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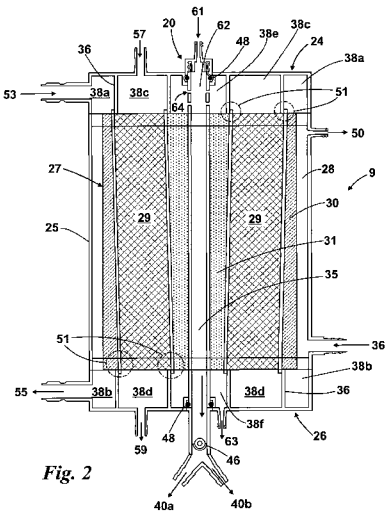

Fig. 2

(57) Abstract: An oxygenator for extracorporated treatment of blood, the oxygenator comprising an internal haemodialyser or haemoconcentrator, or a haeomodialyser or haemoconcentrator for extracorporeal treatment of blood, the haemodialyser comprising an integral oxygenator.

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EXTRACORPOREAL MEMBRANE OXYGENATION

The invention relates to extracorporeal membrane oxygenation (ECMO).

ECMO is a known technique for oxygenating blood. Blood that has been removed from a patient is passed adjacent a membrane, and oxygen is passed on the opposing side of the membrane. Oxygen diffuses, or is forced, across the membrane and into the blood, whilst carbon dioxide diffuses, or is otherwise drawn, out of the blood. The re-oxygenated blood can then be returned to the patient.

ECMO is most commonly used in an operating theatre where a patient with a severely damaged heart or lung(s) is undergoing surgery. A patient treated for cardiac and/or respiratory problems may be connected to a machine known as a heart lung machine, which provides oxygen to their blood as it flows through an extracorporeal circuit, while a procedure is performed upon them, such as open heart surgery. This allows the patient to be kept alive whilst their own heart or lungs are not functioning correctly, or at all.

The correct operation of a heart lung machine is essential to avoid the risk of severe injury or the death of the patient. Such machines are usually operated by a fully qualified individual known as a perfusionist, whose sole responsibility is the operation of the machine, rather than the care of a patient.

Very occasionally, heart lung machines can be found in intensive care units, and can be used to allow a patient having badly damaged lungs to rest their lungs whilst they recover.

It is more usual, however, for patients in intensive care who have poor blood oxygenation or carbon dioxide transfer to be ventilated using a ventilator. Such a device involves supplying positive pressure, high oxygen-content gas (sometimes as high as 100% oxygen) to the patient's own lungs, possibly via a mask. Alternatively, a patient may be intubated, wherein pressurised oxygen is supplied directly to the patient's lungs via a tube inserted into the patient's trachea.

There are many disadvantages to ventilation and intubation, not least because those techniques require the patient's own lungs to perform the oxygen/carbon dioxide transfer function. If the patient's own lungs are damaged, this does not allow their lungs to rest, and the high pressure oxygen itself may cause additional damage to the lungs, including collapse, perforation and haemorrhaging. In addition, intubation and ventilation can provide a route of ingress for infection.

It is known that patients supplied with high pressure oxygen rich gas (for example, more than 50% oxygen) for more than 24 hours have a very high mortality rate. Despite these known disadvantages to ventilation, clinicians continue to provide high pressure oxygen to patients in this way, because there is no real alternative way of supplying oxygen to a patient on a ward, such as intensive care. Ensuring that a patient gets sufficient oxygen is essential to avoid damage to the brain.

Dialysis machines are commonly found on wards, and can be used by trained nursing staff. It is not uncommon for a seriously ill patient to require both dialysis and ventilation. In some cases ECMO is required, and it is known to connect an ECMO machine to a dialysis machine. The connection is achieved using exterior tubing to connect the two machines together. However, there is a risk that such tubing may disconnect, or that blood may pool in loops in the tubing, which may result in clotting in

the patient. Either of those occurrences would result in very serious complications for the patient, such that machines connected in this way must be monitored continually by a nurse. Thus a patient connected to a dialysis machine and an ECMO machine in this way requires at least two nursing staff, one to attend the patient, and one to attend the machines.

It is estimated that there are only 20 ECMO machines in 4 centres in the UK, while approximately 25 thousand open heart operations are performed in 60 centres around the UK. The demand for these machines is such that they are rarely used on a ward, especially in view of the requirement for the machine to be supported by its own trained operator.

It is an object of the invention to alleviate some or all of the above problems.

According to a first aspect of the invention there is provided an oxygenator for extracorporeal treatment of blood, the oxygenator comprising an integral haemodialyser or haemoconcentrator.

Alternatively, there is provided a haemodialyser or haemoconcentrator for extracorporeal treatment of blood, the haemodialyser comprising an integral oxygenator.

In either embodiment both an oxygenator and a dialyser is provided in a single housing, as an integrated unit. The combined oxygenator/dialyser can be installed in a single oxygenation unit in order to perform a dual function. It is thus not necessary to provide two machines (or even a separate oxygenator and a separate dialyser within one machine) in order to both dialyse a patient and oxygenate their blood.

We have realised that it would be useful to simultaneously provide both an oxygenator and, either a haemodialyser or a haemoconcentrator, in a single integrated unit. Not only have we realised that this would be an advance in the technology, we have also realised that it should be done for patient safety and wellbeing, and that it has unexpected significant benefits.

By adding an additional compartment to an oxygenator we can provide an oxygenator and either a haemoconcentrating, or haemodialysing function, also. That additional compartment could replace the heat exchanger compartment commonly used in existing oxygenators, or could be in addition to it.

For patients having a normal heart bypass operation use of the invention would mean that an extra item (a haemodialyser) does not need to be added at some stage in the procedure, as it is already there. This improves safety and reduces priming volume over the present situation. It would also allow dialysis to be carried out on a conventional bypass patient without the use of a further device. It can also, in extreme cases, avoid an operation being cancelled because of not being able to locate a haemoconcentrator.

Patients undergoing extracorporeal membrane oxygenation would not then require an additional device to be added into the system in order to have dialysis, again improving safety. They would be able to have dialysis directly through the oxygenator.

The oxygenator allows a patient to be dialysed and oxygenated more safely than using prior art machines, because there is less opportunity for a machine to be incorrectly set up, or for tubing to disconnect. This is because the tubing needed to connect the oxygenator to the patient is

substantially all internal to the oxygenation unit. Like a conventional dialysis machine, the machine can be set up by a nurse, and left unattended whilst the patient is treated on a ward.

In those intensive care units that do not have the facilities to carry out extracorporeal membrane oxygenation (very few have this facility) the invention enables another method of oxygenating or removing carbon dioxide from very ill patients, without having to place them on a ventilator. As discussed above, ventilators have a potential morbidity involved with them, due to infection and other complications.

Our devices make it possible to exploit the functionality of both a conventional oxygenator and, either a haemodialyser or a haemoconcentrator, simultaneously using a single integrated unit. Our devices could replace conventional oxygenators and haemodialysis machines where patients need both.

This also provides a solution to the long-established problem of providing oxygen rich blood under high pressure via a ventilator into a patient with damaged lungs that needs haemodialysis or haemoconcentrating. It also avoids or minimises malignant inflammation due to acute respiratory distress syndrome resulting from ventilator use.

The oxygenator may comprise a housing, the housing comprising an oxygenation compartment in fluid communication with a dialysis compartment. The dialysis compartment may be surrounded or encircled by the oxygenation compartment. For example, the dialysis compartment may be provided radially inwardly of the oxygenation compartment.

The patient's blood may be re-oxygenated and/or have carbon dioxide removed in the oxygenation compartment and/or may be dialysed or concentrated in the dialysis compartment.

An oxygenator may further comprise a heat exchange compartment disposed within the housing and in fluid communication with the oxygenation compartment. The oxygenation compartment may be surrounded by or encircled by the heat exchange compartment.

The temperature of the blood may be regulated using the heat exchange compartment.

The housing may be substantially cylindrical, and may comprise a blood inlet disposed radially outwardly of a blood outlet, so that blood flowing from the blood inlet to the blood outlet flows so as to have at least a generally radially inwards component of flow through the oxygenator, through each of the oxygenation and dialysis compartments, and the heat exchange compartment (if present). Alternatively, the housing may comprise a blood outlet radially outwardly of a blood inlet, so that blood flowing from the blood inlet to the blood outlet flows so as to have at least a generally radially outwards component of flow through the oxygenator. In either embodiment, the blood inlet and blood outlet may be interchangeable, so that blood may, at the option of an operator, flow through the oxygenator in either direction.

The direction of the blood flow may be caused to have a vertical component in addition to a radial component in at least one of the compartments. That is, blood is caused to have a flow component that is substantially perpendicular to the radius of the housing, so that the blood flows through each compartment in a direction that is at an angle (of less

than 90 degrees) to the radius of the housing. As well as moving vertically, the blood moves generally radially, in such embodiments.

The direction of the blood flow may be caused to have a vertical component in all three compartments.

When the blood has a component of its flow in a vertical direction, for a given input flow rate, the blood remains inside each compartment for a longer time than if it were moving in a purely radial direction, allowing extended contact with the fluid transfer medium (see below) resulting in a more efficient gas/molecule/heat transfer.

The vertical component in the oxygenation compartment may be in an opposite direction to the vertical component in the heat exchange and dialysis compartments, so that the longitudinal blood flow component changes direction within the oxygenator. The blood may be caused to have a vertically downward flow component (with respect to an intended working orientation of the oxygenator) in the oxygenation compartment.

This means that blood in the oxygenation compartment flows against gravity, and any air bubble in the blood will rise upwards, in a different direction to the majority of the blood flow. Air bubbles are thus less likely to be carried towards the blood outlet.

The dialysis compartment, the oxygenation compartment, and the heat exchange compartment may each comprise a fluid transfer medium. The fluid transfer medium may comprise a plurality of hollow fibres arranged around a mandrel, the fibres extending from adjacent a first end of the housing towards a second end of the housing.

At least one tapered aperture (for example, and elongate slit that is wider at one end than at the other) may be provided in the mandrel of the or each compartment. The tapered aperture may cause at least some of the blood flowing through that compartment to flow towards a wider end of the tapered aperture, in order to influence the direction of the blood flowing towards that aperture through the compartment.

The fibres may be arranged around each mandrel obliquely with respect to a longitudinal axis of the housing. That is, the fibres may be arranged diagonally around each mandrel.

