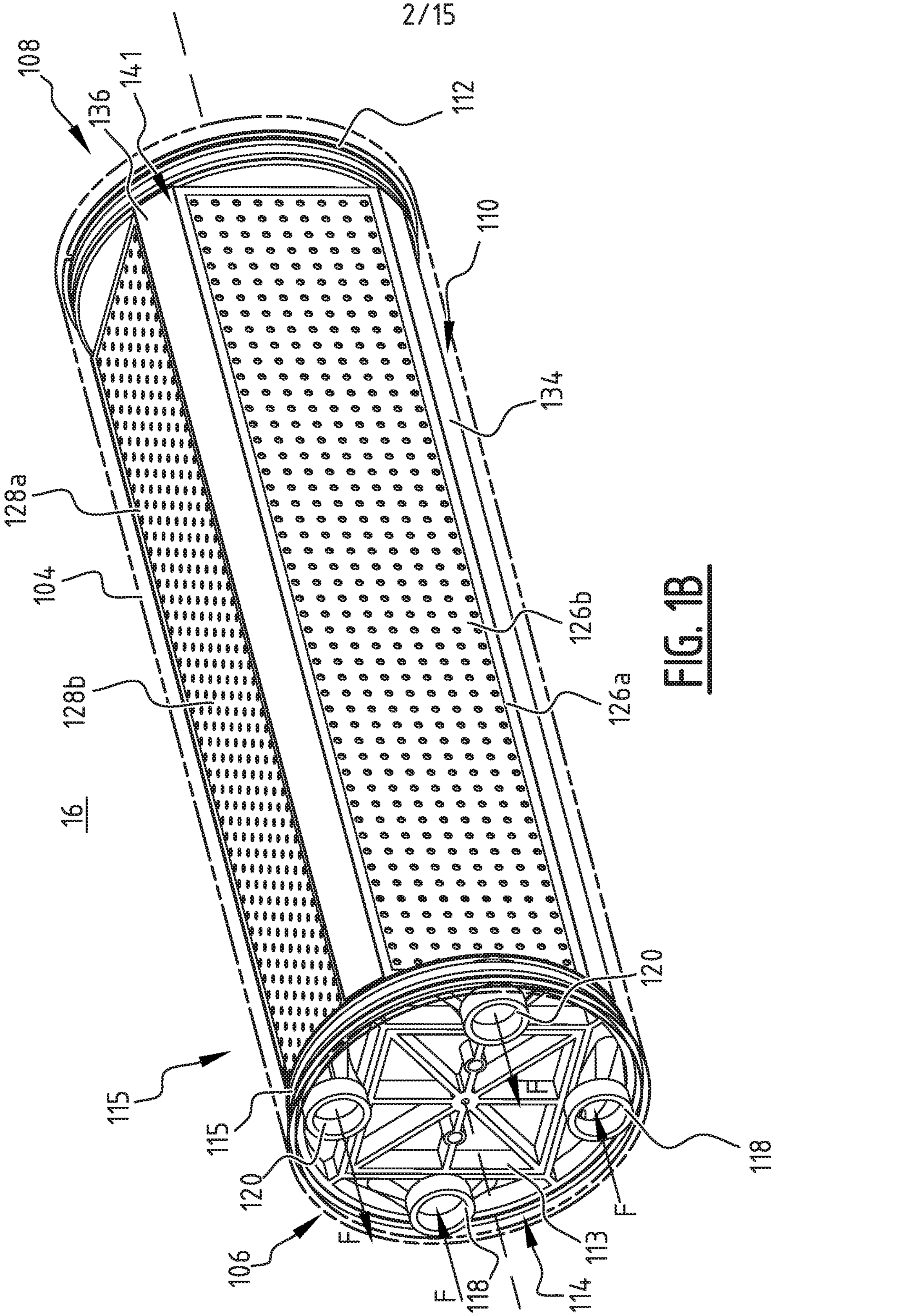
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FIG. 1B

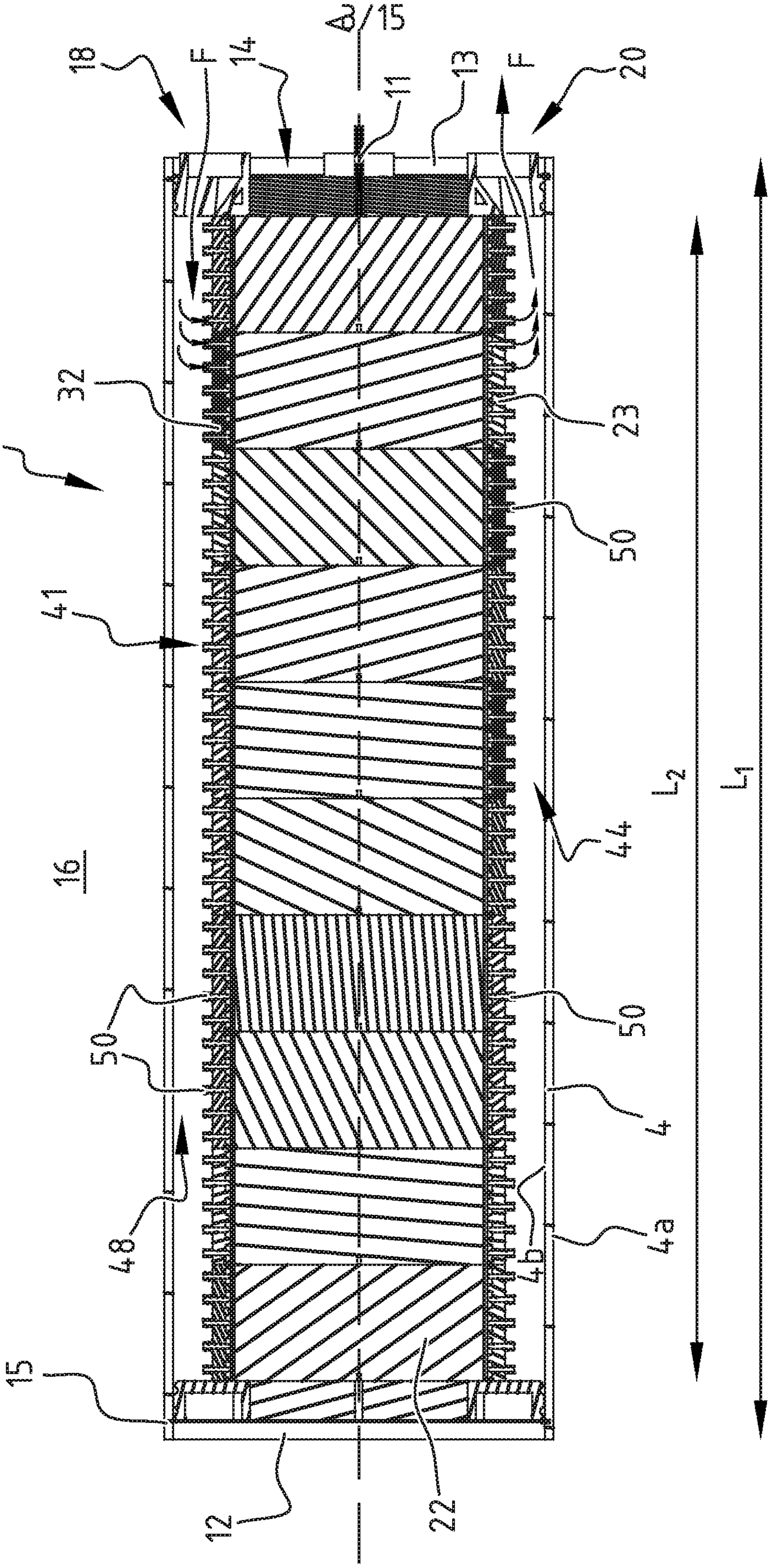
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FIG. 2A

