(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
4 March 2004 (04.03.2004)

PCT

(10) International Publication Number
WO 2004/018067 A2

(51) International Patent Classification[7]: B01D

(21) International Application Number: PCT/US2003/023614

(22) International Filing Date: 29 July 2003 (29.07.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/404,944 21 August 2002 (21.08.2002) US
10/261,107 30 September 2002 (30.09.2002) US

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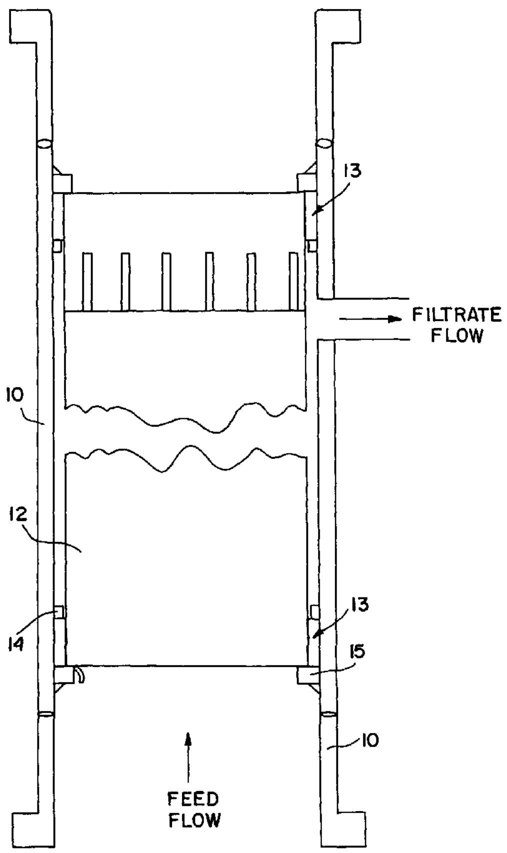
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO,

[Continued on next page]

(54) Title: AIRLIFT MEMBRANE DEVICE AND MEMBRANE BIOREACTOR AND BIOREACTOR PROCESS CONTAINING SAME



(57) Abstract: A submerged, vertically-mounted membrane device, the device receiving a gas-sparged feed stock at a bottom feed inlet to provide airlift circulation of the feed stock through the device and separating the feed stock into filtrate and residual gas-containing retentate which passes from the top end of the device. The device comprises a structure of one or more monolith segments of porous material each monolith segment defining a plurality of passageways extending longitudinally from a bottom feed end face to a top retentate end face. A porous membrane is applied to the walls of the monolith segment passageways to provide a separating barrier. At least one filtrate conduit within the device carries filtrate from within the device toward a filtrate collection zone of the device, and the filtrate conduit provides a path of lower flow resistance than that of alternative flow paths through the porous material. A seal is provided to separate feed stock and retentate from the filtrate collection zone.

WO 2004/018067 A2

SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report*

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AIRLIFT MEMBRANE DEVICE AND MEMBRANE BIOREACTOR AND BIOREACTOR PROCESS CONTAINING SAME

This application claims priority of provisional patent application Serial No. 60/404,944 filed on August 21, 2002 and U.S. patent application Serial No. 10/261,107 filed on September 30, 2002, the disclosures of which are hereby incorporated by reference.

FIELD OF THE INVENTION

This invention relates to an airlift membrane device, an airlift membrane bioreactor containing same, and an airlift bioreactor process. The membrane device utilizes one or more multiple passageway porous monoliths as a microfiltration or ultrafiltration membrane support. The monolith-based membrane device provides a compact, low cost device that has well-controlled and efficient airlift for membrane flux maintenance. The use of a ceramic membrane offers a hydrophilic membrane resistant to fouling by the bioreactor biomass feed stock.

BACKGROUND AND PRIOR AND RELATED ART

The rapid emergence of the membrane bioreactor (MBR) has lead to the deployment of several types of membrane devices in such MBR's, in both "submerged membrane" and pumped "external loop" membrane module configurations. For the submerged membrane configuration, which is favored due to lower costs, there are primarily two membrane types employed: polymeric hollow fibers and polymeric plate devices. Descriptions of the state of the art for both submerged and external loop technology can be found in the following:

1. Articles in the June 2002 issue of Filtration + Separation, Vol. 39, no. 5, pages 26-35.
2. Proceedings of the Microfiltration III Conference, Costa Mesa, CA, May 5-7, 2002.
3. "Membrane Bioreactors: Wastewater Treatment Applications to Achieve High Quality Effluent", by Steven Till and Henry Mallia, presented at the 64th Annual Water Industry

The last paper describes the two leading st systems, hollow fibers sold by Zenon (Canada) and plate sold by Kubota (Japan). The invention that is the sub this patent application and that can be used in a submer is a substantially different membrane configuration, multiple passageway monolith membrane device. The str covered by this invention have the characterist intrinsically low cost and a very high membrane surfa per unit volume of the device.

Similar devices in various structures when u crossflow membrane modules, as could be used in extern MBR's, have been disclosed in the following p specifically incorporated herein by reference:

1. USP 4,781,831 (Goldsmith), which discloses in F: therein, and described in the patent Specificat cluster of individual multiple passageway mo arranged to have "filtrate flow conduits" formed space among the monolith elements.
2. USP 5,009,781 and USP 5,108,601 (Goldsmith), which disclose in the Figures and Specification unitary m structures with filtrate conduits formed with monoliths.
3. USP 6,126,833 (Stobbe, et al.), which discloses str comprised of a collection of monolith segments con both segment internal filtrate conduits and a f conduit arrangement formed by the gap among the m segments.

