



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ³: F04B 39/00	A1	(11) International Publication Number: WO 80/01825 (43) International Publication Date: 4 September 1980 (04.09.80)
<p>(21) International Application Number: PCT/US79/00107</p> <p>(22) International Filing Date: 22 February 1979 (22.02.79)</p> <p>(71) Applicant; and (72) Inventor: DEUTSCH, Daniel, H. [US/US]; 141 Kenworthy Drive, Pasadena, CA 91105 (US).</p> <p>(74) Agent: RADKE, Richard, P.; P. O. Box 1315, 8399 Topanga Canyon Blvd., Suite 213, Canoga Park, CA 91304 (US).</p>		<p>(81) Designated States: BR, CH, DE, GB, JP, SE, SU (Inventor's certificate).</p> <p>Published <i>With international search report</i></p>
<p>(54) Title: ASYMMETRIC PERMEABLE MEMBER</p> <p>(57) Abstract</p> <p>Fluid circulating systems and more particularly for use in bacteriological research where a sterile flask has a plug (110) in the neck thereof and ambient air or other gas is allowed to pass therethrough. A major shortcoming of the use of a cotton plug in the sterile shake flask is the very slow rate of gas exchange through the cotton plug. The present invention provides an improved plug (110) in the manner of an asymmetric permeable member comprising at least one sheet like member (114, 115, 116) for causing the circulation of a gas therethrough. The asymmetric member has numerous shaped pores (116, 120) through it such that the absolute effusional resistance to gas flow is anisotropic. The member is useful in causing the circulation of gases.</p> <div data-bbox="754 1254 1212 1883" data-label="Image"> </div>		

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ASYMMETRIC PERMEABLE MEMBERBACKGROUND OF PRIOR ART

The circulation of fluids through open and closed systems has many applications in the arts, sciences and technology. Mechanical reciprocating pumps, centrifugal pumps, undulating tubes, thermal gradients and fans are all commonly used to move fluids. One particular application where the above listed circulating systems are often impractical is in bacteriological research where a sterile flask has a plug of cotton or other porous substance in the neck thereof and ambient air or other gas is allowed to pass through the cotton. For many reactions such as fermentation reactions the rate at which the air passes through the cotton is an important factor which determines the rate at which the reaction takes place.

A major shortcoming of the use of a cotton plug in the sterile shake flask is the very slow rate of gas exchange through the cotton plug. Consequently, the gas exchange through the cotton plug is rate limiting rather than the biological process in the bacteriological medium. Elaborate sterile gas pumping systems have been developed and used to increase the rate of air throughput. However, such systems are quite expensive, difficult to operate and maintain and provide a source of possible contamination. Some bacteriological processes are carried out under reduced pressure or elevated pressure and reactions are also carried out in the presence of a particular



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gas.

More particularly, the forced flow of gases has typically utilized mechanical compressors or other devices which can give rise to impurities caused by the necessary presence of lubricants. The need for moving gases in highly purified conditions has made most mechanical systems impractical. Furthermore, many gases are not compatible with the common materials of construction and thus cannot be pumped by conventional devices. Still further, some processes require elevated temperatures or reduced temperatures. Systems for circulating air or other gases is made more difficult by the presence of such conditions.

BRIEF DESCRIPTION OF INVENTION

It is thus an object of the present invention to provide a gas circulating system which is simple to use, inexpensive to maintain and yet effective to increase the flow of gas through a conduit.

It is another important object of the present invention to provide a gas circulating system useful for depolluting industrial smoke stack gases.

It is a still further object of the present invention to provide a gas circulating system which consumes no energy.

The circulating system of the present invention comprises at least one sheet of a relatively impermeable material positionable within a gas impervious conduit and attachable in such a manner as to form a gas-tight seal across the conduit. The sheet has a thickness of less than about 3 millimeters and greater than about .001 microns. The sheet contains a plurality of tapered holes passing from one surface of the sheet to the other surface. A substantial majority of the holes are aligned so that they have their smaller openings on the first surface of the sheet and their larger openings on the second surface of the sheet. These holes may also be irregular and of a highly interconnected branched nature. The distance across the smaller openings is



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less than three times the mean free path of the molecules of the gas which is to be employed with the sheet. The sheet is both chemically and physically stable to the gas and of a relatively non-volatile nature under the conditions of temperature and pressure to be used. The mean absolute effusional resistance coefficient, ξ , is greater than 10^{-4} and less than 2.0 in the gas to be circulated, and when the sheet is positioned within a conduit to form a gas-tight seal across the conduit and the conduit is filled with the gas the gas is urged through the member and thusly through the conduit.

