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3,266,629

GAS AND LIQUID EXCHANGE APPARATUS

Filed March 31, 1964

2 Sheets-Sheet 1

FIG. 1.

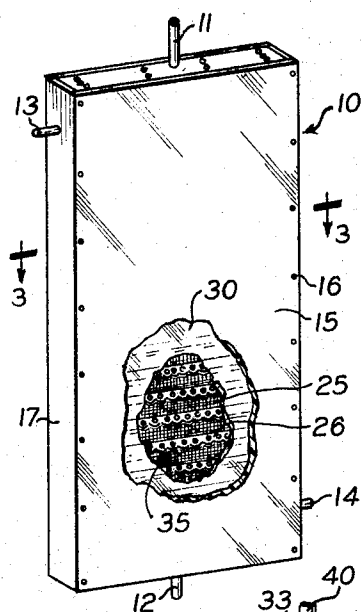
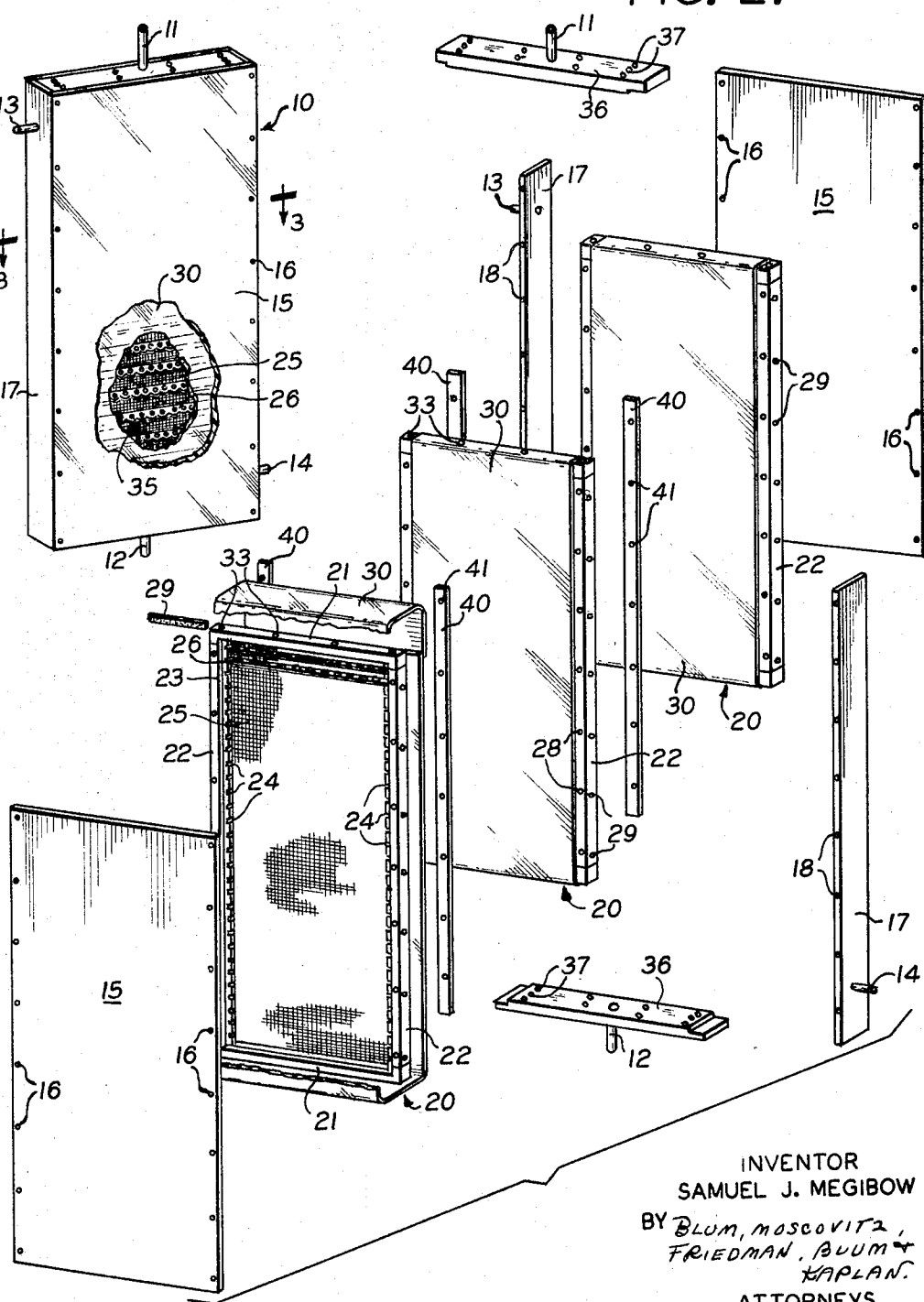