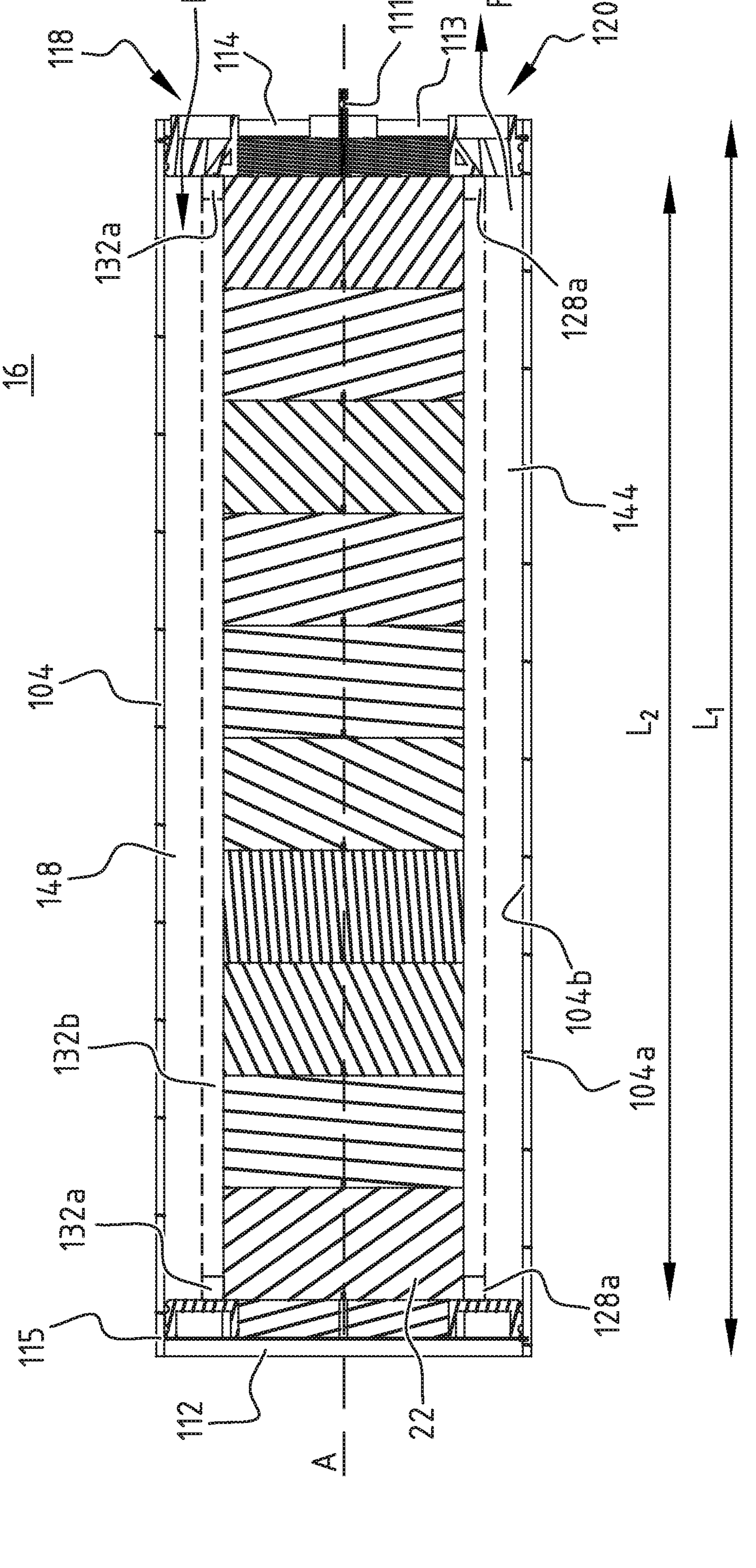

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FIG. 2B

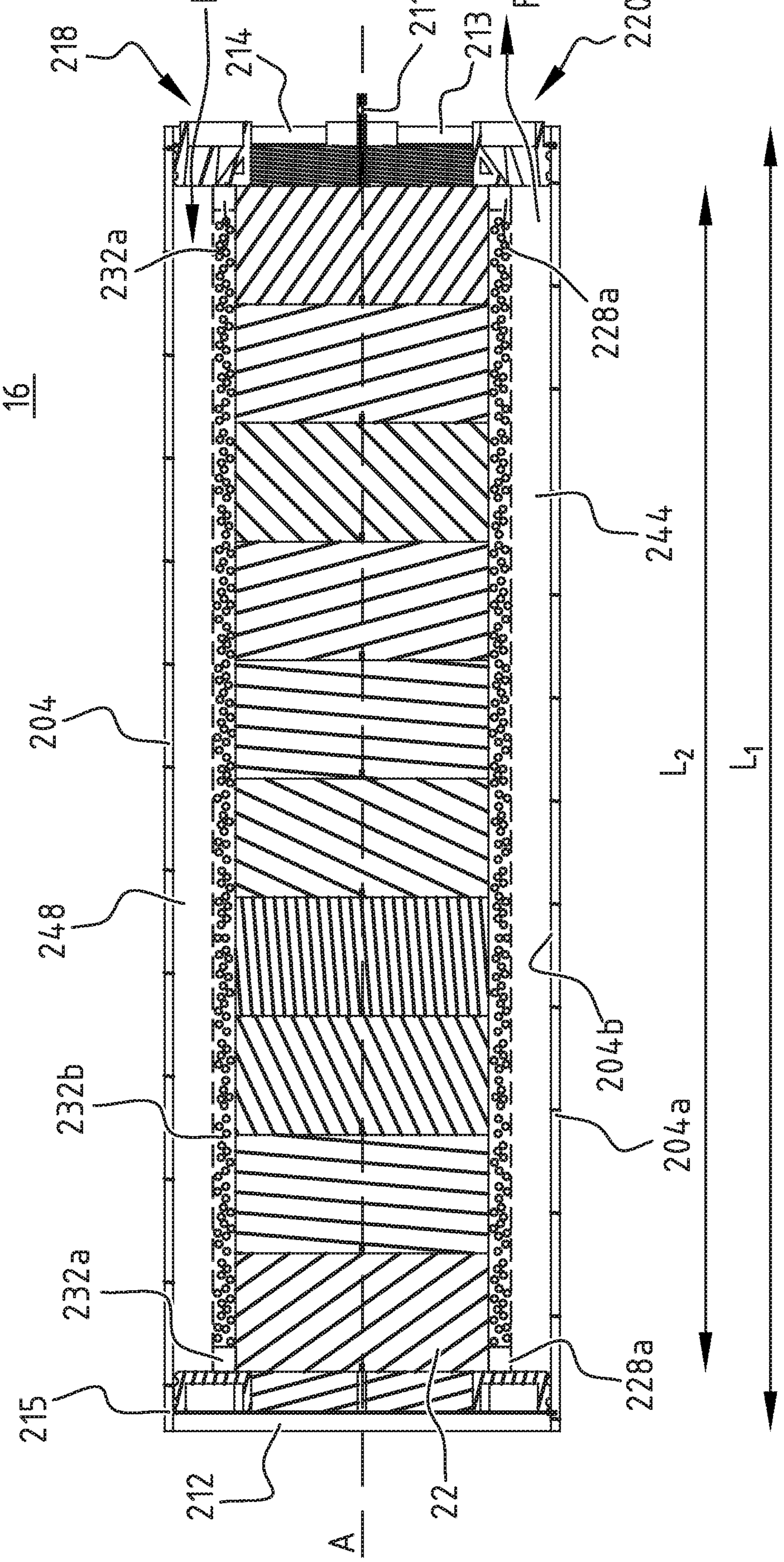
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FIG. 2C