Some characteristics of the asymmetric gas-pervious members may be set forth by a series of equations set forth below wherein:

R_i = the absolute effusional resistance of the member to the gas in the first direction, from side i of the member to side ii of the member (see Figure 7 of the drawing discussed below.)

T = the absolute temperature, $^{\circ}\text{K}$, of the gas adjacent to the member.

P_i = the pressure of the gas on side i of the member.

d = the thickness of the member.

A = the area of the member.

Q = the net gas flow rate through the member.

R_{ii} = the absolute effusional resistance of the member to the gas in the second direction, from side ii of the member to side i of the member.

P_{ii} = the pressure of the gas on side ii of the member.

When the gas pressure is set so that P_i is the operating pressure on side "i" at $T^{\circ}\text{K}$, and at the same time P_{ii} is held near zero Torr so that P_i is much greater than P_{ii} , R_i is defined by Equation (1)

$$R_i = \frac{AP_i}{Qd} \quad \text{Eq. (1)}$$

and correspondingly when the gas pressure is set so that P_{ii} is the operating pressure on side ii at $T^{\circ}\text{K}$,



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and at the same time P_i is held near zero Torr so that P_{ii} is much greater than P_i , R_{ii} is defined by Equation (2).

$$R_{ii} = \frac{AP_{ii}}{Qd} \quad \text{Eq. (2)}$$

When for a particular member with a given gas and at a temperature, $T^{\circ}\text{K}$, if R_i and R_{ii} , the absolute effusional resistance of the given member in the two opposite directions, as calculated from Equations (1) and (2) respectively are not equal under conditions where P_i and P_{ii} in Equations (1) and (2) respectively are equal, then the member's absolute effusional resistance is anisotropic for those specific operating conditions.

The member's mean absolute effusional resistance coefficient, ξ , is defined by Equation (3)

$$\xi = \frac{2(R_i - R_{ii})}{R_i + R_{ii}} \quad \text{Eq. (3)}$$

and ξ is a measure of the member's anisotropy. For a given single asymmetric gas-pervious member and a given gas under specified temperature and pressure, the mean absolute effusional resistance coefficient ξ must be greater than 10^{-4} and less than 2.0, in the gas to be circulated.

The tapered holes through the member are of such a size that the diameter of the openings of the holes at the smaller end are less than about three (3) times the mean free path of the molecules of the gas under the conditions employed and greater than the mean diameter of the molecules of the gas with approximately one tenth to one fiftieth of the mean free path of the gas molecules a typical useful range and where the gas molecules pass through the smaller end of the tapered holes by effusion.

As referred to herein the term "aerator" will be used to denote a gas circulating device which causes the flow of air or other gas through it.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 is a perspective view, partially



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cut away, of the aerator of the present invention.

Figure 2 is a side elevation showing the aerator of the present invention installed in the neck of the flask.

5 Figure 3 is an enlarged cross-sectional view taken along the line 3-3 of Figure 1.

Figure 4 is an enlarged cross-sectional view showing an alternate configuration of the openings of Figure 3.

10 Figure 5 is a cross-sectional side elevation of an alternate configuration of the aerator of Figure 1.

Figure 6 is a cross-sectional side elevation of an alternate configuration of the aerator of Figure 1.

15 Figure 7 is a cross-sectional side elevation of an aerator comprising an asymmetric porous sheet.

Figure 8 is a cross-sectional side elevation of a singly supported asymmetric permeable sheet gas circulator.

20 Figure 9 is a cross-sectional side elevation of a doubly supported asymmetric permeable sheet gas circulator.

Figure 10 is a side elevation of a pair of tanks connected by a pair of conduits, one of which contains a member of the present invention.

25 Figure 11 is a side elevation of a room having a conduit containing a plurality of members of the present invention.

30 DETAILED DESCRIPTION OF INVENTION

The aerator 110 of Figure 1 is particularly adapted for use in the neck of a flask. Although numerous other uses of the aerator are possible, this application will serve to describe the aerator and is not to be considered a limitation on its possible use. Aerator 110 has cylindrical wall 111 which may be made from a glass tube or other hollow, member. A screen 112 may be positioned over the upper end of wall 111 and screen 113 is positioned over the lower end to



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protect the gas circulating members. Within wall 111 is a plurality of asymmetric gas pervious members 114, 115 and 116.