Preferred embodiments of the monolith based m device would be fabricated from a porous ceramic m support and a finer-pored ceramic or polymeric membrane applied to the passageway wall surfaces of the m support.

Ceramic membrane microfiltration (MF) and ultrafil (UF) devices have been used in external MBR systems. E

08/17, Vol. 5, No. 3, pp 283-287 (Sept. 2000)) and an by Fan, Urbain, Qian, and Manem ("Ultrafiltration of Ac Sludge with Ceramic Membranes in a Cross-Flow M Bioreactor Process", Water Science & Technology, Vol. 10-11, pp 243-250 (2000)).

There has been little work using ceramic membrane submerged MBR configuration. A recent presentation Xing, and Xu entitled "Design and Application of Membrane-Bioreactor for Municipal Wastewater Recla describes the use of an airlift MBR using single ceramic UF membrane elements and a five (5) multichannel UF membrane element (Presentation at th American Membrane Society Meeting, May 11-15, 2002, Long CA).

SUMMARY OF THE INVENTION

This device features a submerged, vertically- airlift membrane device. The device comprises a struc one or more monolith segments of porous material, each m segment defining a plurality of passageways ex longitudinally from a bottom feed end face to a top re end face. The surface area of the passageways in the m segment is at least 150 square meters per cubic me monolith segment volume, and the porous material has a p of at least 30% and a mean pore size of at least 3 μm membrane with mean pore size below 1 μm is applied to th of the monolith segment passageways to provide a sep barrier. A gas sparger is located below the device to a gas-sparged liquid feed stock at the bottom end provide airlift circulation of the feed stock throu device, which separates the feed stock into filtrate residual gas-containing retentate that passes from the face of the device. At least one filtrate conduit is within the device for carrying filtrate from within the has at least one seal to separate feed stock and retenta the filtrate collection zone.

In a preferred embodiment, the porous material membrane device is ceramic. The device structure comprised of a single monolith or an assembly of n segments. The membrane device can be contained in a for filtrate collection and the filtrate collection zone annular space between the device and the h Alternatively, the device can be isolated along the e surface and the filtrate can be withdrawn from an end the device.

The membrane used in the device can be a microfil membrane with a pore size from about 0.1 to about 1 mi an ultrafiltration membrane with a pore size from about about 0.1 micron. Preferably, the membrane is a membrane.

The vertically mounted membrane device can cor shroud extending below the bottom end face of the dev the gas is sparged into a cavity created by the Preferably, the hydraulic diameter of the passageways about 4 to 15 mm and the preferred hydraulic diameter monolith segments is greater than about 50 mm.

This membrane device can be used in a membrane bic that includes, in addition to the cross flow membrane de membrane bioreactor feed tank with means of introducti liquid feed stock and a means to convey the filtrate f filtrate collection zone of the device to the i discharge point of the bioreactor.

The membrane device can be installed within a bic feed tank in an internal airlift circulation loop, or installed external to the feed tank in an external circulation loop. The sparged gas can be air or oxygen bioreactor can operate under aerobic conditions, or the

This invention further features a bioreactor proce includes introducing a feedstock into a submerged membrane bioreactor. Gas is sparged at a bottom feed i at least one submerged, vertically-mounted membrane de provide airlift circulation of the feedstock throu device, and the feed stock is separated into filtr residual gas-containing retentate which passes from the of the device. The device consists of a structure of more monolith segments of porous material each monolith defining a plurality of passageways extending longitu from a bottom feed end face to a top retentate end fa surface area of the passageways in the monolith segmen at least 150 square meters per cubic meter of monolith volume. The porous material has a porosity of at least a mean pore size of at least 3 μm and a porous membra mean pore size below 1 μm is applied to the walls monolith segment passageways to provide a separating l At least one filtrate conduit within the device filtrate from within the device toward a filtrate co zone of the device, and the filtrate conduit provides a lower flow resistance than that of alternative flo through the porous material. The device has a m separate feed stock and retentate from the filtrate co zone. The filtrate collected in the filtrate collecti is conveyed to the filtrate discharge point of the biore

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross-sectional view of a potted element in an enclosing housing in accordance w embodiment of the present invention;

Figure 2 is a perspective view of a segmented s assembled around a central cavity in accordance w embodiment of the present invention;

Figure 4 is a cross-sectional view of an aerobic m bioreactor wherein air is sparged at the bottom ends membrane devices in accordance with an embodiment present invention;

Figure 5 is a cross-sectional view of an aerobic m bioreactor wherein air is sparged within shrouds at the ends of the membrane devices in accordance with an emb of the present invention; and

Figure 6 is a top view of banks of membrane module bioreactor tank in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF INVENTION

The description which follows focuses on an airli However, the membrane element that is the subject present invention can be used for any pressure-driven m process in which a liquid feed stock is separated into f and retentate streams. The transmembrane pressure force can be applied by using a filtrate pump to cr filtrate pressure below that of the pressure of the feed Alternatively, the filtrate can be withdrawn at a l physically below the level of the membrane element, i case the elevation of the membrane element higher th withdrawal point of the filtrate creates a gravit transmembrane pressure. While processes in which th stock is essentially at atmospheric pressure are envisi pressurized feed stock can also be used to create the ne transmembrane pressure. Membrane processes for whic invention is especially applicable include microfiltrat ultrafiltration. However, if the necessary transm pressure can be generated, the invention could be us nanofiltration and reverse osmosis.

airlift MBR, viz.