Gaps existing between the fibres, and between the fibres and the mandrels, may be sealed at the first and second ends of the housing, so that blood is able to flow through each compartments between the seals, adjacent the fibres extending through the compartments, and a transfer fluid (or fluids) is (or are) able to flow inside the fibres. The ends of the fibres extend through the seals, and are not sealed themselves.

In use gas may flow through the fibres extending through the oxygenation compartment, so that gas is transferred to and/or from blood flowing adjacent the fibres through the fibre membranes so as to re-oxygenate the blood and/or remove carbon dioxide from the blood.

Dialysis fluid may flow through the fibres extending through the dialysis compartment, so that molecules are transferred from blood flowing adjacent the fibres through the fibre membranes so as to dialyse the blood. Alternatively, no fluid may flow through the fibres extending through the dialysis compartment, so that water is transferred from blood flowing adjacent the fibres through the fibre membranes so as to concentrate the blood.

Heat transfer fluid, such as water, may flow through the fibres extending through the heat transfer compartment, so that heat is transferred to or from blood flowing adjacent the fibres through the fibre membranes to regulate the temperature of the blood.

The oxygenation compartment and/or the heat transfer compartment (where present) mandrels may be substantially conical. The fluid transfer fibres of the dialysis compartment and/or the oxygenation compartment may be arranged conically.

The fibres of the dialysis compartment may comprise a first conical outer surface shaped to cooperate with a first conical inner surface of the oxygenation compartment mandrel, and/or the fibres of the oxygenation compartment may comprise a second conical outer surface shaped to cooperate with a second conical inner surface of the heat transfer compartment mandrel.

The compartments can thus easily be assembled by stacking them together until a close fit is achieved. In such a design it is also not necessary to precisely locate the fibre winding positions.

The housing may further comprise an upper cap and a lower cap, each cap comprising upstanding annular walls disposed to cooperate with the conical mandrels so as to form upper and lower annular chambers in the caps. Each upper annular chamber may be in fluid communication with the fluid transfer fibres of a respective compartment at the first end of the housing, and each lower chamber may be in fluid communication with the fluid transfer fibres of a respective compartment at the second end of the housing. The conical mandrels and the annular walls may overlap.

Providing such an overlap simplifies the connection between the caps and the mandrels, as the caps do not need to be accurately aligned with the conical mandrels, due to the 'self-aligning' nature of cones. The connections may be implemented using an interference fit, as well as or instead of adhesive.

An oxygenator may further comprise a central mandrel in fluid communication with, and encircled by, the dialysis compartment, the blood outlet being provided in the central mandrel. The central mandrel may be turned with respect to the housing in order to direct the outlet. An o-ring may be situated around the central mandrel in order to seal the central mandrel to the dialysis compartment, especially when the central mandrel is turned.

According to another aspect of the invention there is provided an oxygenation unit comprising an oxygenator in accordance with the first aspect of the invention.

According to a further aspect of the invention, there is provided a method of treating a patient, wherein the method comprises re-oxygenating and/or dialysing/concentrating the patient's blood using an oxygenator according to the first aspect of the invention.

According to another aspect of the invention there is provided apparatus for the extracorporeal treatment of blood the apparatus comprising a first compartment and a second compartment, wherein the first compartment comprises a substantially conical outer surface shaped to cooperate with a substantially conical inner surface of the second compartment.

The first compartment may be an oxygenation compartment and the second compartment may be a heat exchange compartment, or vice versa.

Alternatively, the first compartment may be a dialysis compartment, and the second compartment may be an oxygenation compartment, or vice versa. A third dialysis or heat exchange compartment may be provided.

According to a further aspect of the invention there is provided apparatus for the extracorporeal treatment of blood the apparatus comprising a first compartment and a second compartment separated by a wall, wherein blood is permitted to flow between the first and second compartments through an aperture provided in the wall, and wherein the aperture is tapered.

The tapered aperture may cause at least some of the blood flowing between the compartments to flow towards a wider end of the tapered aperture. The tapered aperture is thus able to influence the direction of the blood flow between the two compartments.

The first compartment may be an oxygenation compartment and the second compartment may be a heat exchange compartment, or vice versa. Alternatively, the first compartment may be a dialysis compartment, and the second compartment may be an oxygenation compartment, or vice versa. A third dialysis or heat exchange compartment may be provided.

According to yet another aspect of the invention there is provided a method of constructing apparatus for the extracorporeal treatment of blood comprising nesting a first fluid transfer compartment having a substantially conical outer surface within a second fluid transfer compartment having a substantially conical inner surface shaped to cooperate with the substantially conical outer surface of the first fluid transfer compartment.

The apparatus may further comprise arranging fluid transfer fibres around a conical mandrel to form the first and second fluid transfer compartments.

An embodiment of the invention will now be described, by way of example only, with reference to the following drawings, in which;

Figure 1 shows a schematic overview of an oxygenator and/or dialysis unit;

Figure 2 shows a cross sectional view of a membrane oxygenator in accordance with one embodiment of the invention;

Figure 3 is a cross sectional view showing in more detail components of the oxygenator of Figure 2;

Figure 4 shows (a) a top view and (b) a bottom view of the oxygenator of Figure 2;

Figure 5 shows representative internal components of the oxygenator of Figure 2, being (a) an oxygenator compartment, (b) a heat-exchange compartment, (c) and (d) outer and inner mandrels, and (e) a dialysis compartment;

Figure 6 is a schematic perspective view showing the construction of a fluid transfer compartment;

Figure 7 is a view similar to Figure 2 showing blood flow through the oxygenator of Figure 2;

Figure 8 is a view similar to Figure 2 showing another embodiment of the invention; and

Figure 9 is a view similar to Figure 3 of the embodiment shown in Figure 8.

Figure 1 shows a schematic view of a combined oxygenation and haemodialysis unit 1. As used herein, the word dialysis, or haemodialysis, includes haemoconcentration, as the dialysis portion of the machine can perform either function.

The unit 1 comprises as inlet 3 which in use is connected to a patient's vein or artery, and along which blood to be oxygenated and/or cleaned is extracted from the patient. The pressure of incoming blood is monitored and regulated using an arterial pressure monitor 5. A pump 7, which may consist of a roller pump, drives the blood through the unit 1 towards an oxygenator 9. In the unit, the blood flow to the oxygenator may be controlled using an inflow pressure monitor 11. Heparin, or other suitable anti-clotting drug, may be administered to the blood via a pump 13.

In the oxygenator 9 blood is treated, as will be described in more detail later. Treated blood is then returned to the patient's body via an air trap 15, which prevents potentially dangerous bubbles which may have formed in the blood from passing into the patient. The pressure at the machine outlet 17 is controlled using a venous pressure monitor 19.

The unit 1 comprises a blood transfer path 21 which is made up from tubing, such as plastic, for example polythene, tubing 23 and the oxygenator itself 9. The components of the blood transfer path 21 are disposable, and are discarded after each use of the unit (to reduce the

chance of cross-contamination, or infection). The remainder of the machine, including the mechanical components such as the pumps and pressure monitors, is not discarded after use, as blood is never directly in contact with those parts of the machine.

The oxygenator 9 is shown in more detail in Figure 2. The oxygenator 9 differs from prior art oxygenators in that it is able to perform both an oxygenation and a dialysis/concentration function, either separately, or simultaneously. Thus in order to both oxygenate and dialyse a patient's blood, a patient can simply be connected to a single machine: the unit 1. It is not necessary to connect two independent machines via external tubing, meaning that the machine is greatly simplified over prior art machines, and the risk to the patient is greatly reduced. The machine can be used as an alternative to, or in addition to, a conventional ventilator.

All of the components of the oxygenator 9 are made from plastic. The plastic components are transparent, to enable blood to be seen as it passes through the device. Transparency also means that air bubbles existing within the blood can be seen. This is useful as the sight of air bubbles can prompt a machine user to check the operation of the unit 1. It is desirable that air bubbles are not returned to the patient with treated blood. The oxygenator 9 is a single-use disposable item.

The oxygenator 9 is substantially cylindrical, and comprises three main substantially cylindrical portions within a housing 25. Working inwards, the housing comprises a heat transfer compartment 27. The heat transfer compartment has a radially outer intake area 28 and a radially inner heat transfer portion 30.

Radially inward of the heat transfer compartment 27 is an oxygenation compartment 29. Radially inward of that oxygenation compartment 29 is

a dialysis compartment 31. It will be appreciated that the three compartments, collectively referred to herein as fluid transfer compartments, may be in a different radial order if required.

The housing 25 is capped at its upper and lower ends by an upper cap 24 and a lower cap 26, shown in more detail in Figure 4. The upper cap 24 comprises an outer and a middle annular chamber 38a and 38c, substantially in line with and fluidly connected to the upper end of a respective fluid transfer compartment 27 or 29. Likewise, the lower cap 26 comprises outer and middle annular chambers 38b and 38d, which are also substantially in line with and fluidly connected to the lower end of, respectively, heat transfer compartment 27 or oxygenation compartment 29. Upper annular chambers 38a and 38c respectively comprise fluid inlets 53 and 57, whilst lower annular chambers 38b and 38d comprise respective fluid outlets.

'Upper' and 'lower' and other similar relative terms are used herein to refer to the orientation shown in the drawings. Such terms are not intended to be limiting, as the device could have a different orientation in use to the orientation shown in the drawings.

The fluid transfer compartments 27, 29, and 31, are separated from each other by substantially cylindrical (in fact, frusto-conical) walls 33, referred to herein as mandrels. A first mandrel 33a separates the heat exchange compartment 27 from the oxygenation compartment 29. A second mandrel 33b separates the oxygenation compartment 29 from the dialysis compartment 31. A central mandrel 33c separates the dialysis compartment from a central compartment 35.

The fluid transfer compartments are fluidly connected to each other and to the central compartment, so that fluid (blood) can flow between them.

Each mandrel comprises apertures 37, shown in more detail in Figure 5 (for clarity, apertures are not shown in respect of the central mandrel), through which blood can pass. The apertures are wedge-shaped, that is, wider at one end than the other, and assist in directing the flow of blood through the device (described in more detail later).

The central mandrel 33c extends through the centre of the device. Two more annular chambers 38e and 38f are formed in the upper and lower cap adjacent the inner mandrel 33c, and fluidly connected to dialysis compartment 31.