FIG. 2.



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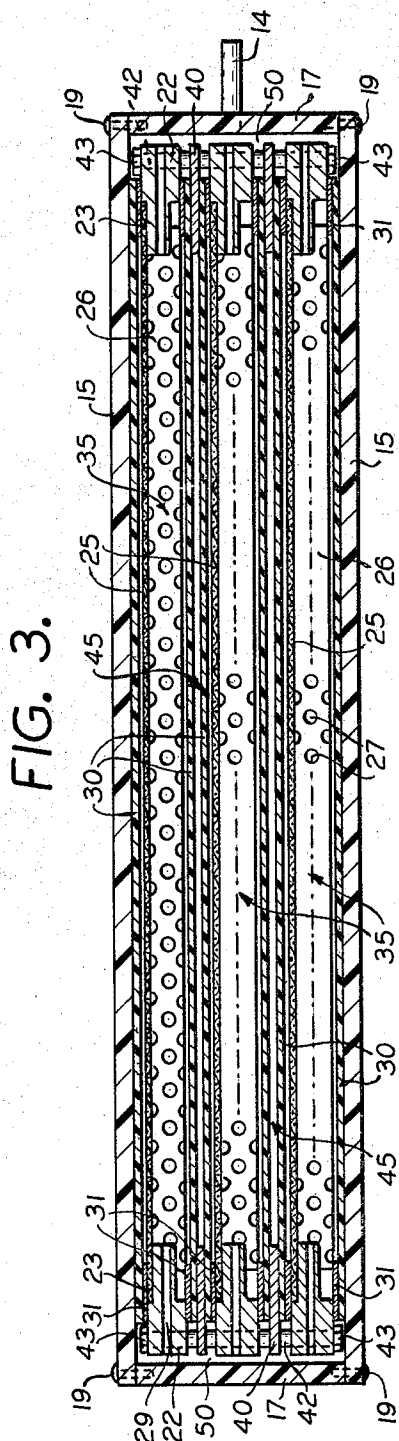


FIG. 3.

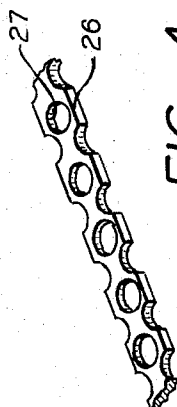


FIG. 4.

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GAS AND LIQUID EXCHANGE APPARATUS

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This invention relates to fluid exchange apparatus and, more particularly, to an improved and more efficient apparatus of this type constructed on a modular principle and readily and easily disassembled for inspection and replacement of parts, as well as being well adapted for efficient sterilization.

Fluid exchange apparatus of the type to which the present invention is applicable is used, for example, in dialyzing, wherein two fluids are passed through chambers on opposite sides of a pervious membrane so that there can be an interchange, by permeation through the membrane, between the two fluids, one of which usually is a gas and the other a liquid. For example, the apparatus is useful as an artificial lung or an artificial kidney.

As hitherto constructed and proposed, fluid exchange apparatus of the pervious membrane type has been complicated, expensive, bulky, and very difficult to maintain in sterilized condition. These factors have mitigated against widespread use of, for example, artificial lungs and artificial kidneys.