1. Operation of the MBR at a relatively low transm pressure (TMP), and the resultant requirement of ha monolith membrane support and membrane coating wit permeability;
2. Operation of the MBR with a high level of suspended (e.g., 10,000-20,000 mg/l), which can plug pass below a minimum dimension; and
3. The need to have a membrane with a pore size suffi small to efficiently retain the MBR biomass.

In the present invention, one or more porous ho monolith segments are used as membrane supports. The m material is preferably a ceramic, but can also be a metal, plastic, filled resin, resin-bonded glass or s metal, or other composites. For ceramics, preferred ma have been disclosed in the US Patents of Goldsmith and et al., cited above, as well as the reaction bonded monolith disclosed in US Patent Application Seri 10/097,921 filed March 13, 2002, the disclosure of wl hereby incorporated by reference..

The monoliths can have a circular, square, hex rectangular, triangular or other cross-section. The pas hydraulic diameter should be 2 mm or greater, preferably range of about 4 to 15 mm, selected to be sufficiently l as to resist blockage by solids under operating condit an airlift MBR. The monolith porosity should be great 30%, preferably greater than 40% to maximize permeabilit monolith passageway wall thickness should be sufficient to provide adequate strength and permeability, but not so as to deleteriously reduce the passageway wall area p volume. Typically, the monolith passageway wall th would be between 20% and 40% of the passageway hy diameter. To minimize costs of the device, the hy

The structure of the monolith support can be as di in the cited patents of Goldsmith and Stobbe, et al. include a single monolith with internal filtrate condu: assembly of monolith segments with the filtrate conduit by the space among segments, and the same with the s having one or more internal filtrate conduits.

The monolith support (or supports) can be coated wi membrane or a UF membrane. The membrane could be c polymeric, or metallic. Membrane coating materia procedures for coating tubular and monolith supports a: known in the membrane art. One category of preferred me includes MF membranes which have a pore size in the r about 0.1 to 0.5 μm, and which are capable of having ve retention efficiency for microorganisms. A second t membrane that can be employed is an UF membrane, with size in the range of about 0.01 to 0.1 μm and which c retain viruses with high efficiency.

The single or multiple monolith segment device, coating with a membrane, becomes a membrane element th be configured with a means to separate filtrate from feed contents. For the honeycomb monolith membrane structures, means of filtrate withdrawal have been discl the patents of Goldsmith, cited above and included he reference. One means is withdrawal of filtrate from al sides of the monolith membrane element into an er housing. One simple means to accomplish this is to membrane element into a housing. As shown in Figure individual filter element 12 with internal filtrate conc potted into a housing 10 with potting compound 13. The 10 includes a standoff ring 14 and a support ring 15 as Another method of filtrate withdrawal is to extract f from an end face of the membrane element. This accomplished, for example, with the segmented struct Stobbe, et al., with the filtrate collection tubes of Gc (USP 5,009,781), and to withdraw the filtrate from an e of a multi-segment element. Such a structure is illust:

wrapped with an impermeable sleeve or otherwise sealed the assembly together and to prevent filtrate from exi the lateral circumferential surface of the structure central cavity 17 is connected to a filtrate wit tube(scaled in the cavity 17 but not shown), which need the length of the structure. The intersegment portion intrasegment portion 19 of the filtrate conduit are se the end faces. The assembled segmented structu appropriately sealed at the ends to prevent contamina the filtrate by feed wastewater. The filtrate withdraw can also serve as a mechanical support for the membrane mounted vertically in a MBR waste treatment tank.

Structures of the type described above can have high membrane packing density. For example, for di passageway sizes and monolith wall thicknesses, assum utilization of the passageways for contacting a feed stc packing densities of Table 1 are achievable.

Table 1. Properties of Monolith Based Membrane Devi

Passageway size, mm	Wall thickness @ 25%, mm	Percentage passageways used for filtrate conduits	Approxima Membrane area/volume m/cu m
4	1	80%	510
6	1.5	80%	340
8	2	80%	255
10	2.5	80%	205
12	3	80%	170

transmembrane pressure (TMP) to drive filtrate can be a by either of the means normally employed in other su MBR's, viz. gravity head or a filtrate pump which j partial vacuum on the filtrate side of the device.

Multiple membrane devices can be mounted vertical MBR wastewater tank in a closely packed array, such as s Figures 3a and 3b. Figure 3a illustrates a 2 x 8 a square filter elements 12'. The elements can have f withdrawn from the side of the enclosure (not shown) tubes can be connected to internal filtrate co cavities. Figure 3b illustrates a 4 x 7 array of round elements 12". The elements can have filtrate withdra individual housing shells or end tubes from the top or end faces. For an aerobic MBR, air (or oxygen) is spa the bottom ends of the membrane devices with a suitable 21 in communication with a source of compressed air or and the rising gas 22 provides the airlift for liqu through the passageways and oxygen for the biological o process (Figure 4). It is possible to provide shr around the lower part of the membrane devices and to h air (or oxygen) sparged within the shroud to insure t sparged gas will flow up through the device passageways 5). This will provide the most efficient means of oxygen introduction in terms of efficient airlift mass within the membrane devices since all of the gas wi through the membrane devices with negligible bypas found, especially, in hollow fiber MBR contactors.