The annular chambers 38a-f serve as entry or exit chambers for different transfer fluids, as will be described later.

Blood enters the housing 25 through an inlet 36. A purge outlet 50 is provided in the intake area 28, through which air can escape, to assist in removing bubbles within the oxygenator. This process is known as priming.

Blood moves generally radially inwards through the different compartments of the oxygenator 9 towards the central compartment 35. Fluid may flow through the compartments in a countercurrent manner, described in more detail later so that the fluids on either side of the membrane in each compartment are travelling in opposite directions. This may enhance the rate of transfer within each compartment.

Blood exits the central compartment via one or both of two outlets 40a or 40b. A first outlet 40a has a larger diametric cross-section than a second outlet 40b, meaning that a higher flow rate can be achieved using the first outlet 40a. The second outlet 40b can be used as a cardioplegic outlet, to

return blood mixed with cardioplegic fluid to the heart of the patient to stop the heart and/or begin to start it again.

The outlets can be directed by turning the central mandrel 35. Two sealing o-rings 48 ensure that fluid does not escape whilst the central mandrel is turned. The inlet 36 can thus be positioned at any desired angle with respect to the outlets. Port 46 is a luer port used to sample blood exiting the device.

Each of the fluid-transfer compartments, 27, 29, and 31, comprises a plurality of fluid transfer members, which in this example are hollow fibres 39 (shown in more detail in Figure 6, wherein the number of fibres shown is greatly reduced for clarity) arranged around its respective mandrel 33. Each fibre 39 is formed of a membrane, which facilitates the exchange of a substance, such as gas, waste or nutrients, or of energy, such as temperature, across the membrane from one side of the membrane to another.

The membrane carries out a different transfer function in each fluid transfer compartment 27, 29, 31. In the heat transfer compartment 27, the membrane serves to transfer heat to or from a temperature regulating fluid, such as water, to blood. In the dialysis 31 and oxygenation 29 compartments, the membrane is porous, and allows certain molecules, such as oxygen or carbon dioxide to pass across the membrane, whilst other molecules cannot pass across the membrane. In the example shown, a different membrane is used for each compartment. However, the same membrane, which is able to perform more than one function, may be used for more than one of the compartments, or all of the compartments, if required.

There may be between 100 and 100,000 fibres arranged around a single mandrel. The fibres 39 are arranged diagonally, so that fluid can pass down the centres of the fibres from one end of the device to another in a path that is inclined to a longitudinal axis 41, as shown by arrow 43. Successive layers of fibres may incline at differing angles or in differing directions to assist in mass transfer. Small gaps exist between the fibres such that fluid can also flow around the outside of the fibres. However, fluid that is between the fibres cannot flow out of the ends of the device, because at the ends the gaps between the fibres are sealed, for example using a polyurethane seal 45.

The components of the oxygenator are constructed separately, and then assembled.

To construct each fluid transfer compartment 27, 29, 31, five or six long continuous hollow fibres are wound repeatedly around each respective mandrel to form a body, like a cylindrical 'ball of string'. Each compartment may be wound onto its respective mandrel separately. Alternatively, pre-woven fibre mats may be used and rolled up to produce the media of the transfer compartment and inserted around or between the mandrels.

In the construction shown in Figures 2, 3 and 7, the compartments 29 and 31 are assembled around the dialysis membrane (without central mandrel) and the central mandrel is inserted later, when the upper and lower caps are added, as described below. In the alternative, and preferred, construction shown in Figures 8 and 9, the dialysis membrane is formed around the central mandrel. The three compartments are then assembled one inside the other.

In each embodiment, the three assembled compartments are inserted into the housing 25 to form the overall middle part of the device. Polyurethane resin 45 is then introduced at the top and bottom of the oxygenator, and the device is centrifuged, to ensure that the majority of the resin remains at the ends of the device whilst the resin sets.

After the resin sets, the looped ends of the fibres project through the resin, with the resin sealing the gaps in between the fibres. The looped ends are then cut off so as to open up the fibres. The fibres are cut slightly below the tips of the mandrel walls, so that the mandrels extend out from the cut fibres by a small amount.

The fluid transfer members now consist of a large number of "straws" (that is, fibres) extending diagonally through the oxygenator 9. In use, one fluid (blood) passes outside the fibres (ie on one side of the membrane), whilst another (the various transfer fluids) passes on the other side of the fibres (ie down the centre of the fibres).

The cylinders of material forming each compartment 29, 30, 31, have to fit together well so that no shunting of blood occurs between the various sections. It is desirable that blood cannot bypass any of the chambers, which might be possible if the walls were poorly fitting. In the illustrated embodiments the mandrels 33a and 33b that are not truly cylindrical; instead they are substantially cone-shaped. In the embodiments shown the angle of the cone is slight, differing from a true cylinder by approximately 2 to 5%. However, it may be desirable to provide other angles, for example up to 10° or even 20° degrees in alternative embodiments.

The fibres 29 are wound onto the mandrels 33c and 33b in a conical shape, so that the conical outer surface of dialysis compartment 31, for

example, cooperates with the conical inner surface of mandrel 33b. This conical construction means that the mandrels and the fibre windings do not need to be quite so accurately constructed, or aligned, as a little axial movement can compensate for small variations in radial size. Like stacking cups, there is more tolerance in the mating of cones (or frustums) than truly cylindrical components. An interference fit holds one compartment tightly inside another whilst the device is being assembled, and the compartments continue to fit tightly once the device has been assembled.

The conical construction also means that it is easier to assemble the device, by sliding one cone inside another, than it would be to assemble a device formed of true cylinders.

It can be difficult to force one tightly fitting cylinder inside another, especially when doing so may result in damage to some of the fibre membranes. Sometimes the prior art uses a sheet of polypropylene as a "shoehorn" to temporarily surround the fibres whilst they are slipped into a cylindrical housing. Then the sheet of propylene is pulled out, hopefully without disturbing the fibres. Such a "shoehorn" is not necessary with the illustrated invention. Using cones, it is easier to achieve a tight fit.

Next the upper and lower caps 24 and 26 are added to form a sealed oxygenator unit. The tips of the walls 33a, 33b, which were left extending beyond the cut fibres, engage with walls 36 projecting from the upper cap 24 and the lower cap 26 to form the annular chambers 38a and 38c at the upper end of the device, and the annular chambers 38b and 38d at the lower end of the device. The compartment walls 33 are secured to the annular chamber walls 36 using adhesive.

Because the mandrels 33a and 33b are frusto-conical, rather than cylindrical, their ends are slightly offset from the ends of the cylindrical walls 36. This allows the walls 33 to be bonded to the walls 36 with an area of overlap 51 between the ends, rather than requiring the walls to be bonded end-to-end. This lateral overlap is mechanically stronger as a join than an end-to-end join. The area of overlap also reduces the need for highly accurate tooling, as the cones are able to slide inside the cylinders in the lower cap 26 (or vice-versa in the upper cap 24) until a tight fit is achieved.

An interference fit can assist in holding the end caps 24 and 26 onto the central portion, in addition to or instead of adhesive.

The central mandrel 33c acts as a locking pin to hold the oxygenator together. The central mandrel 33c is provided with screw threads 34 which engage with cooperating screw threads on a closure 20, which is held in a recess 22 provided in the upper cap 24. The central mandrel can be screwed into the upper cap, until a lip 42 provided in the lower cap 26 engages with a shoulder 44 provided on the central mandrel. Rather than providing a separate closure member 20, the central mandrel 33c could screw directly into the upper cap 24.

Figures 8 and 9 show a central mandrel 33c having an alternative construction in which the outlets 40a and 40b are detachable from the rest of the mandrel as part of a lower closure 73. The lower closure screws onto screw threads provided on the lower cap 26, in a similar manner to closure 20, until it abuts the shoulder 42. This construction allows the dialysis compartment to be formed around the central mandrel, whereas in the construction shown in Figures 2, 3 and 7, it is necessary to insert the central mandrel afterwards.

The central mandrel 33c mechanically secures the central housing 25, with it three compartments, to the top and bottom caps 24 and 26, holding the device together. The mechanical coupling assists the adhesive and/or interference coupling between the walls 36 and 33a and 33b.

The use of the oxygenator will now be described, with reference to Figures 2 (or 8) and 7.

A temperature regulating fluid, in this case water, is introduced into the oxygenator via a water inlet 53. The water enters the upper (or first) outer annular chamber 38a, fills the chamber, and flows down, through the fibres until it reaches the lower (or second) annular chamber 38b. Water can not enter the central body of the device (apart from when it is inside the fibres) because of the resin seals 45, which close off the top and bottom annular chambers 38a and 38b from the middle section by sealing the spaces between the fibres. From the second outer annular chamber 38b the water exits the oxygenator through water outlet 55.

Blood enters the inlet chamber 28 through blood inlet 36, at the bottom right hand side of the Figures. The blood flows between the fibres in the heat transfer portion 30 until it fills the heat transfer chamber 27. The blood migrates generally radially inwards, and also has a vertical, upward, component to its flow. Blood moves generally in the direction shown by arrows 65. The blood moves radially inwards due to presuure from the blood inlet 36. The blood caused to move vertically by the tapering, wedge-shaped apertures 37a in the outer mandrel 33a, because more blood can flow through the wider end of the wedge, and so the blood tends to flow towards the 'path of least resistance'. The angle of the fibres helps to produce a turbulence-like effect at the fibre surface to aid transfer at this point, assisting mass transfer by breaking up the boundary layer effect.

As the blood moves through the heat transfer compartment 27, its temperature rises or falls in dependence upon the temperature of the water flowing through the fibres. The temperature of the blood can be regulated by changing the temperature of the heat transfer fluid.

Blood leaves the heat transfer compartment 27 through the apertures 37a in the mandrel 33a, and enters the oxygenation compartment 29.

Gas enters the oxygenation compartment 29 through the gas inlet 57 in annular chamber 38c at the top of the oxygenator. Gas fills that chamber 38c and flows through the hollow fibres 39 to the lower annular chamber 38d at the bottom of the device from which the gas leaves the oxygenator via the gas outlet 59.