In accordance with the present invention, the disadvantages of prior art apparatus of this type are overcome by employing a modular construction by means of which the size of a unit may be readily changed to fit a particular application, and by constructing the unit for ready disassembly for inspection, cleaning, or replacement or repair of parts. The unit may be readily and easily sterilized, either in the assembled condition or in the disassembled condition. The modular components of the apparatus are readily and easily assembled or disassembled so that the size or capacity of any given unit may be changed readily. In addition, such ready disassembly permits the changing of pervious diaphragm members or membranes, when they have become soiled due to use, or permits the ready sterilizing not only of the membranes but also of the other component parts of the apparatus.

To these ends, the fluid exchange apparatus of the invention comprises two or more relatively rigid and substantially rectangular open frames having opposite faces, with each frame having an intersticed membrane-supporting structure disposed in its frame opening and flush with the opposite faces, the supporting structure providing for fluid flow in the frame opening. After insertion of the supporting structure into the frame opening, a single pervious membrane is wrapped around each frame and sealingly covers both sides of the opening therein, this membrane being interiorly supported by the intersticed supporting structure in the frame opening. The membrane is sealed to the frame in any desired manner, and a preferred manner is to use strips or tapes which are adhesive on both surfaces, these strips or tapes being applied along the side edges of the frame and the membrane then being pressed against the exposed adhesive coated faces of the tape, with the two ends of the membrane being brought into abutting relation substantially centered on a transversely extending double adhesive face tape.

The side members of each frame have perforations or bores extending therethrough for flow of fluid into the opening in the frame and discharge of fluid from such opening. The frames are assembled with very thin spacers disposed between corresponding side members of a pair of adjacent membrane-enclosed frames, these spacers, in cooperation with the two facing membrane outer surfaces, forming relatively shallow fluid flow cham-

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bers between adjacent covered frames. After the desired number of membrane-covered frames and interposed side spacers have been positioned together, the unit is enclosed in side plates, top and bottom plates, and front and rear plates, preferably with the interposition of sealing gaskets. The top and bottom plates are provided with inlet and outlet passages through which fluid may enter to flow in the chambers between adjacent frames and may exit from between the adjacent frames through the bottom outlet, for example. Each side plate also has an opening therein, one opening preferably being located adjacent the bottom of one side plate and the other opening preferably being located adjacent the top of the other side plate. The side plate and the frames are so interrelated that a chamber or manifold extends along each side of the unit in communication with the outer side surfaces of all of the frames. Consequently, a fluid introduced through a side plate may flow into the opening in each frame, and be discharged therefrom into a discharge manifold communicating with the outlet opening in the other side plate.

The unit may be readily sterilized either in the assembled condition or in the partially or completely assembled or disassembled condition, with ready access being had to all exposed surfaces. After use, for example, the membrane may be unwrapped from each frame and replaced by a fresh, clean and sterilized membrane. By virtue of the modular construction, the completed unit may have as many frames, with interposed side spacers, as may be necessary or desirable for a particular application.

For an understanding of the principles of the invention, reference is made to the following description of typical embodiments thereof, as illustrated in the accompanying drawings. In the drawings:

FIG. 1 is a perspective view of one form of fluid exchange apparatus embodying the invention;

FIG. 2 is an exploded perspective view illustrating the components of the fluid exchange apparatus shown in FIG. 1;

FIG. 3 is a transverse horizontal sectional view taken on the line 3—3 of FIG. 1; and

FIG. 4 is a partial perspective view of a supporting strut used in the apparatus.

Referring to FIG. 1, the fluid exchange unit 10 illustrated therein has an upper inlet nipple 11 extending from its top wall and a lower outlet nipple 12 extending from its bottom wall. The inlet nipple 11 and outlet nipple 12 are designed to provide for the flow of one fluid through the unit 10. The unit 10 also has a side inlet nipple 13 adjacent the upper end of one side, and a side outlet nipple 14 adjacent the lower end of the other side. Inlet nipple 13 and outlet nipple 14 are designed for flow, through the unit 10, of a second fluid in exchange relation with the first fluid directed to flow through the unit through inlet nipple 11 and out through outlet nipple 12. The unit is enclosed by front and rear plates 15, and side plates 17, these being formed with mating apertures by means of which a pressure-tight enclosure may be obtained through the insertion of suitable studs or bolts locking the interior parts of the unit in place between the front and rear plates 15 and the side plates 17, 17.