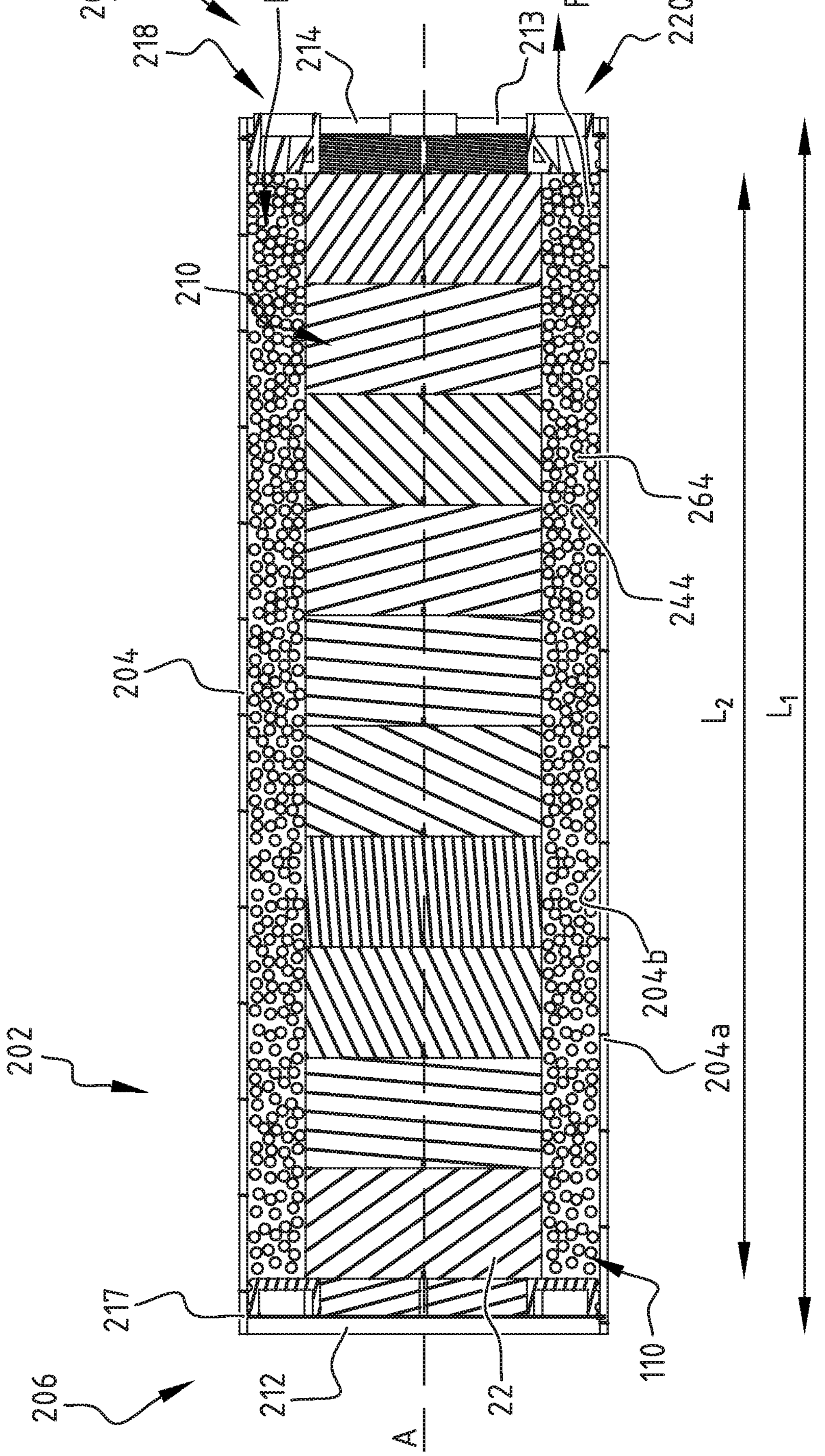
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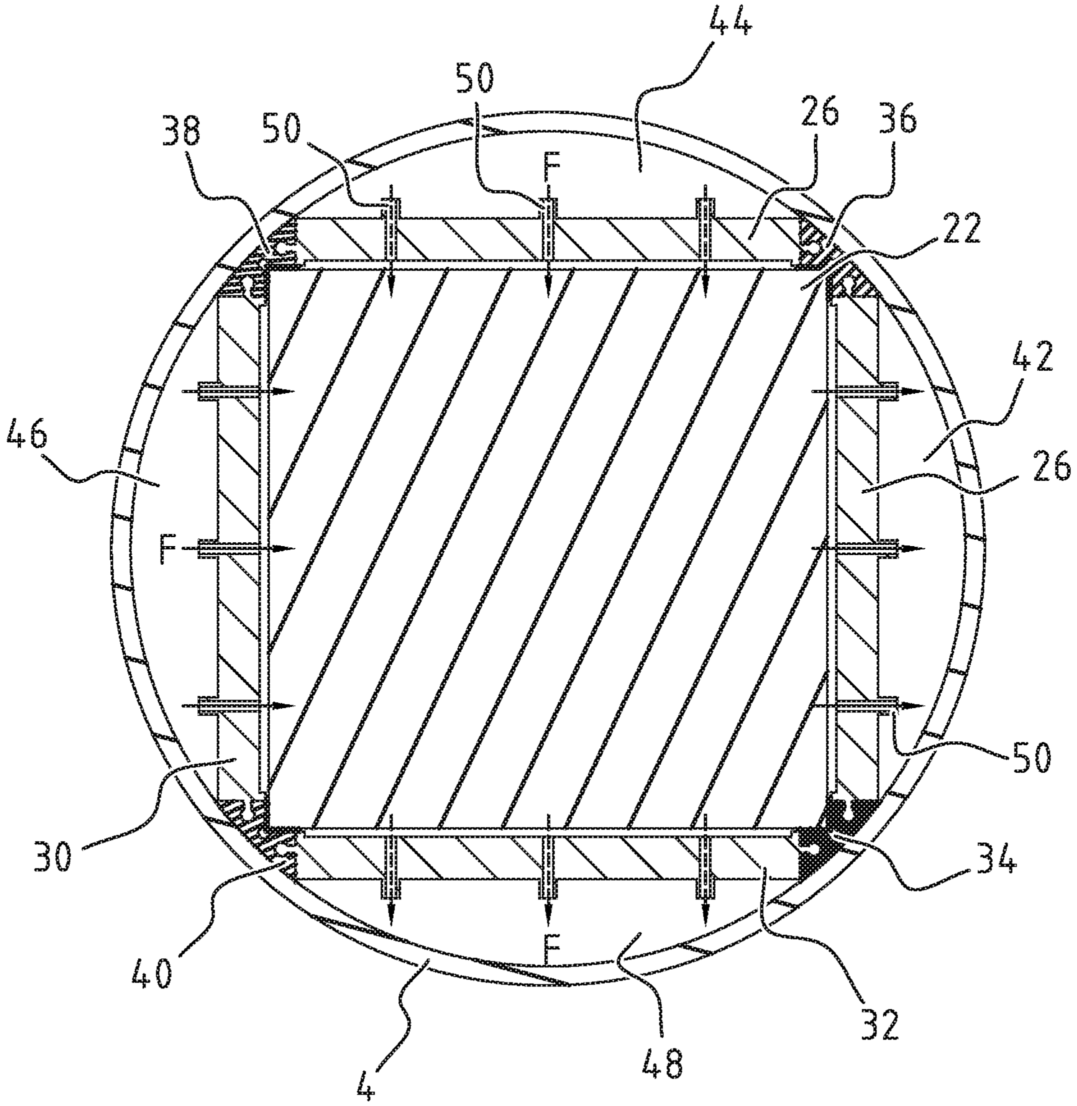
FIG. 2D