Blood that has flowed radially from the heat exchange part of the device through the apertures 37a, enters the gas exchange region 29, and this time as well as having an inward radial component to its movement it moves downwards as well, generally in the direction shown by arrows 67. The blood flow changes direction because the apertures 37b in the inner mandrel 33b are also wedge-shaped. However, this time the wedges are wider at the bottom, rather than the top (that is, wider at the opposite end to the apertures 37a). This acts to draw the flow of blood downwards towards the bottom of the oxygenator.

Causing the blood to move downwards, against gravity, in the oxygenation compartment is advantageous, because any bubbles of gas that do form in the blood tend to migrate upwards (under the influence of gravity, as they are lighter than blood). Thus bubbles move generally in the opposite, or at least a different, direction to the rest of the flow,

reducing the chances of such bubbles being carried to the blood outlets of the oxygenator, and from there potentially into the patient.

In the oxygenation compartment gas, primarily oxygen, from within the fibres passes into blood flowing around the fibres, so that the blood is oxygenated. Alternatively, or additionally, carbon dioxide within the blood is removed from the blood into the fibres, and carried out of the gas outlet 59. If the blood does not need to be oxygenated (for example, because the machine is being used solely for dialysis) no gas is supplied to the gas inlet 57, and blood simply flows through the oxygenation compartment 29 without change.

Haemofiltrate enters the device through dialysate inlet 61, formed in the closure 20 sealing the top of the central mandrel 33c. The dialysate enters a top chamber 62 in the central mandrel 33c, which is separated from the central compartment by seal 45. The dialysate flows from the top chamber 62 into the inner annular chamber 38e through dialysate apertures 64 in the central mandrel 33c. From that chamber 38e the filtrate flows downwards through the hollow fibres 39 to exit the oxygenator via the lower inner chamber 38f and the dialysate outlet 63 at the bottom of the oxygenator.

Dialysis takes place when or if a dialysis liquid is introduced at inlet 61. If one is not introduced (and inlet 61 is capped), then water is still expelled from the blood via outlet 63, and the blood is concentrated. Thus the device can be used either for dialysis or haemoconcentration depending on the input fluid. The device can thus also be used solely as an oxygenator, without a dialysis function.

Blood moves from the oxygen/CO_2 transfer area 29 into the dialysis area 31 through the conical wall 33b that surrounds the dialysis area

through apertures 37b. The blood now has an upward migration caused by further wedge-shaped apertures in the central mandrel (not shown), as well as a radially inward migration, between the fibres, substantially in the direction indicated by arrows 69.

Blood enters the central mandrel 33c and flows downwards through the wedge shaped apertures (not shown) and flows downwards through central compartment 35 towards the blood outlets 40a and 40b. Again, the downward flow of the blood encourages gas bubbles trapped in the blood to move upwards, away from the outlet.

During its passage through the oxygenator, blood is diverted upwards and downwards, as it migrates radially through the device, by the varying diameter slits 37a and 37b in the supports 33a-c for the fibres 39. By moving the blood upwards and downwards inside the device, rather than just radially the blood is in contact with the fibres in each compartment for a greater time (because the blood travels further in each compartment when it travels at an angle to the radius than it would if it simply travelled radially). That extended contact increases the amount of substance (including heat) which can be transferred during a pass through the device.

It will be appreciated that it is not necessary to include a heat exchange compartment in an oxygenator in accordance with the invention. The temperature of the blood need not be regulated, or can be regulated by other means. The oxygenator could thus be made up from only two compartments: an oxygenation compartment and a dialysis compartment.

In addition, some features of the invention are not limited to use with a combined oxygenator/dialyser, and can provide additional advantages to oxygenator only and dialyser/concentrator only blood treatment units.

For example, prior art oxygenators may comprise a heat exchange compartment and an oxygenation compartment. In accordance with the invention, tapering holes are provided in a wall dividing those two compartments, to influence the direction of the flow of blood within the compartments. As discussed above, it is advantageous for blood have a vertically downwards flow component in at least one compartment, to discourage air bubbles from being carried with the flow towards the outlet. That vertically downward component can be induced by providing elongate wedge-shaped apertures, rather than more regular shaped apertures (such as rectangular or circular), with the wedge widening in the direction in which it is desired to direct the flow.

Furthermore, dialyser/oxygenator only treatment units formed of nested cylinders can benefit from the conical construction described above. Not only does the conical construction allow such a device to be more easily assembled, it also results in a stronger, more efficient device. That is because cones can interlock more tightly than cylinders, without disturbing the fluid transfer fibres. A tighter seal between the compartments can thus be achieved. Allowing an area of overlap between the cones and end caps of the device results in a mechanically stronger device.

A central mandrel of the type described above (extending through the device and rotatable) is also beneficial in an oxygenator or dialyser, as well as in a combined oxygenator/dialyser, as the blood outlet can be arranged to point in any direction, resulting in a more versatile device.

It will be appreciated that many of the features described within, for example conical, nested fluid transfer compartments, providing a vertical component of blood flow, and providing a rotatable central mandrel, are

separate inventions, and can be used separately as well as in combination. The invention is not limited to the embodiment that has been described, and individual features can be combined in any number and/or combination, as required.

CLAIMS

1. An oxygenator for extracorporeal treatment of blood the oxygenator comprising an integral haemodialyser or haemoconcentrator.

2. An oxygenator according to claim 1 further comprising a housing, the housing comprising an oxygenation compartment in fluid communication with a dialysis compartment.

3. An oxygenator according to claim 2, wherein the dialysis compartment is encircled by the oxygenation compartment.

4. An oxygenator according to claim 3 wherein the housing is substantially cylindrical, and comprises a blood inlet disposed radially outwardly of a blood outlet, so that blood flowing from the blood inlet to the blood outlet flows generally radially inwardly through the oxygenator, through each of the oxygenation and dialysis compartments.

5. An oxygenator according to claim 4 wherein the direction of the blood flow is caused to have a vertical component in addition to a radial component in at least one of the compartments.

6. An oxygenator according to claim 5 wherein the direction of the blood flow is caused to have a vertical component in both compartments, wherein the vertical component in the oxygenation compartment is in an opposite direction to the vertical component in the dialysis compartment, so that the blood changes direction within the oxygenator.

7. An oxygenator according to claim 6 wherein blood is caused to have a vertically downward flow component (with respect to an intended working orientation of the oxygenator) in the oxygenation compartment.

8. An oxygenator according to any one of claims 1 to 7, further comprising a heat exchange compartment in direct or indirect fluid communication with the oxygenation compartment, wherein optionally the oxygenation compartment is encircled by the heat exchange compartment.

9. An oxygenator according to any one of claims 1 to 8 wherein the dialysis compartment, the oxygenation compartment, and, optionally, the heat exchange compartment each comprises a fluid transfer medium arranged around a mandrel.

10. An oxygenator according to claim 9 wherein at least one tapered aperture is provided in the mandrel of the or each compartment, the tapered aperture arranged to cause at least some of the blood flowing through that compartment to flow towards a wider end of the tapered aperture.

11. An oxygenator according to claim 9 or claim 10 wherein the fluid transfer medium comprises a plurality of hollow fibres, the fibres extending from adjacent a first end of the housing towards a second end of the housing.

12. An oxygenator according to claim 10 wherein the fibres are arranged around each mandrel obliquely with respect to a longitudinal axis of the housing.

13. An oxygenator according to any one of claims 10 to 12 wherein gaps existing between the fibres, and between the fibres and the mandrels, are sealed at the first and second ends of the housing, so that blood is able to flow through each compartments between the seals,

adjacent the fibres extending through the compartments, and a transfer fluid (or fluids) is (or are) able to flow inside the fibres.

14. An oxygenator according to claim 13 wherein in use gas flows through the fibres extending through the oxygenation compartment, so that gas is transferred to and/or from blood flowing adjacent the fibres through the fibre membranes so as to re-oxygenate the blood and/or remove carbon dioxide from the blood.

15. An oxygenator according to claim 13 or claim 14 wherein in use dialysis fluid flows through the fibres extending through the dialysis compartment, so that molecules are transferred from blood flowing adjacent the fibres through the fibre membranes so as to dialyse the blood.

16. An oxygenator according to claim 13 or claim 14 wherein in use no fluid flows through the fibres extending through the dialysis compartment, so that water is transferred from blood flowing adjacent the fibres through the fibre membranes so as to concentrate the blood.

17. An oxygenator according to any one of claims 13 to 16 wherein in use heat transfer fluid, such as water, flows through the fibres extending through the heat transfer compartment, so that heat is transferred to or from blood flowing adjacent the fibres through the fibre membranes to regulate the temperature of the blood.

18. An oxygenator according to any one of claims 9 to 17 wherein the oxygenation compartment and, optionally, the heat transfer compartment mandrels are substantially conical.

19. An oxygenator according to any one of claims 10 to 18 wherein the fluid transfer fibres of the dialysis compartment and/or the oxygenation compartment are arranged conically

20. An oxygenator according to claim 19 wherein the fibres of the dialysis compartment comprise a first conical outer surface shaped to cooperate with a first conical inner surface of the oxygenation compartment mandrel, and/or wherein the wound fibres of the oxygenation compartment comprise a second conical outer surface shaped to cooperate with a second conical inner surface of the heat transfer compartment mandrel.

21. An oxygenator according to any one of claims 18 to 20 wherein the housing further comprises an upper cap and a lower cap, each cap comprising upstanding annular walls disposed to cooperate with the conical mandrels so as to form upper and lower annular chambers in the caps, each upper annular chamber being in fluid communication with the fluid transfer fibres of a respective compartment at the first end of the housing, and each lower chamber being in fluid communication with the fluid transfer fibres of a respective compartment at the second end of the housing, wherein the conical mandrels and the annular walls overlap.

22. An oxygenator according to any one of claims 5 to 21 further comprising a central mandrel in fluid communication with, and encircled by, the dialysis compartment, wherein the blood outlet is provided in the central mandrel.

23. An oxygenator according to claim 22 wherein the central mandrel can be turned with respect to the housing in order to direct the outlet.

24. An oxygenation unit comprising an oxygenator as claimed in any preceding claim.

25. A method of providing oxygenation and dialysis of a subject's blood, the method comprising attaching the subject to the oxygenation unit of claim 24, and providing oxygenation and dialysis to the subject.