The same membrane device can be used for an anaerol sparging with inert gas or a gas with low oxygen content

The arrangement of membrane devices, as shown in F has the spacing among banks of membrane devices 25 a for liquid downflow after disengagement of the gas anc at the top of the devices. The banks 25 are separated spaces for deaerated liquid downflow. Filtrate wi depends on whether housings or internal cavities are

The advantages of the subject invention inclu following. First, the compactness of the membrane provides a very high membrane area per unit volume submerged MBR reactor, comparable to those of hollow fil plate MBR's. Second, the hydrodynamic control of liquid device passageways will promote very high mass tr uniform throughout the device. The use of shrouds will all gas introduced is used for efficient airlift. This provide high membrane flux and low compressed gas pov unit flux relative to other membrane devices. A pr membrane will be ceramic, which will be very rugg mechanically durable, and can be expected to have a lo relative to polymeric membranes used in hollow fiber an configurations. For ceramic membranes, in particular, possible to apply membrane coatings which are hydrophilic and will be weakly adsorptive of contaminants present in MBR's. This will reduce foul improve effectiveness of chemical cleaning. The devi capable of cleaning by pressurized filtrate backfl pressurized gas backflushing, chemical solution backfl and circulation of chemical cleaning solutions in a operating mode, especially when operating without f withdrawal. Cleaning agents can include acids, caus oxidants such as hypochlorite.

The use of large diameter monolith devices, as di herein, is conducive to production of ceramic membrane that can be cost competitive with lost cost pc membranes. While the membrane devices may be more cost polymeric hollow fibers per unit membrane area, the anti advantages of higher membrane flux, lower power consu and longer membrane life will offset a higher membra cost.

As an alternative to immersion of the membrane dev the MBR feed tank, they can be utilized in an external circulation mode. In this arrangement, the membrane are mounted external to the feed tank and the airlift

Although specific features of the invention are sh in various embodiments, this is for convenience only feature may be combined with any or all of the other f in accordance with the invention. Other embodiments wil to those skilled in the art and are within the scope following claims:

device comprising:

a structure of one or more monolith segments of material, each monolith segment defining a plura passageways extending longitudinally from a bottom f face to a top retentate end face, the surface area passageways in the monolith segment being at least 15(meters per cubic meter of monolith segment volume;

said porous material having a porosity of at least a mean pore size of at least 3 μ;

a porous membrane with mean pore size below 1 m ap the walls of the monolith segment passageways to pr separating barrier;

a gas sparger located below the device to provide sparged liquid feed stock at the bottom end face to airlift circulation of feed stock through the device separates the feed stock into filtrate and residu containing retentate which passes from the top end face device;

at least one filtrate conduit within the dev carrying filtrate from within the device toward a collection zone of the device, the filtrate conduit pro path of lower flow resistance than that of alternati paths through the porous material; and

at least one seal to separate feed stock and r from the filtrate collection zone.

2. The device of Claim 1 in which the porous mat ceramic.

3. The device of Claim 1 in which the struc comprised of a single monolith.

4. The device of Claim 1 in which the struc comprised of an assembly of monolith segments.

5. The device of Claim 1 in which the structure is contained in a housing for filtrate collection and the filtrate collection zone is the annular space between the device and the housing.

6. The device of Claim 1 in which the structure is sealed along the exterior surface and the filtrate is withdrawn from an end face.

7. The device of Claim 1 in which the membrane is a microfiltration membrane with a pore size from about 0.1 to about 1 micron.

8. The device of Claim 1 in which the membrane is an ultrafiltration membrane with a pore size from about 5 nm to about 0.1 micron.

9. The device of Claim 7 in which the membrane is a ceramic membrane.

10. The device of claim 8 in which the membrane is a ceramic membrane.

11. The device of Claim 1, wherein said device has a bottom end face and further comprises a shroud extending below said bottom end face and defining with said bottom end face a cavity, and wherein gas from said gas sparger is sparged into said cavity.

12. The device of Claim 1 in which the hydraulic diameter of said passageways is from about 4 to about 15 mm.

13. The device of Claim 1 in which the hydraulic diameter of said monolith segment or segments is greater than about 50 mm.

14. A submerged airlift membrane bioreactor, comprising:

the membrane device of claim 1;

a membrane bioreactor feed tank with means of liquid feed stock introduction; and a means to convey the filtrate from the filtrate collection zone of the device to the filtrate discharge point of the bioreactor.

15. The bioreactor of Claim 14 in which the membrane device is installed within the bioreactor feed tank in an internal airlift circulation loop.

16. The bioreactor of Claim 14 in which the membrane device is installed external to the feed tank in an external airlift circulation loop.

17. The bioreactor of Claim 14 in which the sparged gas is air or oxygen and the bioreactor operates under aerobic conditions.

18. The bioreactor of Claim 14 in which the sparged gas has low or negligible oxygen content and the bioreactor operates under anaerobic conditions.

19. A bioreactor process comprising:

providing a submerged airlift membrane bioreactor having at least one submerged, vertically mounted membrane device having a bottom feed end face having an inlet, and a top end face;

introducing a liquid feedstock into said submerged airlift membrane bioreactor;

sparging gas at said bottom feed inlet of said at least one submerged, vertically-mounted membrane device to provide airlift circulation of the feedstock through the device, and separating the feed stock into filtrate and residual gas-containing retentate which passes from said top end of the device;

said device comprising a structure of one or more monolith segments of porous material each monolith segment defining a plurality of passageways extending longitudinally from said bottom feed end face to a top end face, the surface area of the passageways in the monolith segment being at least 150 square meters per cubic meter of monolith segment volume, the porous material having a porosity of at least 30% and a mean pore size of at least 3 μ and a porous membrane with mean pore size below 1 μ applied to the walls of the monolith segment passageways to provide a separating barrier;

at least one filtrate conduit within the device carrying filtrate from within the device toward a filtrate collection zone of the device, the filtrate conduit providing a path of lower flow resistance than that of alternative flow paths through the porous material, and the device having a means to separate feed stock and retentate from the filtrate collection zone; and

conveying the filtrate from the filtrate collection zone to the filtrate discharge point of the bioreactor.