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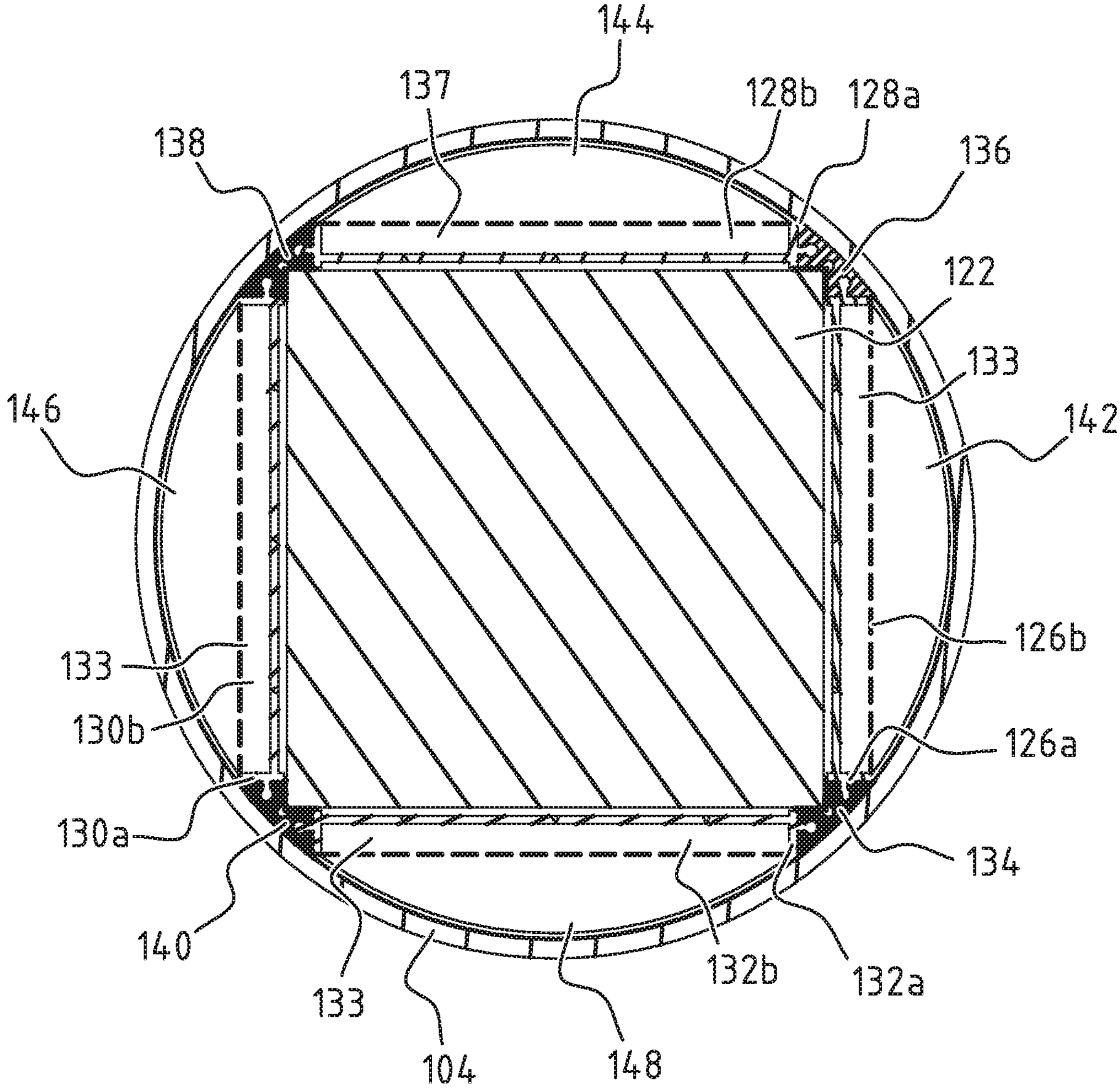
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FIG. 3B

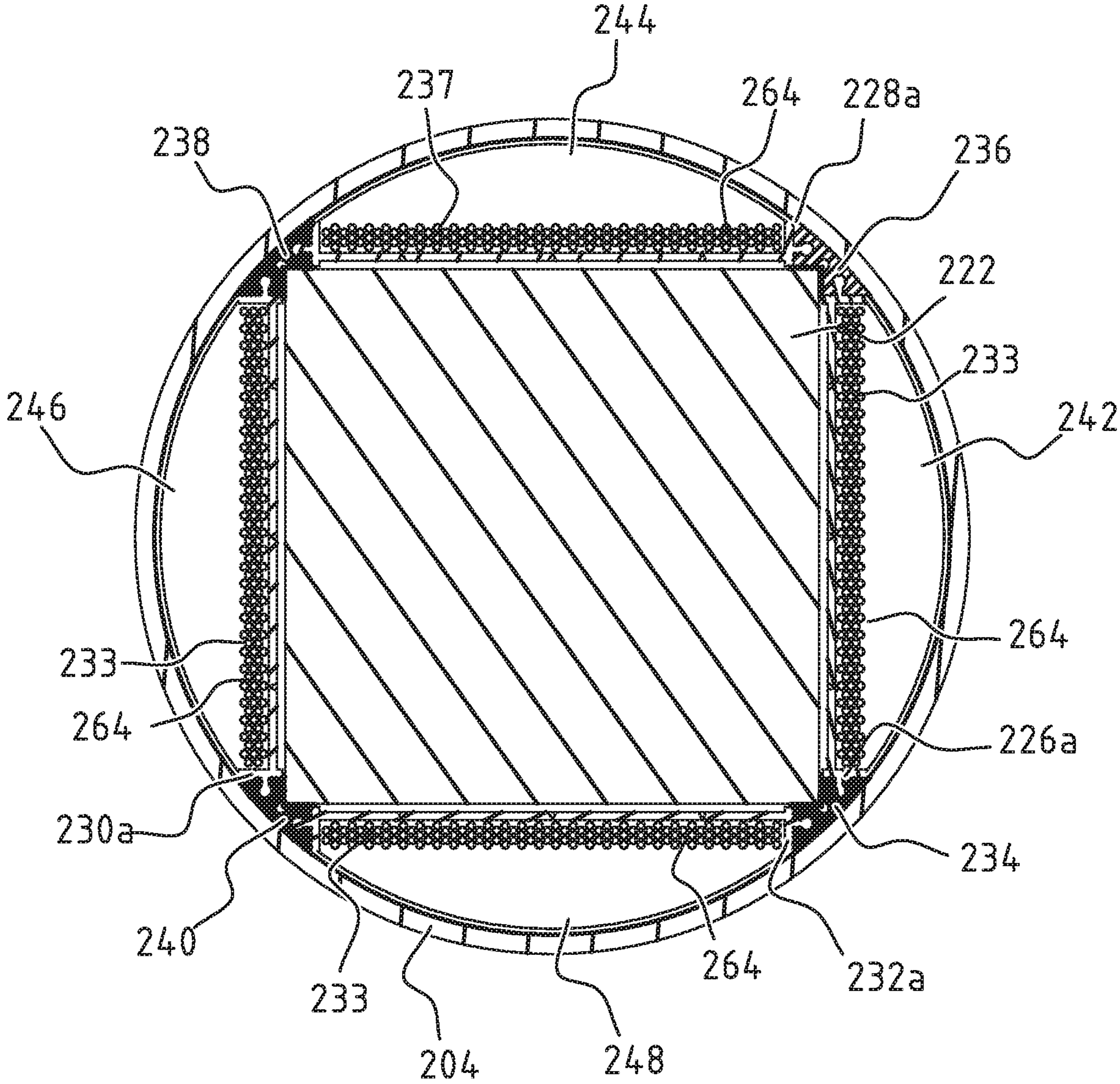
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FIG. 3C