26. An oxygenator substantially as described herein, with reference to the drawings.

27. An oxygenation unit substantially as described herein, with reference to the drawings.

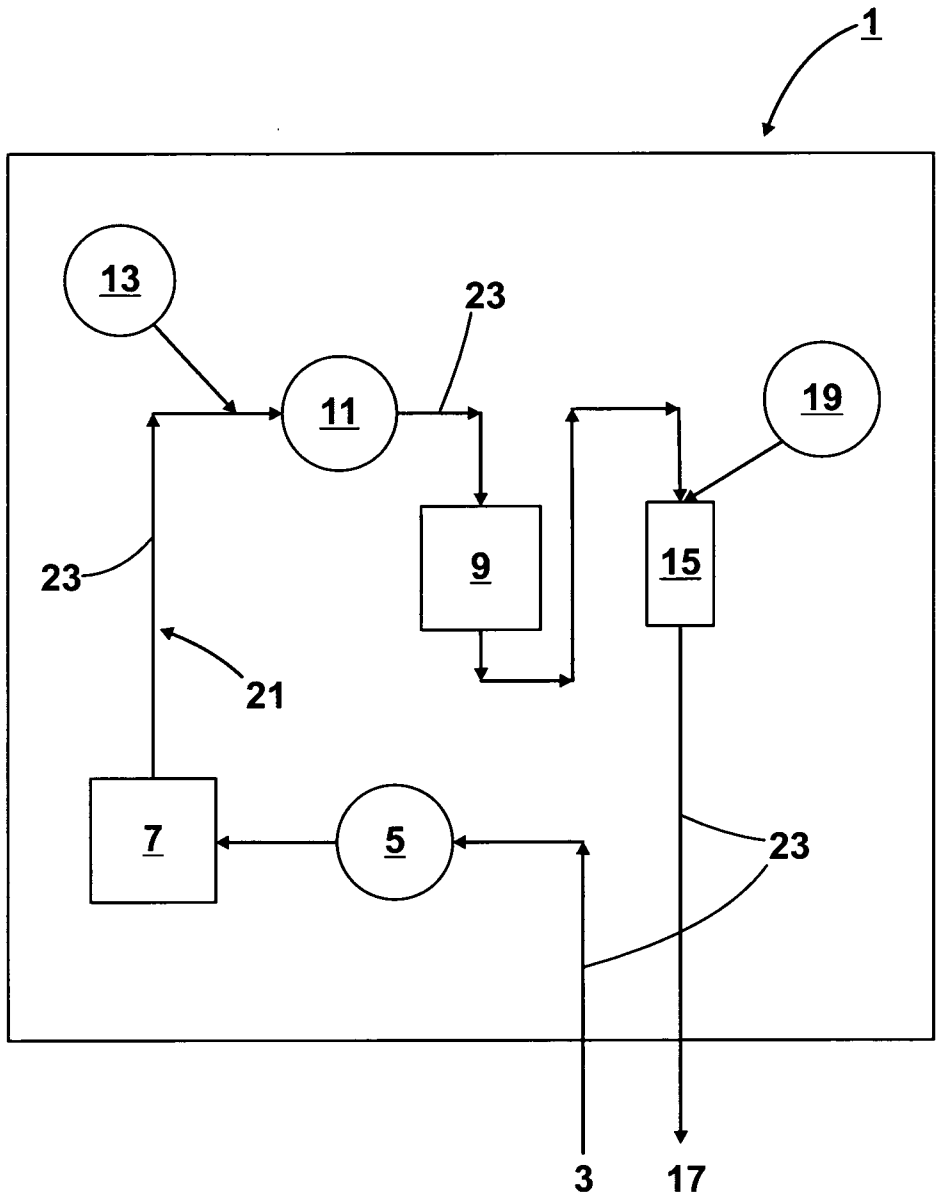

Fig. 1

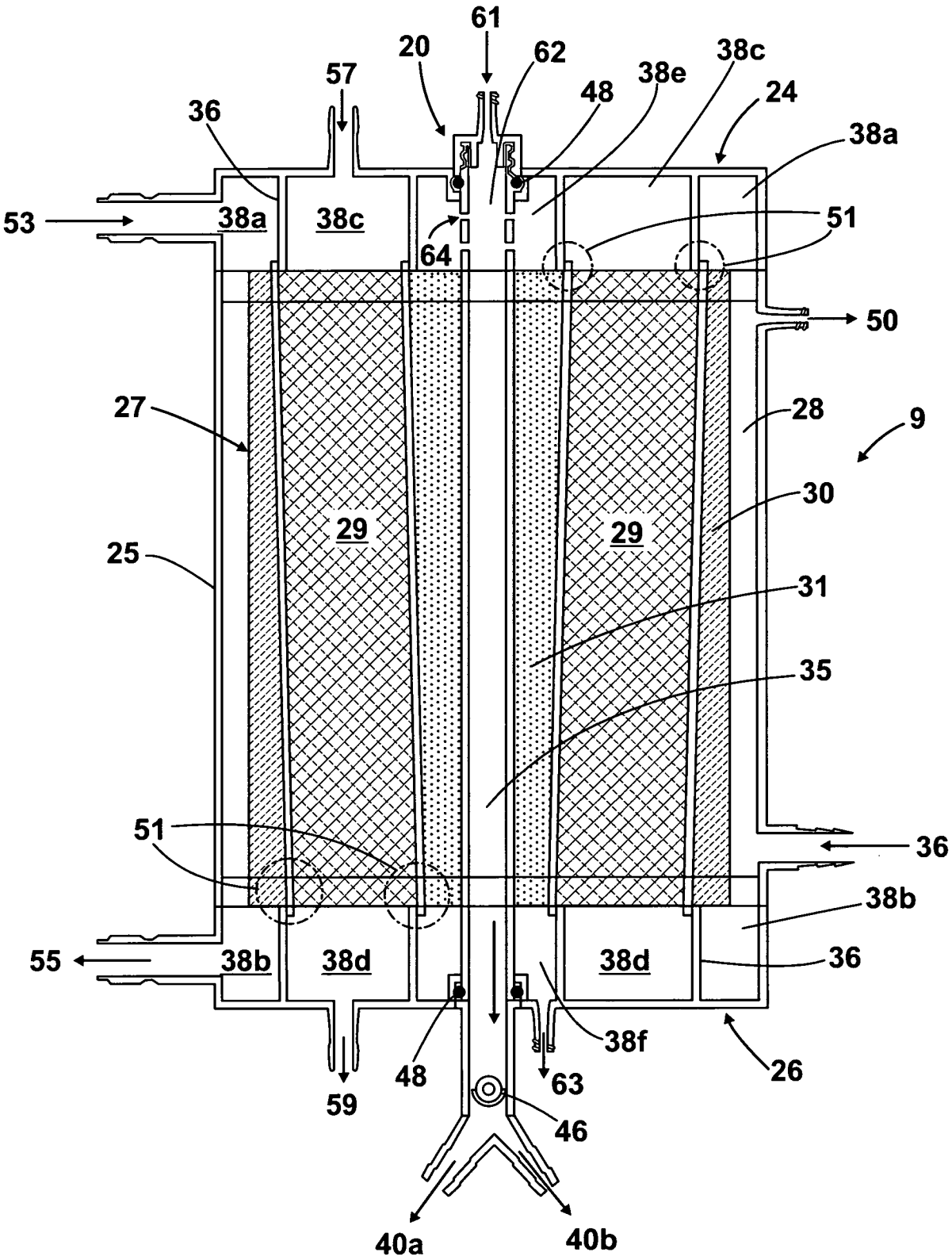
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Fig. 2

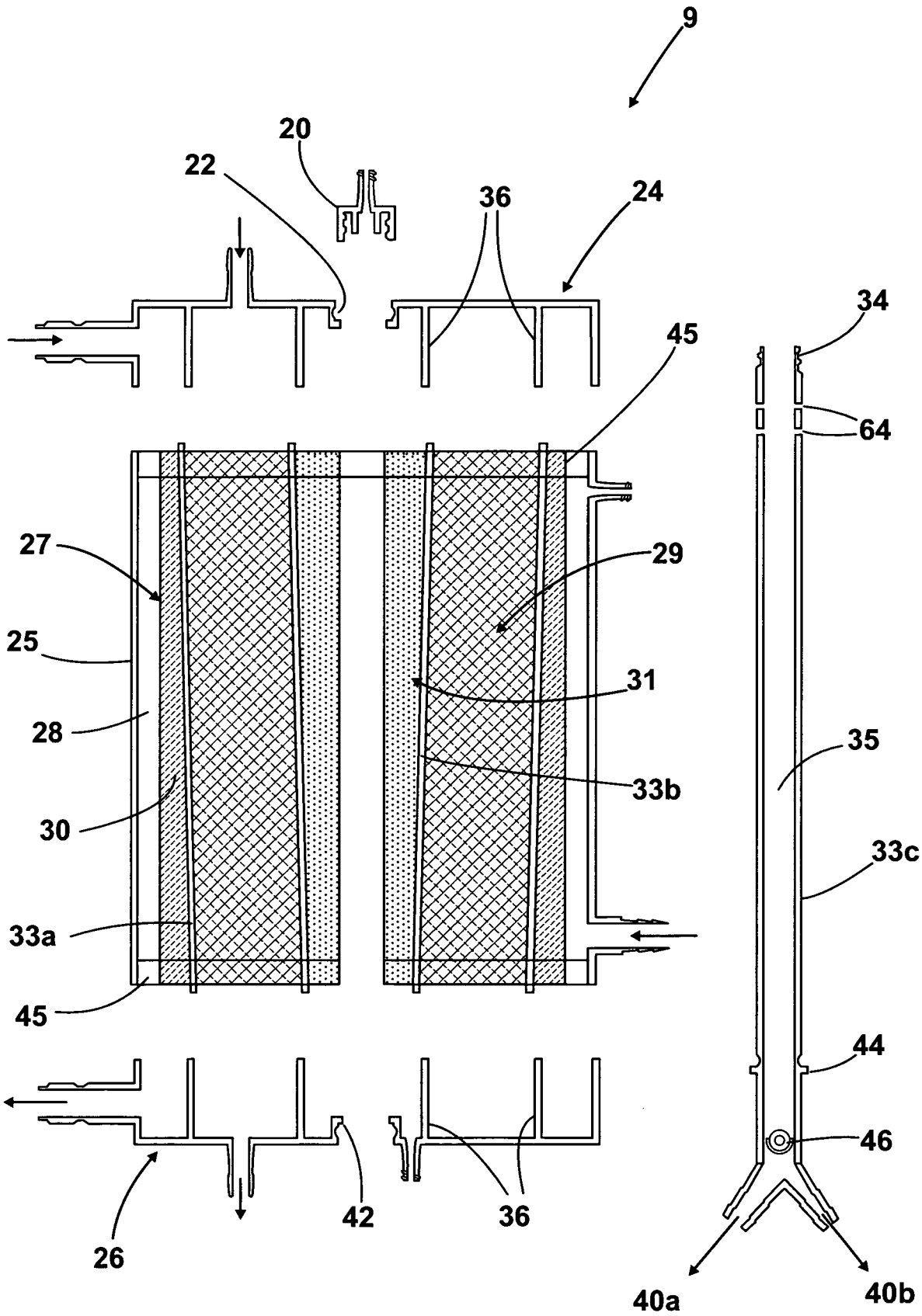
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Fig. 3