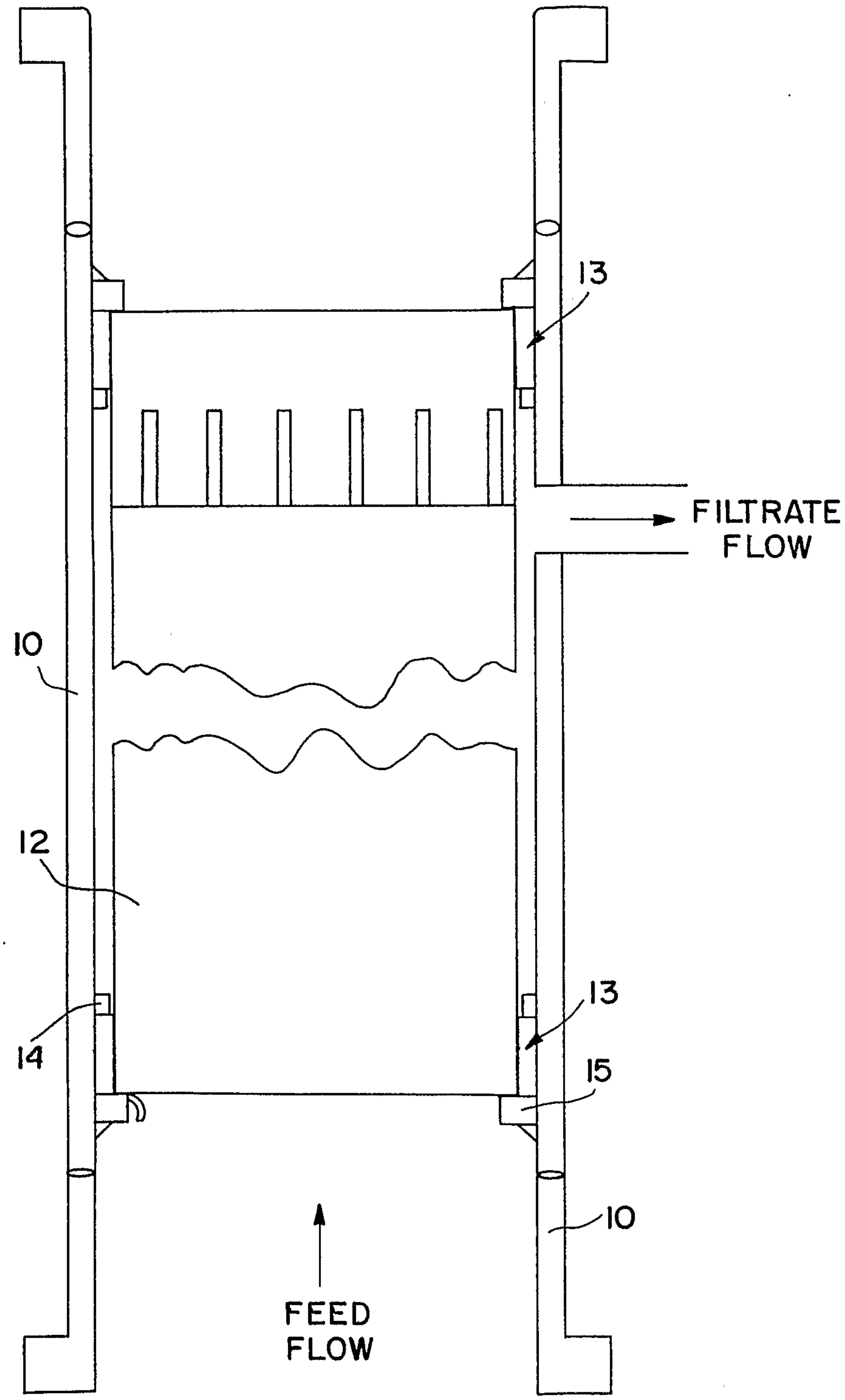

FIG. 1

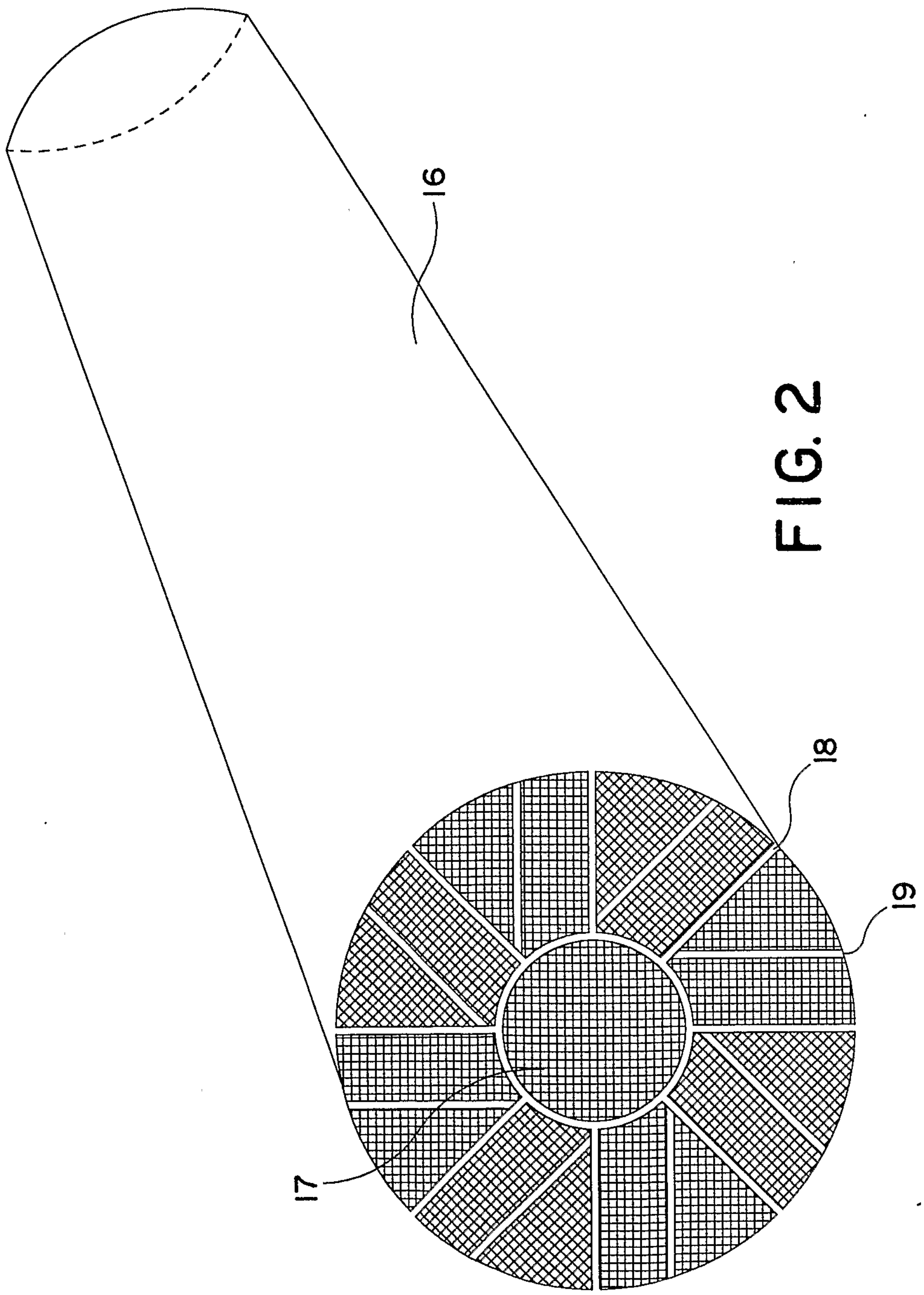