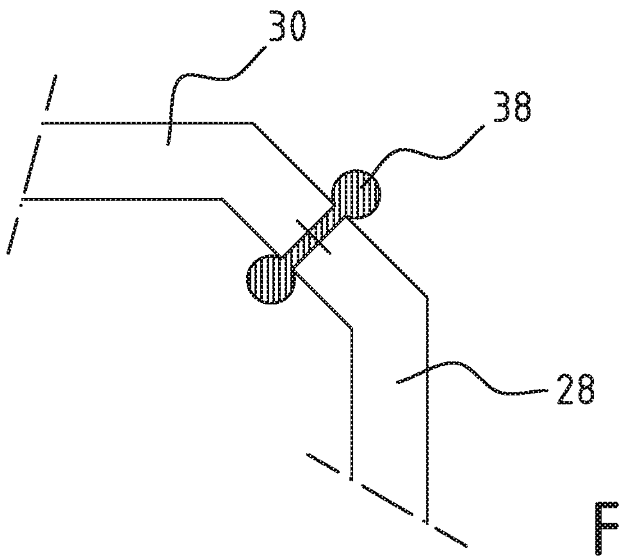

FIG. 3D

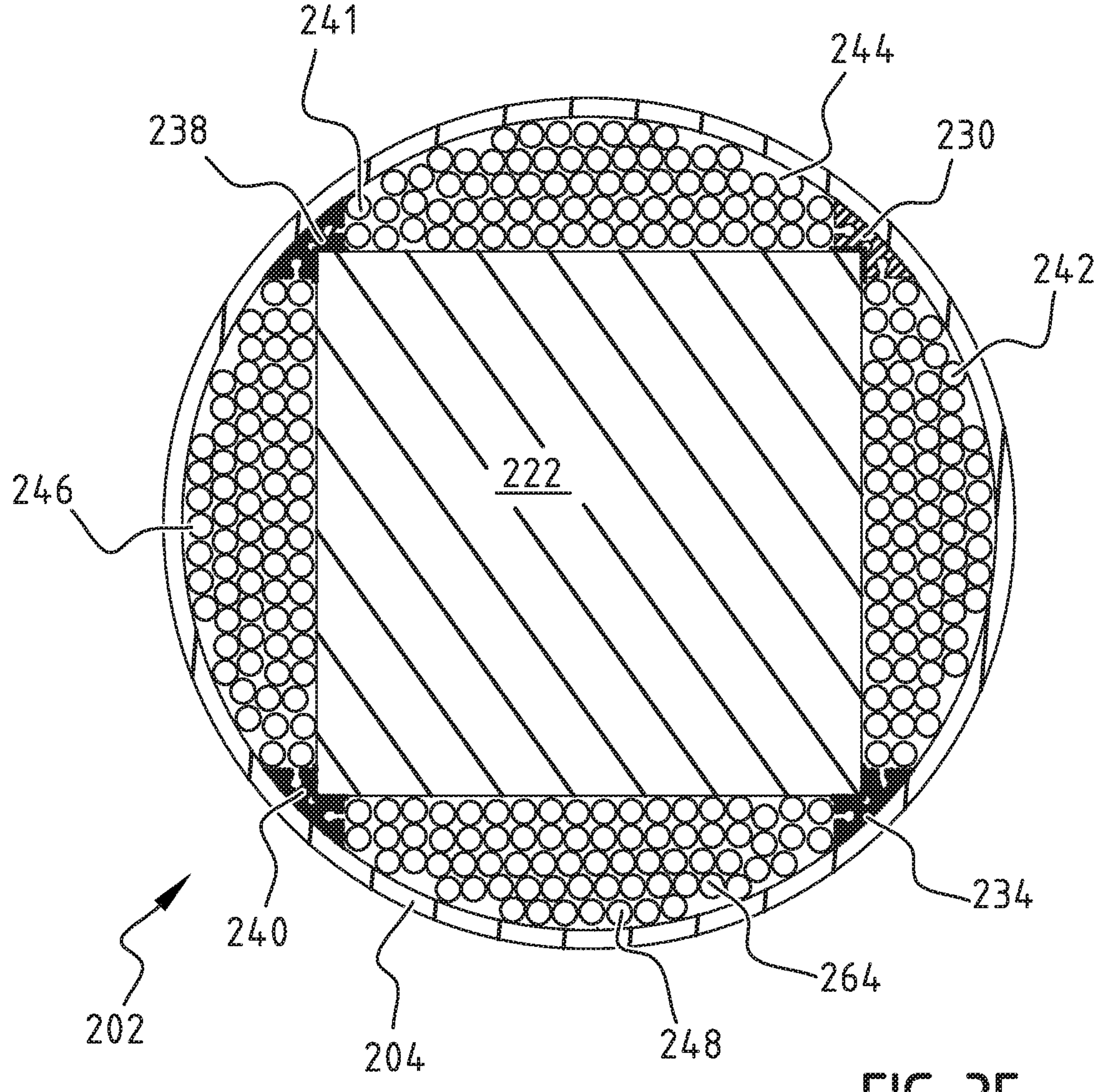

FIG. 3E

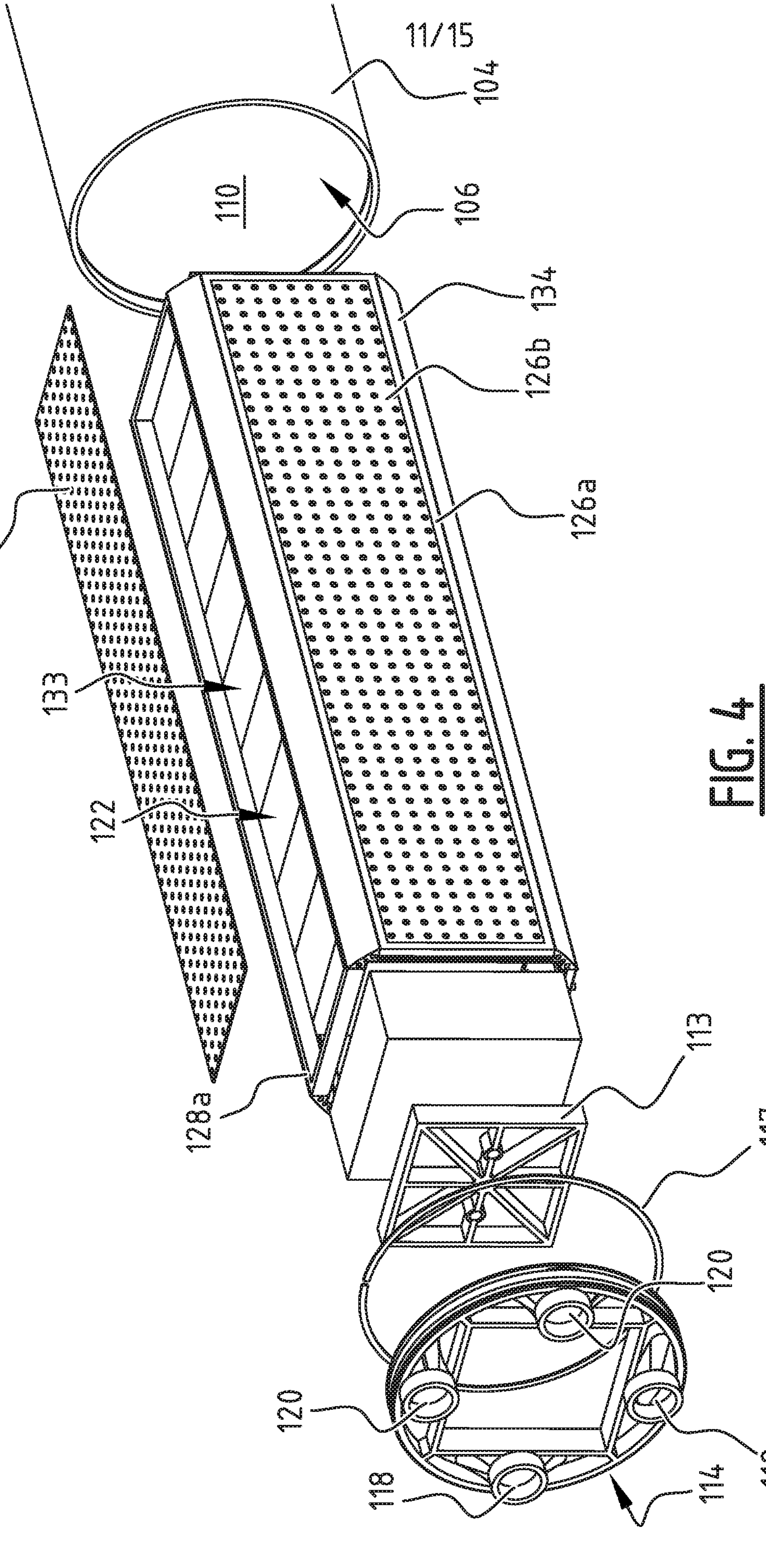
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FIG. 4