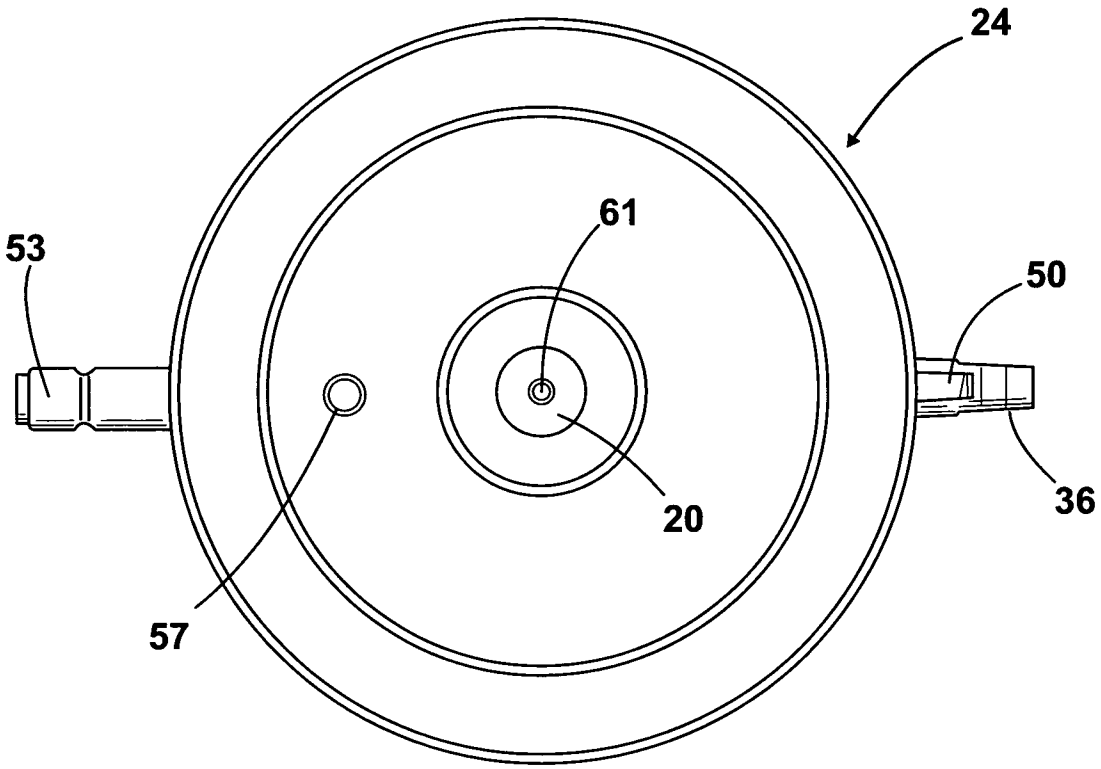

Fig. 4(a)

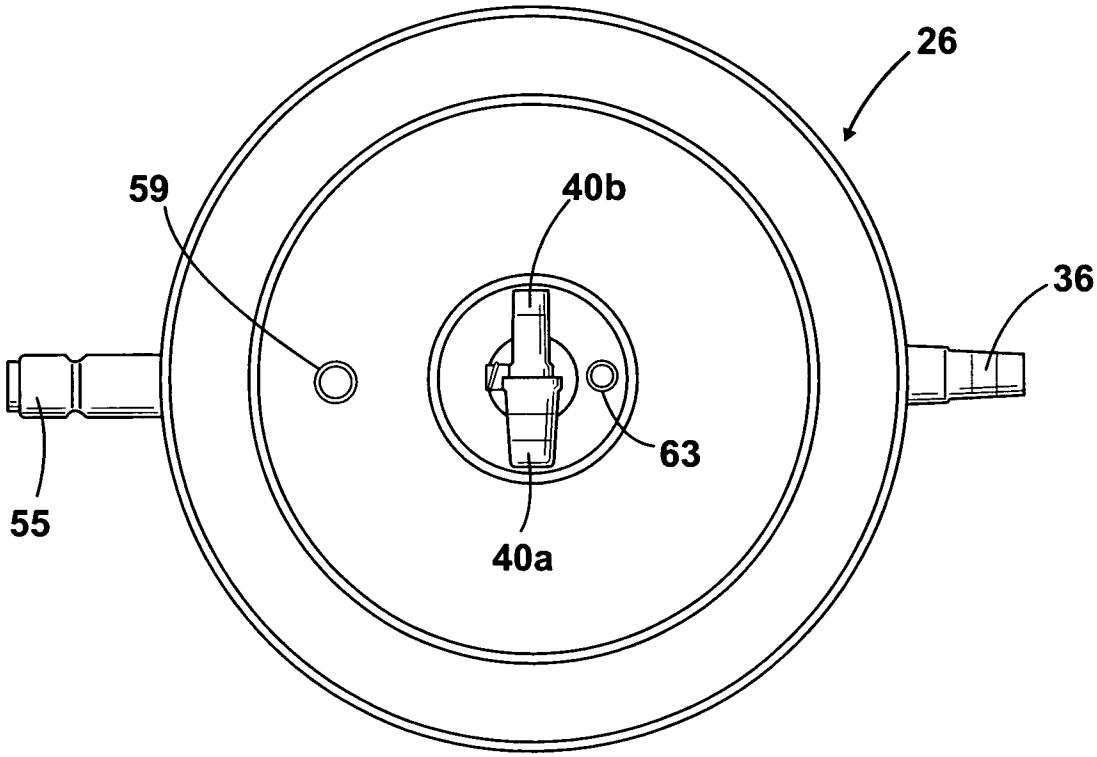

Fig. 4(b)

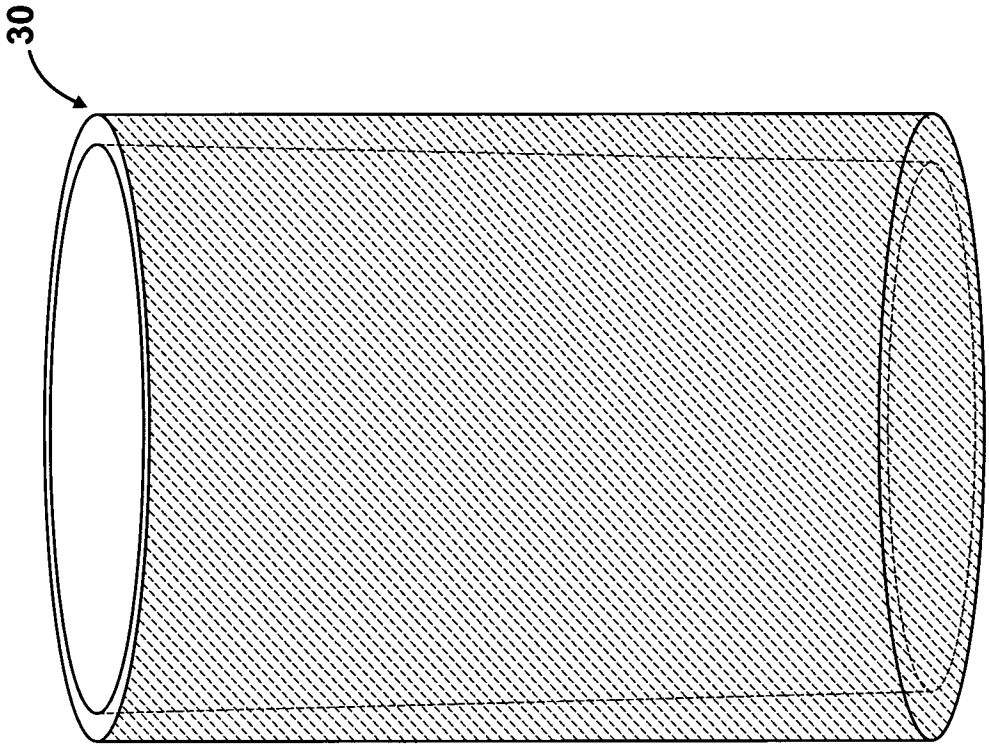

Fig. 5(b)

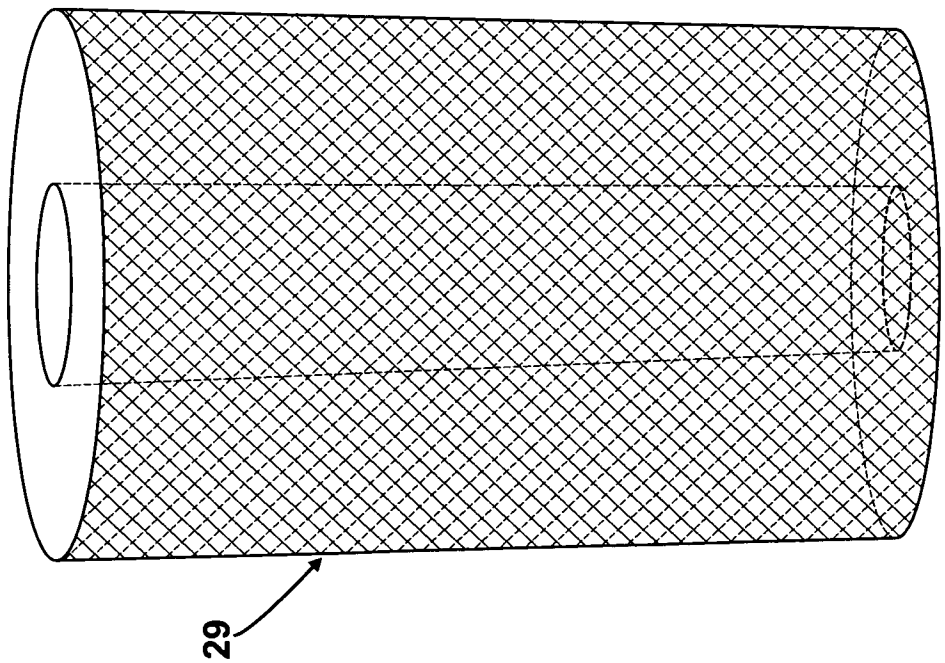

Fig. 5(a)