FIG. 2

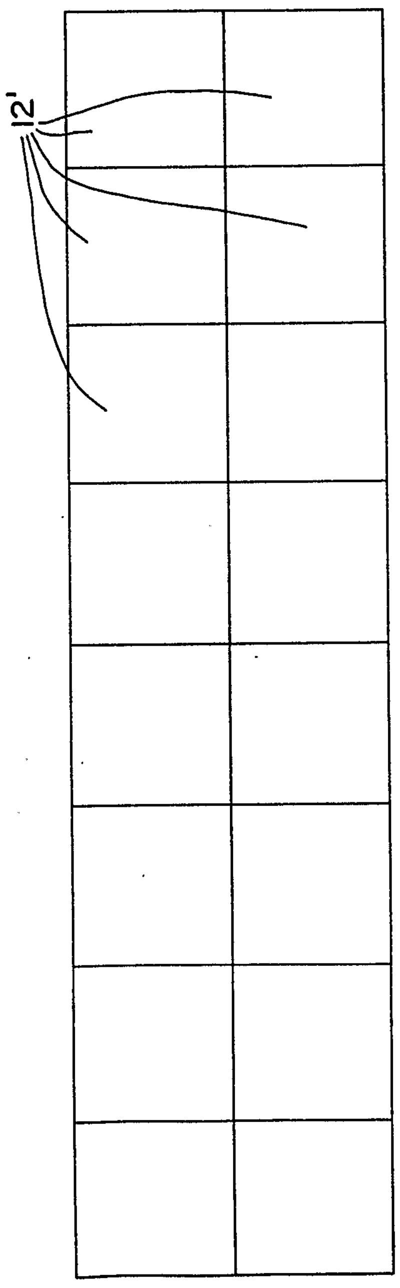

FIG. 3a

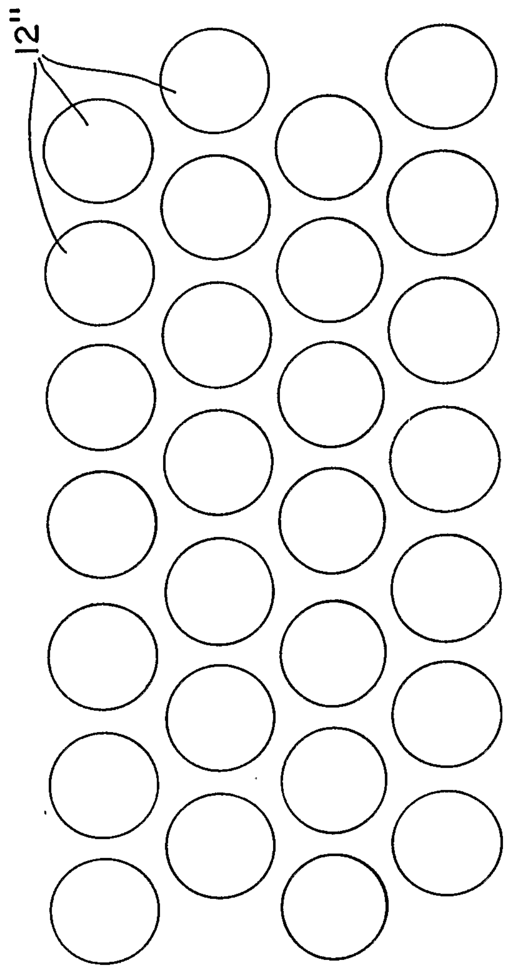