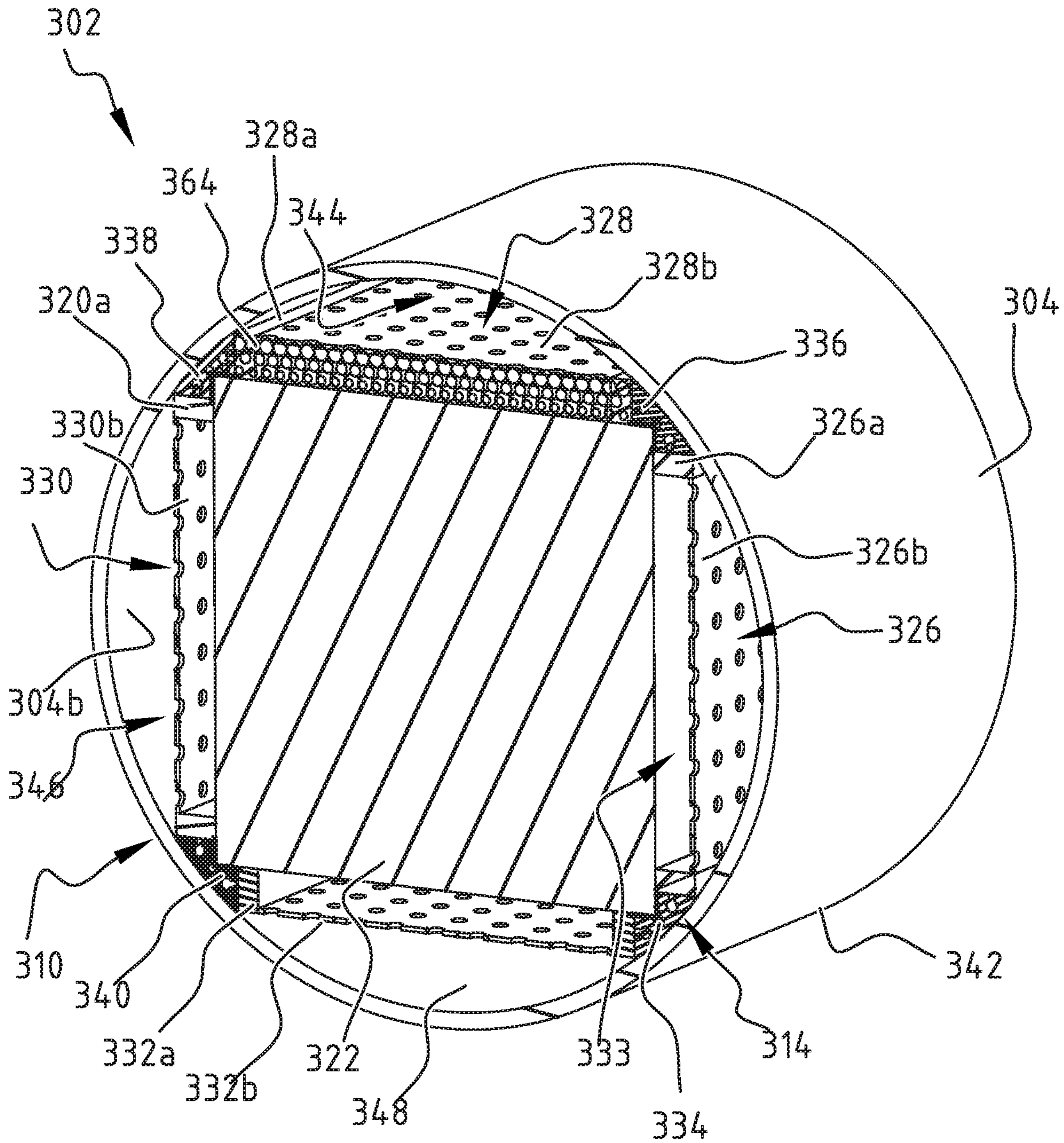
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FIG. 5

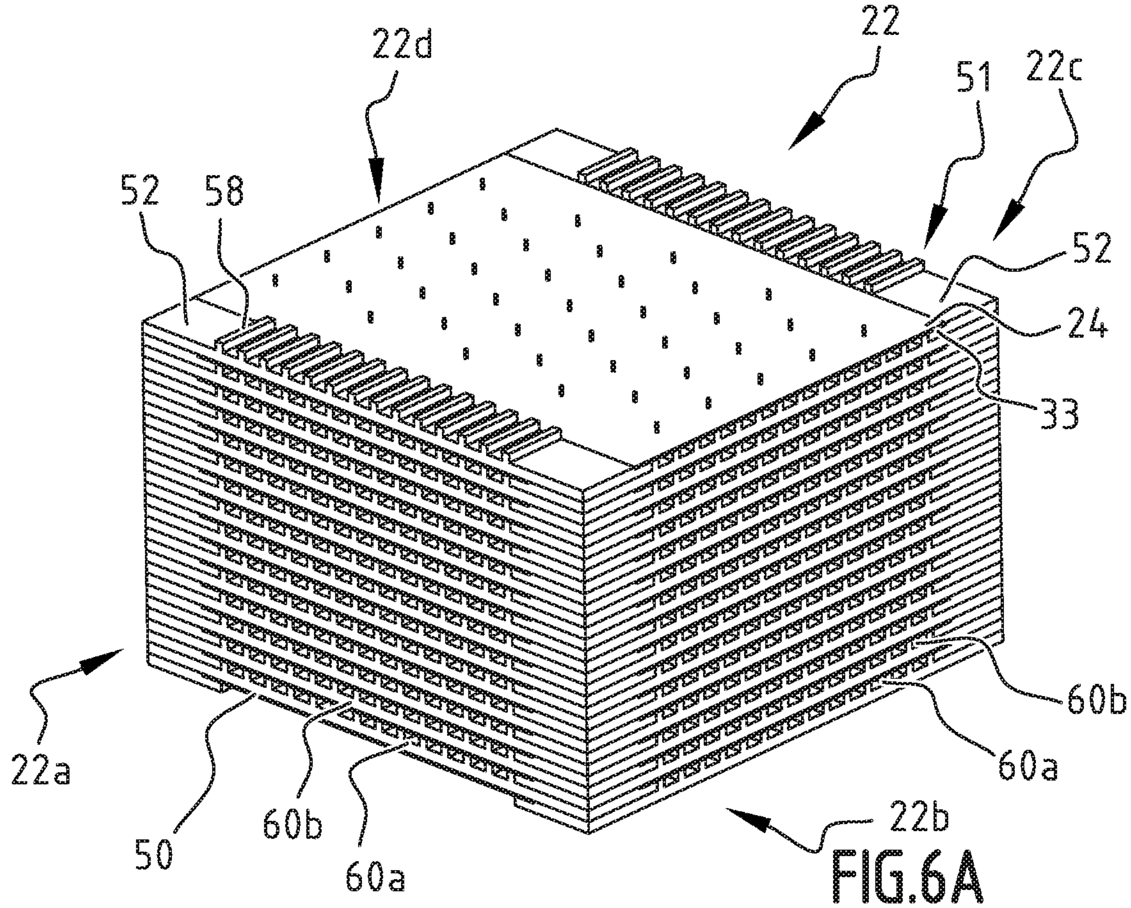
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FIG.6A