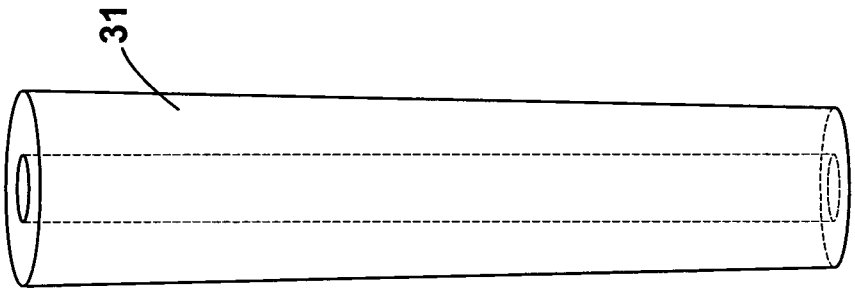

Fig. 5(e)

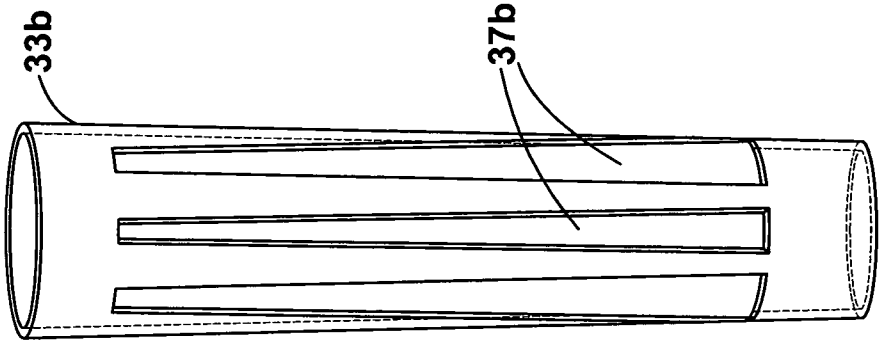

Fig. 5(d)

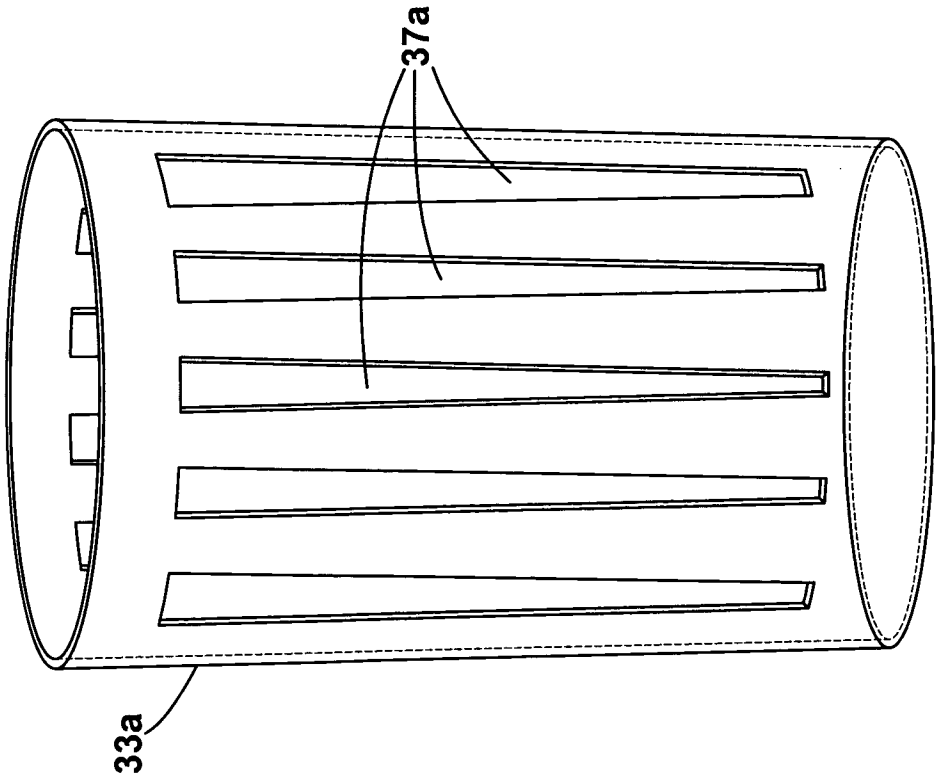

Fig. 5(c)