FIG. 3b

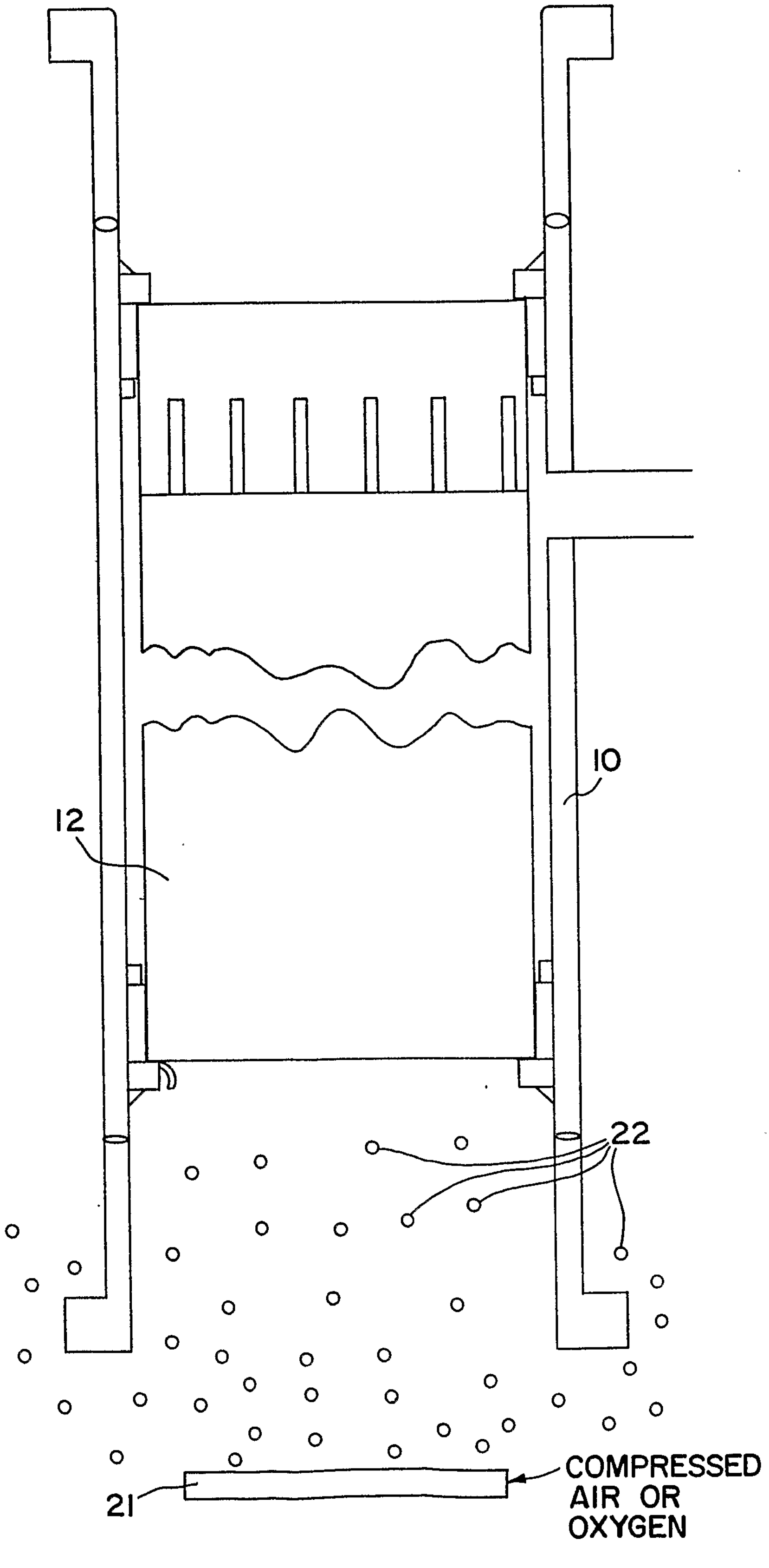

FIG. 4