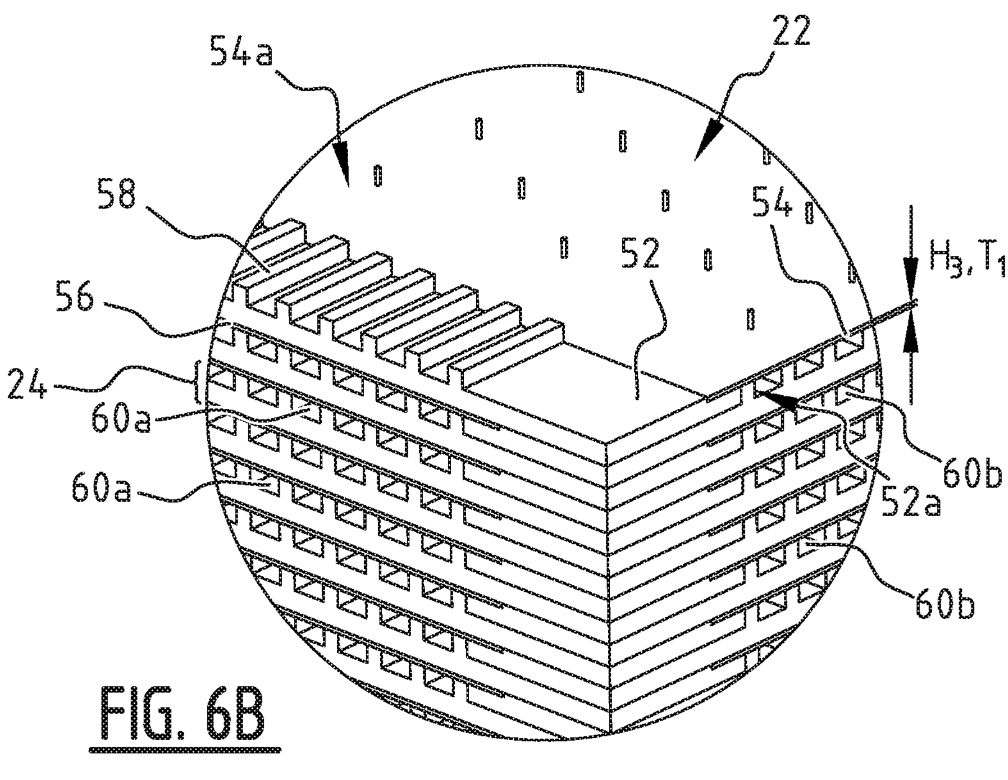
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FIG. 6B

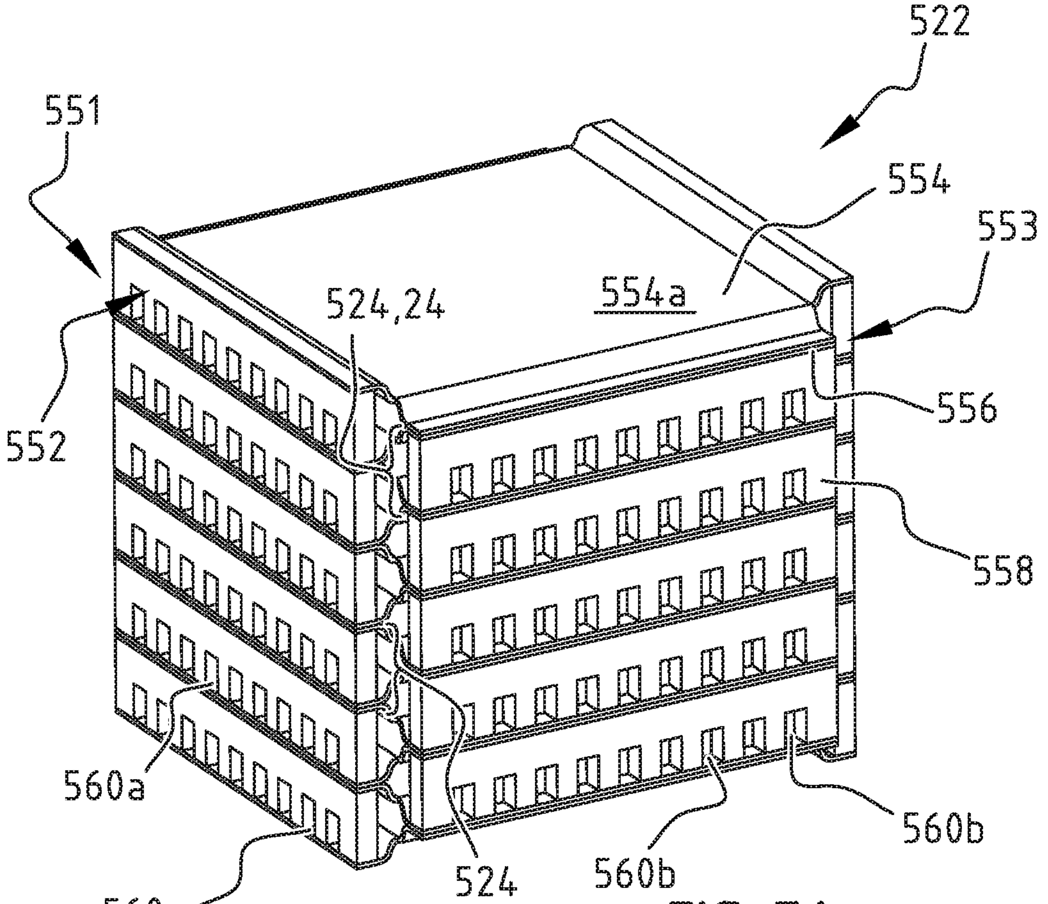
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FIG. 7A