Alternatively, the openings 28 in the longitudinal edges of the side plates 17 may be threaded to receive studs, such as 19, inserted through the apertures 16 in the front and rear plates 15.

Referring to FIG. 2, the basic construction component of the exchange unit comprises a series of frames 20 each formed of substantially parallel top and bottom members 21 uniting substantially parallel side members 22. Frames 20 are substantially rectangular in cross section, and the members of each frame are secured together to form an integral unit by any desired means, such as welding, braz-

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ing, soldering or the like. Each frame has opposite side faces and defines a rectangular opening. On both faces of each frame 20, the inner margins of the members 21 and 22 are recessed, as at 23, for a purpose to be described. Furthermore, the inner edges of the side members 22 are formed with uniformly vertically spaced slits or slots 24, also for a purpose to be described, the respective slots in the two side members being at the same level.

The interior of each frame 20 contains an intersticed membrane-supporting structure which is substantially flush with the opposite faces of the frame. This membrane-supporting structure may take various forms, such as a pair of screens with supporting struts disposed therebetween, a honeycomb structure, or combination of a honeycomb structure and screens.

In the particular arrangement shown in FIGS. 1 through 4 of the drawings, each membrane-supporting structure includes a pair of screens 25 which are seated in conforming engagement in the recesses 23. The pair of screens 25 for each frame are properly spaced and supported by perforated spacers or struts 26 extending transversely across each frame, each spacer being seated in a pair of the horizontally aligned slots 24 in the inner edges of the side frame members. The spacers 26 as best seen in FIG. 4, may be strips cut from a sheet having perforations 27. Struts or spacers 26 are so disposed as to allow flow of fluid through the frame opening or chamber defined by the frame 20 and the screens 25, which are later covered with a thin membrane as will be described.

After the struts 26 and screens 25 have been assembled to a frame 20, the latter is ready for enclosure in the membrane. For this purpose, strips of double adhesive face tape 31 are adhered along the side members 22 of the frames 20, on both faces of the frame. A suitable tape of this type may be that known to the trade as "Mylar." This leaves an exposed adhesive face on each tape strip 31 for adherence of the membrane thereto.

The membrane material should have the following properties:

(1) It should be semi-permeable or osmotic so that the apparatus may be used for osmosis of materials across the membrane, or for dialysis, ultra-filtration, selective diffusion, or the like.

(2) The membrane material should be in the nature of a fine film or ultra-thin sheet, as the thinner the membrane, the more effective the membrane is for semi-permeable dialysis or osmotic properties.

(3) The membrane material should be non-wettable, so that it will offer the least resistance to flow and disturbances in the fluids flowing over the membranes.

(4) The membrane material should be substantially completely chemically inert.

(5) The membrane material should be heat resistant and able to withstand temperatures at which heat-pressure sterilization normally is effected. However, the membrane materials may, in certain instances, be cold sterilized by antiseptic solutions or by gas, such as ethylene oxide.

A suitable membrane material is 0.125 mil cast tetrafluoroethylene polymer film, such as a "Teflon" film, which has the foregoing properties. However, cellophane, polyethylene, silicon rubber or many other materials, of this nature may be used.

To apply the membrane 30 to each frame, a roll of the membrane material is used and, starting at the top of each frame, the membrane material is adhered to the adhesive tapes 31 at each side. This roll is then rolled downwardly along the frame on the front face of the frame, around the bottom of the frame, and up over the rear face of the frame and then over the top. As the trailing edge of the membrane meets the leading edge thereof, the membrane is severed from the roll and the two edges are interconnected by a transverse strip of single-face adhesive tape indicated at 29 in FIG. 2, or may be pressed against a transverse strip of double ad-

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hesive face tape. Thus, the frames are completely wrapped in the membrane 30 so that their faces, tops and bottoms are covered by the membrane, but the side edges of the frame remain at least partially exposed. With the covering of the frames by the membrane 30, the frames are substantially complete.