As shown in Figure 3, member 115 has a plurality of holes such as those indicated by reference character 116 and 117. Although the holes in member 115 are depicted as conical, the side wall of the holes may be convex or concave as viewed from the axis of the holes. Convex holes 120 and 121 are shown in member 122 of Figure 4. These form generally conical holes which are flared at their larger openings. A substantial majority of the tapered holes are aligned so that their larger openings are on the same side of the member.

The size and shape of the holes form an important aspect of the present invention. When the end openings of the tapered holes are approximately circular, then the mean diameter of the smaller of the two openings must be less than three times as great as the mean free path of the molecules of the gas in which the aerator is to operate at the given temperature and pressure. When the opening of the holes is not circular, the important dimension is the shortest distance across the opening which passes through the center of the opening in the plane of the surface of the sheet. This dimension will be referred to herein as "the distance across the smaller opening". The mean free path of the molecules depends upon the composition, pressure and temperature of the gas and may be calculated by methods known to those skilled in the art. The "distance across the smaller opening" also must be greater than the minimum diameter of the given gas molecules. For air at 293°K and 75 centimeters of mercury pressure, the mean free path of the molecules is about 0.09 microns. The "distance across the smaller opening" must therefore be less than 0.27 microns and greater than 3×10^{-4} microns with 2×10^{-3} microns being typical.

For pure oxygen at 293°K at 7.5 centimeters



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of mercury pressure, the mean free path of oxygen molecules is about 1 micron. The "distance across the small opening" for an aerator for use under these conditions must be less than 3 microns and greater than 3×10^{-4} microns. A typical diameter would be 2×10^{-3} microns. For pure nitrogen at 278°K and 0.75 centimeters of mercury, the mean free path is about 9 microns and the "distance across to the smaller opening" must be less than 27 microns and greater than 3×10^{-4} microns with about 2×10^{-3} microns being preferred. For helium at 293°K and 7.5 centimeters of mercury pressure the mean free path is about 3 microns. The "distance across the smaller opening" must be less than 9 microns and greater than 2×10^{-4} microns with 2×10^{-3} microns being preferred. For hydrogen at 293°K and 750 centimeters of mercury pressure the mean free path is 0.03 microns. The "distance across the smaller opening" must be less than 0.09 microns and greater than 2×10^{-4} microns with 2×10^{-3} microns being preferred dimension. For carbon dioxide at 293°K at 750 centimeters of mercury pressure the mean free path is 0.006 microns. The "distance across the smaller opening" must be less than 0.018 microns and greater than 3×10^{-4} microns with 4×10^{-3} microns being preferred. For air at 203°K and 7500 centimeters of mercury, the mean free path equals 9×10^{-4} microns. The "distance across the smaller opening" must be less than 2.7×10^{-3} microns and greater than 3×10^{-4} microns with 6×10^{-4} microns being preferred. In addition to the above mentioned gases the system is useful with a wide variety including but not limited to carbon dioxide, hydrogen, helium, argon sulphur dioxide, ammonia, monochlorotrifluoromethane, hexafluorocyclobutane, dichlorodifluormethane, tetrafluoromethane and water vapor or steam, and perhalogenated hydrocarbons.

The angular dimension between the opposite sides of the conical hole indicated in Figure 3 by reference character "a" should be between 2° and



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and 150° with about 10° being preferred. When the opening is conical and in addition the larger opening is flared as shown by 121 in Figure 4, the angle of the flare, indicated by reference character "b" should be between 10° and 180° with 150° being a preferred angular opening. While the exact angular dimension is not necessarily critical it is important that most of the openings on the upper side, as shown in Figure 4, are larger than the openings on the lower side. With irregularly shaped holes it is difficult to quantify the size and shape and members containing irregularly shaped holes are best characterized by the member's mean absolute effusional resistance coefficient, ξ , for a specified gas at a given pressure and temperature.

The member thickness should be less than three millimeters with about .02 millimeters being preferred. Member thickness such as .005 millimeters, .05 microns and as small as .001 microns are contemplated.

The member may be glued, welded or otherwise affixed to the inner wall of the aerator conduit. Alternatively, as shown in Figure 5, a plurality of spacers 125 through 128 hold members 130 through 132 in wall 133. Another method of holding the members within the wall is to provide a conical wall such as shown in Figure 6 where frustro-conical wall 140 holds plates 141 through 144.

For use in the neck of a flask, the aerator is placed in the neck of flask 150 shown in Figure 2. The reaction medium 151 is held in the flask and the air or other gas 152 is above the reaction medium 151. Aerator 110 is held in neck 153 of flask 150 by a wad of cotton 154. The direction of air flow is indicated by arrows 155. As shown by arrows 155 the gas passes downwardly through aerator 110 and upwardly through cotton wad 154. When used in this specific application, surrounded by a wad of cotton or similar material as in Figure 2, screen 134 and 135 of Figure 5; screen 145

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and 146 of Figure 6 and screens 112 and 113 of Figure 1 may be used to protect the members.