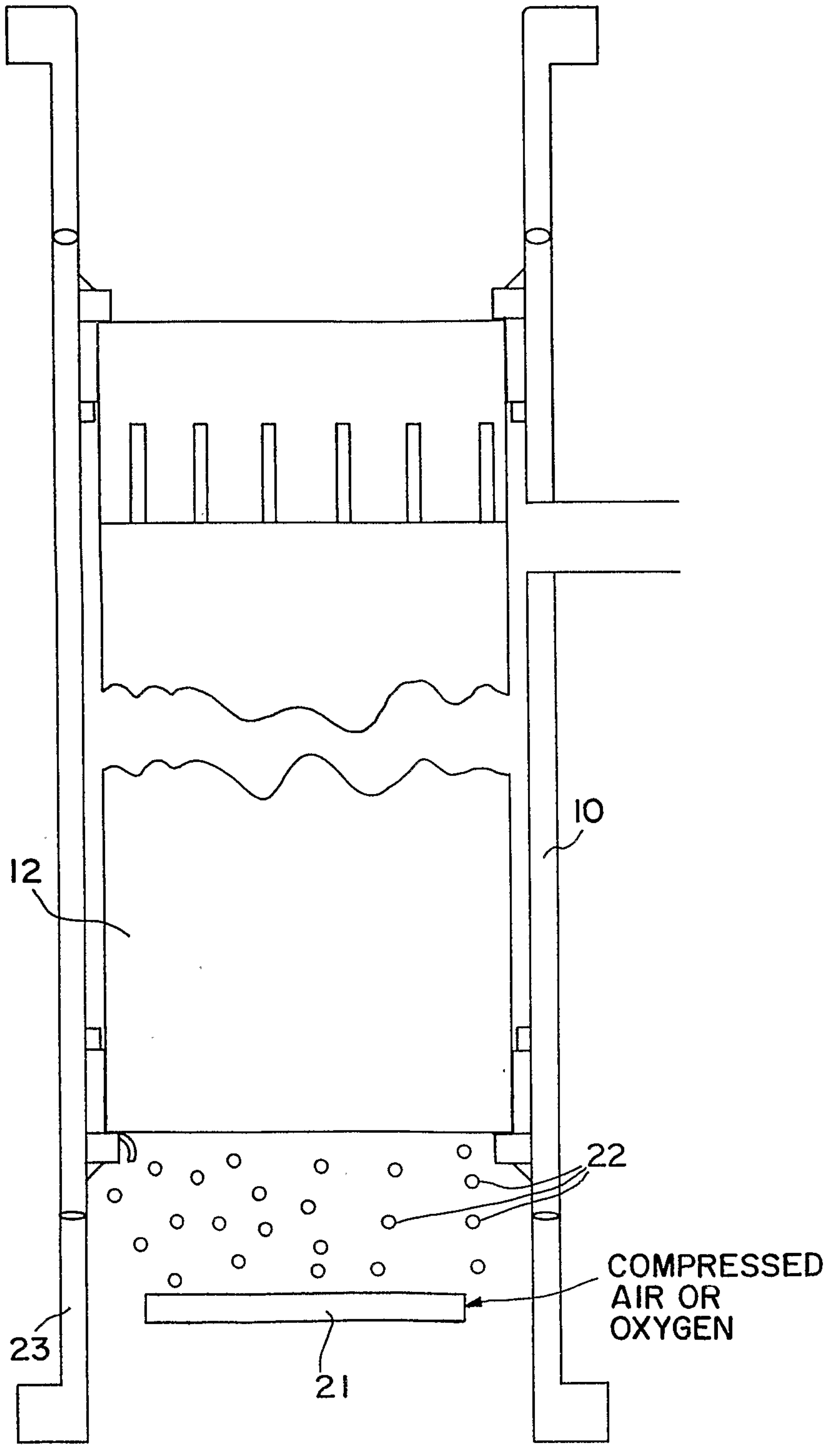

FIG. 5

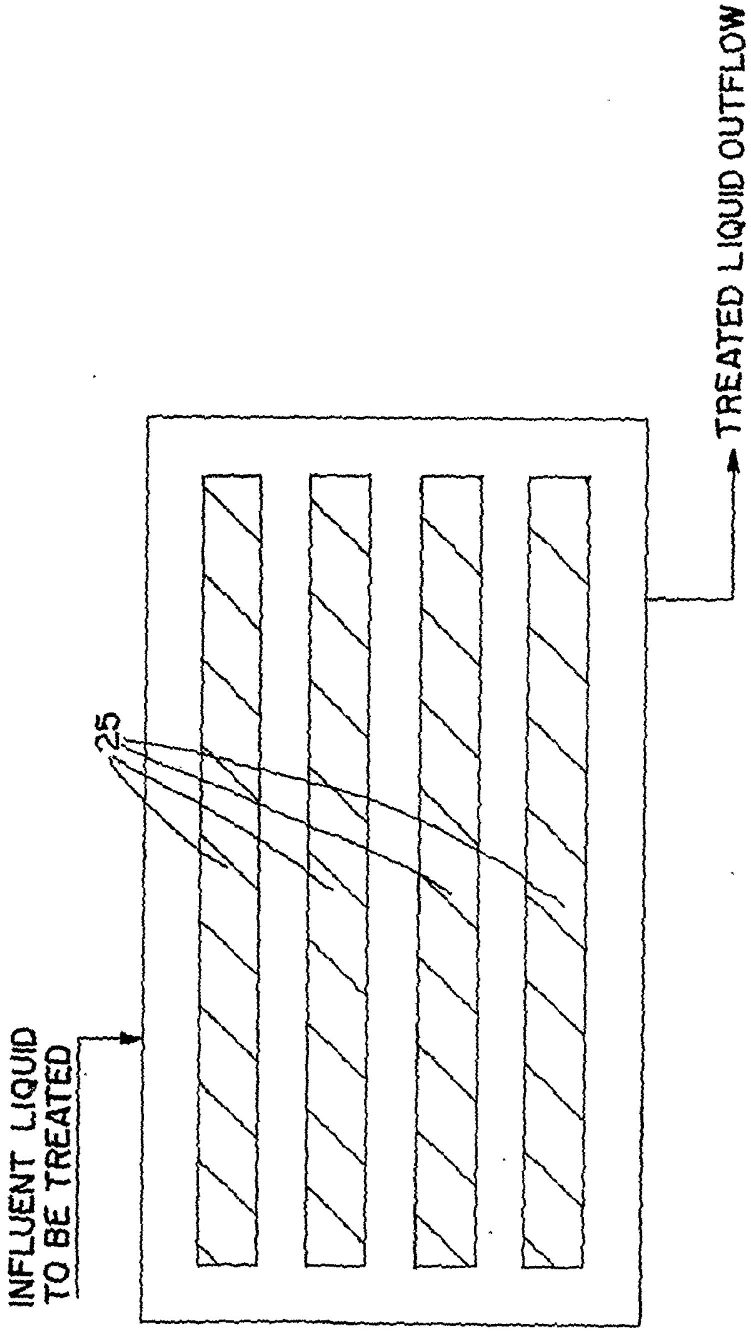

FIG. 6