The enclosure of each frame, with its membrane-supporting structure, within a sheet of the membrane material 30, forms a first chamber 35 for flow of fluid through the exchanger. The fluid in the chambers 35 is in contact with the interior surfaces of the membranes 30, so that it may act in exchange relation with fluid in contact with the exterior surfaces of the membranes 30. For this purpose, between each pair of adjacent membrane covered frames, there is provided what may be termed a membrane-spacer chamber through which another fluid is directed. These chambers, which are designated 45, are formed by the outer surfaces of a pair of adjacent membranes 30 and a pair of spacers 40 extending along the side frame members 22 of a pair of adjacent membrane-covered frames. These spacers 40 determine the depth of the membrane lined chambers and also serve as gaskets or pressure-fit seals for the sides of the membrane lined chambers. The spacers must be of material which is similar to that of the membranes and having similar properties, since the fluids flowing through the chambers 45, defined by the membranes 30 and the spacers 40, will be in engagement with the inner edges of the spacers 40. Among materials which may be used for the spacers are "Teflon" and silicone rubber.

For a purpose to be described, the spacers 40, which are essentially relatively elongated flat strips of the desired material, have holes or apertures 41 therethrough and spaced therealong. These holes or apertures 41 correspond, in location, to holes or bores 28 which extend through the side frame members 22. The aligned apertures 28 and 41 are arranged to receive studs 22 which extend through the spacers and the side frame members and have their opposite ends threaded to receive nuts 43 by means of which the membrane-covered frames and the spacers may be maintained in assembled relation. The "stack" of membrane-covered frames and membrane-spacer chambers 45 may be built up to any desired size depending upon the desired capacity of the fluid exchanger. After the desired number of covered frames, separated by the spacers 40, have thus been assembled, the entire arrangement is enclosed within pressure covers.

With the interposition of suitable gasket material along the top and bottom members 21 of the frame 20, top and bottom plates 36 are placed along the top and bottom edges of the assembly or unit of the membranes-covered frames and spacers 40. These top and bottom plates have widths equal to the thickness of the assembly and have lengths somewhat longer than the lengths of the top and bottom frame members 21. Plates 36 are provided with rows of apertures 37, the number of apertures in each row corresponding to the number of frames in the assembly. These apertures align with apertures 33 in the top and bottom frame members 21, so that studs may be inserted through apertures 37 and threaded into apertures 33 to lock the covered frames 20, the spacers 40, and the plates 36 into a unitary assembly.

The properties of the material used for the plates 36 must be equivalent to those used for the membranes 30. One suitable material is "Teflon," and with this material the plates 36 are made substantially one-half inch in thickness. The top plate 36 is provided with the inlet nipple 11, which is likewise formed of a material having the same properties as that of the membranes, and the bottom plate 36 is provided with the outlet nipple 12 which is also formed of material having the same properties as that of the membranes 30. At this time, if desired or indicated, the assembled unit can be sterilized

either by heat-pressure sterilization or by liquid or gas sterilization.

With the interposition of suitable gaskets, the side plates 17, each of which has a width equal to that of the top and bottom plates 36, are placed in engagement with the ends of the top and bottom plates. One of these side plates has the inlet 13 at its upper end and the other of the side plates has the outlet 14 at its lower end. Again with the interposition of suitable gasketing material, the front and rear plates 15 are placed against the edges of the side plates and of the top and bottom plates, and the enclosure of the exchanger is completed by the use of studs or bolts extending through the aperture 16 in the front and rear plates 15 and the apertures 18 in the side plates 17.

The front, rear and side plates serve to confine pressures developed within the exchanger, and for this purpose must be made of material of suitable strength and thickness. They also serve to maintain the two chambers 35 and 45 in proper relation, including the frames 20 and the spacers 40. A suitable material which may be used for the front and rear plates is "Plexiglas," as this will permit observation of the functioning of the exchanger, and the same material may be used for the side plates 17. Alternatively, stainless steel may be used for these parts as well as for the frames.

It will be noted that, due to the top and bottom plates 36 having a length greater than that of the frame members 21, side chambers or manifolds 50 are formed in the assembled unit.