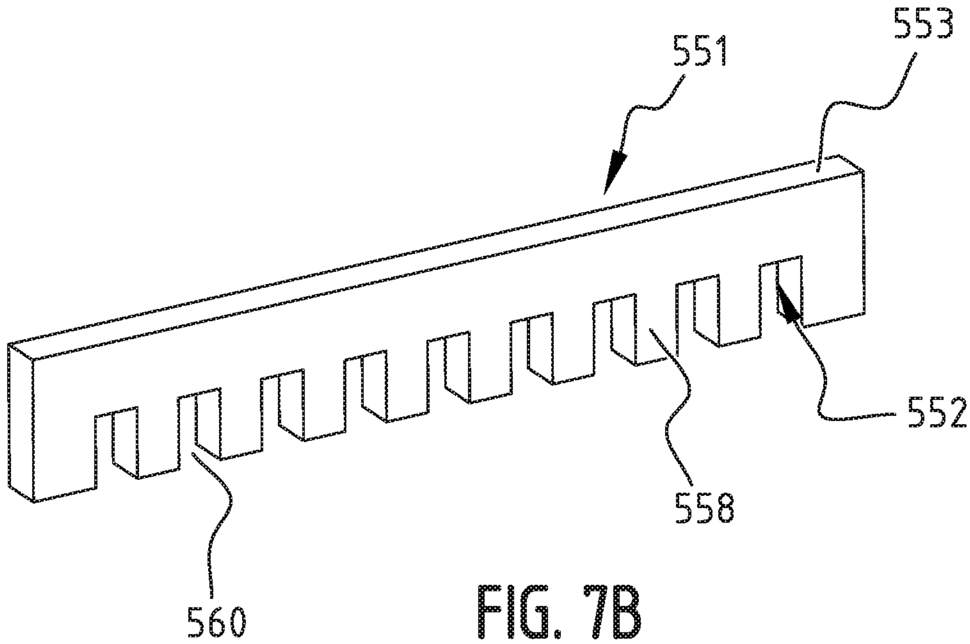
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FIG. 7B

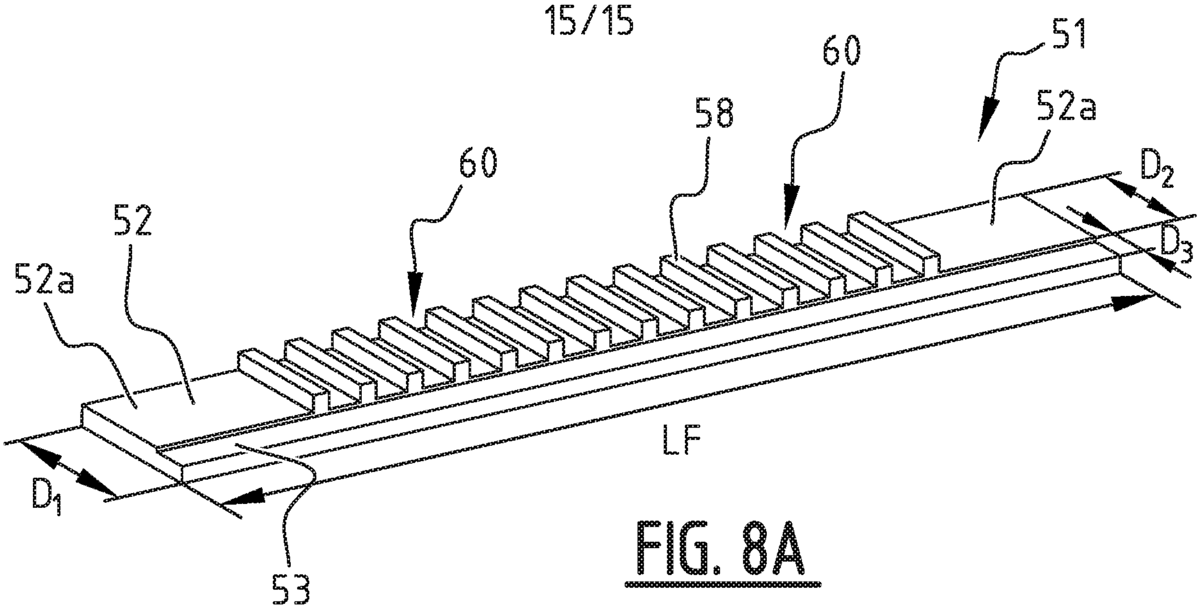

FIG. 8A

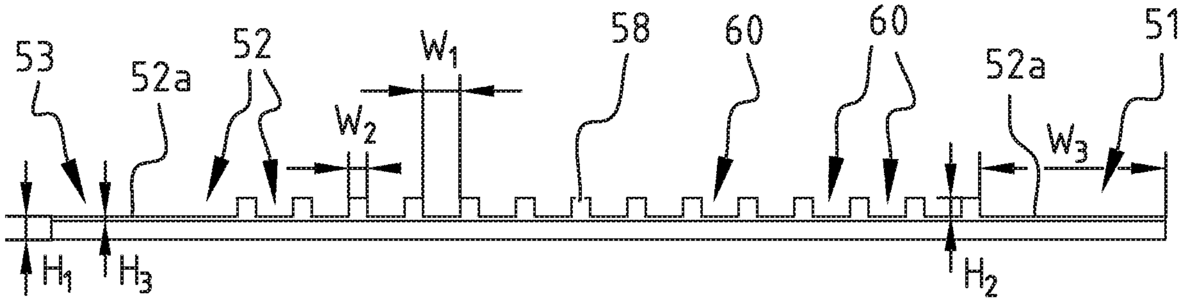

FIG. 8B

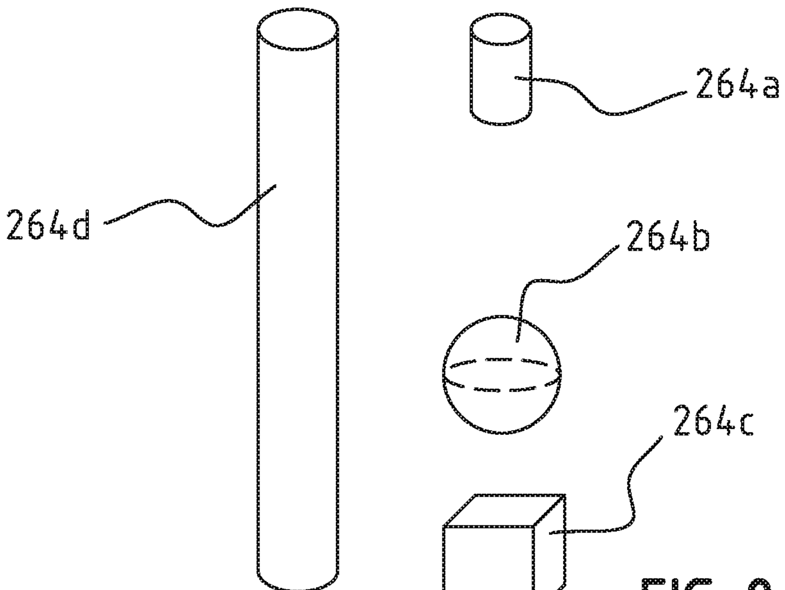

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2019/050420

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01D61/50 B01D63/08 H01M8/22
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B01D H01M

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2016/009573 A1 (EVOQUA WATER TECHNOLOGIES LLC [US]; LIANG LI-SHIANG [US]) 14 January 2016 (2016-01-14) paragraphs [0064], [0073], [0084], [0094]; figures 2,8,10,13-14A, 16-17 -----	1-18
X	EP 1 676 624 A2 (AIR PROD & CHEM [US]) 5 July 2006 (2006-07-05) paragraphs [0073], [0143], [0150], [0157]; claim 8; figures 1,5,18 -----	1,3,5-18
X	US 2012/117789 A1 (LIANG LI-SHIANG [US] ET AL) 17 May 2012 (2012-05-17) paragraphs [0056], [0094]; figures 16-20 ----- -/--	1-18

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 September 2019	09/10/2019

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2019/050420

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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1

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Information on patent family members

International application No
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