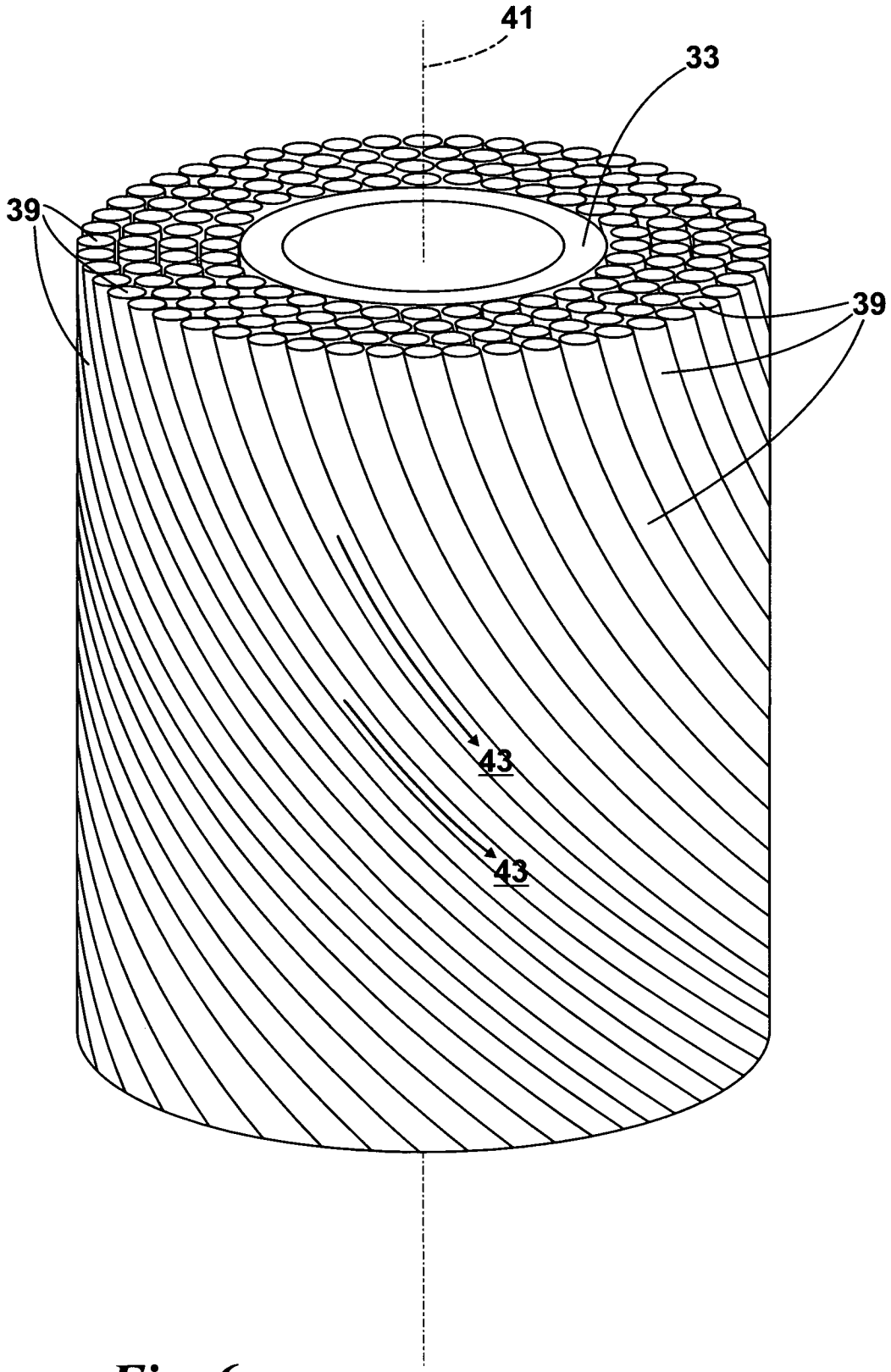

Fig. 6

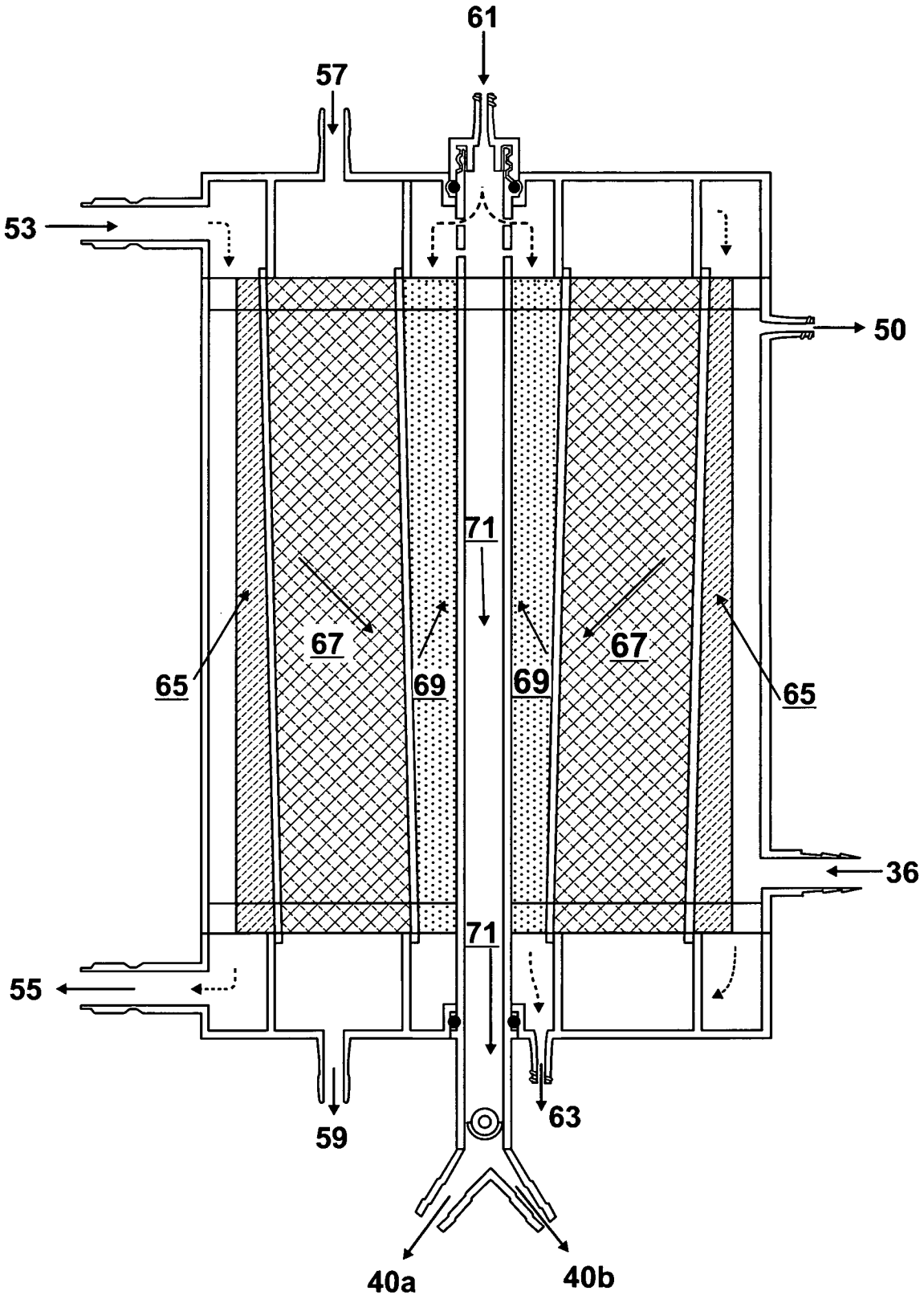

Fig. 7

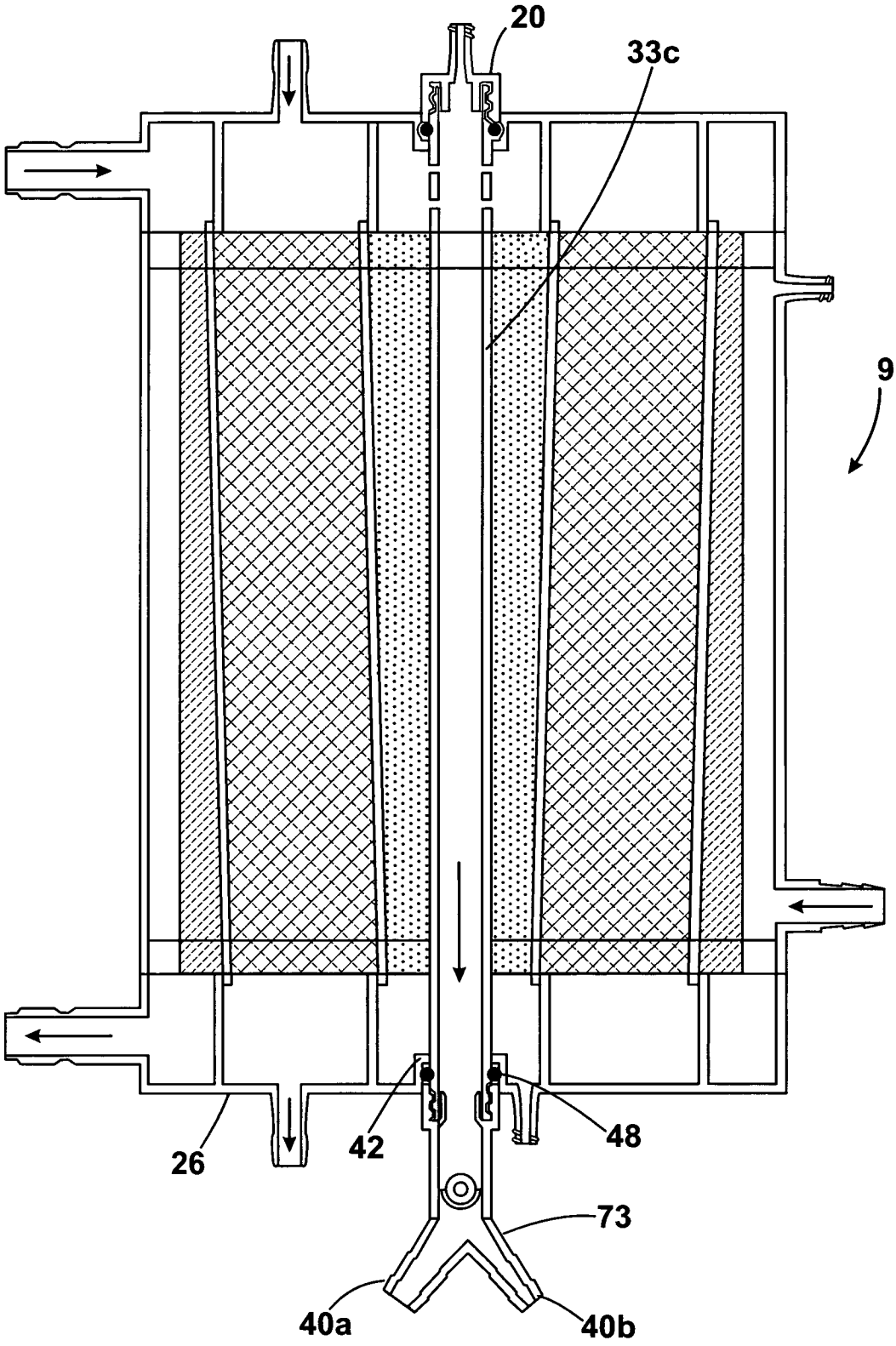

Fig. 8

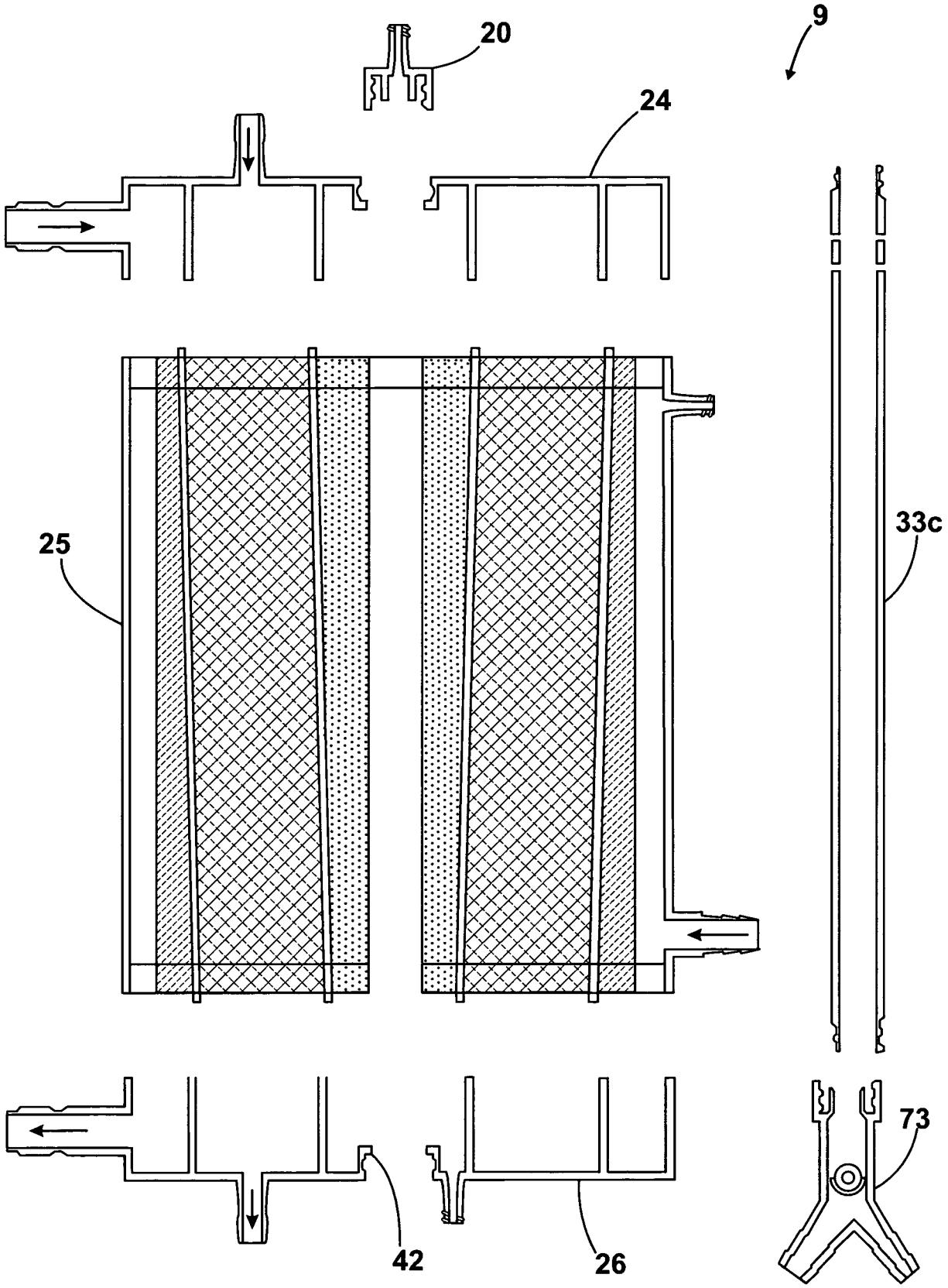

Fig. 9