These side chambers serve for ingress and egress of fluid into the frame chambers 35, such ingress and egress being provided by bores 29 extending through the side frame members 22 intermediate the opposite faces of the frames 20. Due to the interposition of the gasketing material, the top and bottom plates 36 are spaced slightly above the tops of the top and bottom frame members 21, forming chambers establishing communication between inlet 11, outlet 12, and the membrane-spacer chambers 45. The entire assembly may now be tested for leakage both as respects the membrane-spacer chambers 45 and as respects the frame chambers 35. If there is no leakage, the assembled unit is now ready for operation by passing one fluid through the frame chambers 35 and another fluid through the membrane-spacer chambers 45 for interchange through the membranes 30.

The described fluid exchange apparatus has numerous advantages. The size of the membrane-spacer chambers 45 can be rigidly controlled since the supporting intersticed structures are substantially rigid. Nevertheless, and at the same time, the faces of the membranes 30 have maximum exposure to a fluid flowing through the frame chambers 35. Since the membrane-spacer chambers 45 are disposed between two covered frames 20, both surfaces of each chamber 45 have the same exposure.

The apparatus can be completely heat-pressure sterilized as a completely assembled unit or at various stages during assembly thereof, each assuring maximum sterility. However, and if so desired, the apparatus may be gas or liquid sterilized.

The membranes 30 are easy to apply and remove and, following their usage, may be disposed of and new membranes applied to the frames. However, since the unit is of such rigid construction, the entire unit may be easily cleaned, re-sterilized, and re-used. All parts of the apparatus except the membranes are otherwise designed for permanent and re-usable operation.

Both series of chambers, comprising the series of chambers 35 and the series of chambers 45, form completely closed and independent systems. Therefore, the pressure within each series of chambers can be controlled and varied independently of the pressures within the other series of chambers. This enhances the efficiency of the apparatus. This modality may be utilized in varying the pressures within the supporting and structural chambers 35

by varying, rather rapidly, the rate of escape of the fluid at the discharge orifice 14. By varying the rate of pressure within chambers 35 relative to the pressure within the chambers 45, the membranes 30 may be caused to undulate or vibrate, thus reducing the laminar flow within the membrane-spacer chambers 45 and thereby increasing the efficiency. By proper selection of pressure within the chambers 35, the membranes 30 are additionally supported by the internal pressure of the fluid flowing through the chambers 35.

Additionally, by changing the pressure relationship within each series of chambers, the partial pressures of gases and the like can be changed to enhance the efficiency of the apparatus.

The chambers 35 can be modified in such a manner that more than one fluid (gas or liquid) can be circulated through the same at the same time. By controlling the temperature of the circulating liquid, the machine may assume thermostatic properties for control of the temperatures in the membrane-spacer chambers 45.

The spacers 40 are, as a rule, very thin so that the layers of material flowing through the chambers 45 are very fine and film-like. Thereby, the priming volume of the chambers 45 may be relatively small as compared with the rate of flow therethrough.

Since the apparatus is disposed in an upright position, and the flow is from top to bottom thereof, the flow through the machine can be achieved entirely by gravity. However, if desired, a pump may be used for either or both feeds, although a pump is not essential. The rate of flow can also be varied by changing the angle of uprightness of the machine, and also by changing the rate at which fluid is removed from the bottom or discharge orifices.

Membranes 30 of various materials may be interchanged in accordance with the desired end use of the apparatus. For example, and for use of the apparatus as an artificial lung, a membrane comprising an ultra-thin (or 0.125 mil) cast "Teflon" membrane is used. This will allow CO₂ and O₂ to pass through the membrane so that the apparatus may act as an artificial lung. When it is desired to use the apparatus as an artificial kidney, a cellophane membrane 30 may be used and blood will flow through the membrane-spacer chambers 45, with dialyzing or ultra-filtration solutions flowing through the chambers 35. It will therefore be appreciated that the described fluid exchanger is very versatile both in function and in size.

While a specific embodiment of the invention has been shown and described in detail to illustrate the application of the principles of the invention, it will be understood that the invention may be embodied otherwise without departing from such principles.

What is claimed is:

1. Fluid exchange apparatus comprising, in combination, at least a pair of relatively rigid substantially rectangular open frames having opposite faces; intersticed membrane-supporting structures each disposed in a frame opening and substantially flush with said opposite faces, said supporting structures providing for fluid flow in the frame opening; a single pervious membrane wrapped around each frame and sealingly covering both faces of the opening therein, the membrane being interiorly supported by the supporting structure in the associated frame opening; spacer means disposed between each pair of adjacent membrane-covered frames and each defining, with the associated pair of facing outer membrane surfaces, a relatively shallow fluid flow chamber; means holding at least a pair of membrane-covered frames, with interposed spacing means, assembled as a unit; means operable to introduce a first fluid into each chamber and to withdraw the first fluid therefrom; and means operable to introduce a second fluid into each frame opening and to withdraw the second fluid therefrom.

2. Fluid exchange apparatus, as claimed in claim 1,

including pressure and fluid-tight closure means enclosing said unit; said closure means, in cooperation with said unit, defining a first inlet chamber and a first outlet chamber in communication with each of said relatively shallow fluid flow chambers and with said first fluid introduction and withdrawal means, and a second inlet chamber and a second outlet chamber, in communication with said frame openings and with said second fluid introduction and withdrawal means.

3. Fluid exchange apparatus, as claimed in claim 1, in which said unit is arranged for disassembly for access to the membrane covered frames; and adhesive means disengageably securing each membrane to its associated frame, whereby the membrane may be unwrapped from an associated frame for replacement of the membrane.

4. Fluid exchange apparatus, as claimed in claim 1, in which each membrane is impervious to a liquid, constituting said first fluid, and pervious to a gas, constituting said second fluid.

5. Fluid exchange apparatus, as claimed in claim 1, constituting an artificial kidney; said first and second fluids being liquids; each membrane being impervious to said first fluid and pervious to said second fluid.

6. Fluid exchange apparatus, as claimed in claim 1, in which said pervious membrane comprises a very thin sheet of a cast tetrafluoroethylene polymer plastic.

7. Fluid exchange apparatus, as claimed in claim 6, in which the supporting structure in each frame includes a pair of screens each seated in recesses in a respective face of the associated frame; and strut means disposed in the frame opening and in engagement with each screen of the associated pair.

8. Fluid exchange apparatus, as claimed in claim 1, in which said pervious membrane comprises a sheet of cellophane.

9. Fluid exchange apparatus comprising, in combination, at least a pair of relatively rigid, substantially rectangular open frames each having a pair of parallel side members interconnected by a pair of parallel top and bottom members, and each having opposite faces; intersticed membrane-supporting structures each disposed in a frame opening and substantially flush with said opposite faces, said supporting structures providing for fluid flow in the frame openings; a single pervious membrane wrapped around each frame and sealingly covering both faces of the opening therein, the membrane being interiorly sup-

ported by the supporting structure in the associated frame opening; a pair of spacers disposed between each pair of adjacent membrane-covered frames and extending along corresponding side members thereof, each pair of said spacers defining, with the associated pair of facing outer membrane surfaces, a relatively shallow fluid flow chamber open at the top and bottom of each pair of adjacent membrane-covered frames; means holding at least a pair of membrane-covered frames, with interposed spacers, assembled as a unit; top and bottom closure plates in fluid-tight relation with the top and bottom edges of said unit, respectively; a first fluid inlet in said top closure plate communicating with said relatively shallow fluid flow chambers of the unit; a first fluid outlet in said bottom closure plate communicating with the relatively shallow fluid flow chambers of the unit; and means operable to introduce a second fluid into each frame opening and to withdraw fluid therefrom.

10. Fluid exchange apparatus, as claimed in claim 9, in which each of said top and bottom plates extends beyond the side members of said frames; a pair of side cover plates in fluid-tight relation with said top and bottom closure plates and each in spaced relation to the respective side members of the frames of said unit to form a pair of side manifolds; front and rear closure plates in fluid-tight relation with said top and bottom closure plates and said side closure plates; the side members of each frame being formed with apertures therethrough to establish communication between the frame openings and each of said manifolds; said means operable to introduce such second fluid into each frame opening including an inlet in one of said side closure plates and communicating with one respective manifold, and an outlet in the other of said side plates and communicating with the other respective manifold.

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