5 The number of members utilized within the aerator may be varied considerably with one member having some effect and a larger number of members increasing the effectiveness of air flow. Generally, the effect of number of members is additive. For example, the aerator could have 1, 5, 87, 2340 members depending upon the desired effect. The aerator of the
10 present invention will operate either quiescently or in a flask which is secured to a shaker table. Furthermore, the aerator may be inverted causing the air or gas to flow in the reverse direction.

15 The number of holes in any one member may be widely diverse depending upon the surroundings in which the member is to operate. A member having a single, tapered hole could be useful but generally a plurality of the holes is more useful. The number of holes should not, however, be such that adjacent holes
20 intersect so that the geometry of the hole is destroyed. In other words, the number of holes should be such that there are actual separate holes although some limited overlapping is possible.

25 Referring to Equation (3) above, the mean absolute effusional resistance coefficient, ξ , should be greater than 1×10^{-3} and preferably greater than 1×10^{-4} and less than 2.0 in the gas to be circulated. A coefficient of about 0.1 is preferred for many practical applications. There are three different
30 classes of openings which members of the present invention may utilize: first, idealized holes through a member, which is otherwise substantially impervious to the gas, where holes are identical in size and orientation. Such holes may be truncated pyramids
35 where the cross section may be circular, elliptical, triangular, square, or polygonal. Secondly, the openings may be referred to as real holes where the holes are tapered and of distorted shape passing through a member which is otherwise substantially im-



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pervious to the gas. Thirdly, the member may be porous wherein the asymmetric holes through the member are both highly branched and forked with the generally smaller openings on the first surface of the member and the generally larger openings on the second surface of the member. Members may, of course, contain openings of any or all of the three above described types.

For many porous materials it is very difficult to measure the size of the openings on each side of the sheet since the openings can vary in both size and shape. Further, the holes through the member are not necessarily of simple and uniform dimensions. Figure 7 depicts such a member with holes 150 and 151. This porous member as well as other gas pervious asymmetric members can be characterized most readily by the above-described absolute effusional resistances, R_i and R_{ii} along with ξ , the members mean absolute effusional resistance coefficient. An isotropic, gas-pervious member is one where $\xi = 0$ and the degree of anisotropy may be judged by the magnitude of the coefficient, ξ .

Generally speaking, asymmetric pervious sheets which show anisotropic effusional gas resistance properties, that is ξ is different from zero, may be prepared in either of two ways or a combination of these two ways;

- (a) asymmetry is incorporated during the formation of the sheet itself as during the casting;
- (b) the asymmetry is produced by modifying a symmetrical pervious sheet.

The later modification (b), may be carried out by one of two processes (c) or (d) or a combination of them:

- (c) the symmetrical holes through the member are preferentially partially closed or filled on one side of the member in preference to the opposite side by electroplating, acylation, esterification, etherification, vapor deposition, sputtering, heat treating,



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bending, stretching, radiation treatment or other process;

5 (d) the symmetrical holes through the member are preferentially enlarged on one side of the member in preference to those on the opposite side by such processes as etching, leaching, hydrolysis, electro-machining, stretching, bending, heat treatment, radiation treatment, machining, punching, or by other processes.

10 Members may be made from sintered powders. When a compressed, finely-powdered solid is heated to a temperature somewhat below its melting point, the individual solid grains fuse together at their point of physical contact. This sintering, at the early
15 stages, leaves large, interconnected voids and the mass is quite porous. As the temperature is increased or the time of heating is increased or both, the degree of sintering increases. The volume of the mass, upon increased sintering, decreases and the cross section
20 of the void holes decreases in size.

Asymmetric sintered members may be prepared by different degrees of sintering on the two sides of the member such as would occur when the two sides were exposed to different sintering temperatures. If the
25 starting powder was made up of particles of different sizes and the powder was classified by particle size across the member and then sintered, the side having the larger particles would have larger holes, the side with the smaller particles would have smaller holes,
30 and inside the member holes would be of an intermediate size. Thus, generally tapered pores would be produced by such a classification of the particles prior to sintering. Such pores or openings may be highly interconnected and branched but the average mean diameter
35 of the openings on the first surface are smaller than the average mean diameter on the second surface and the average mean diameter of the holes inside the member are of an intermediary average mean diameter. The material of the members is a gas impervious con-



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tinuous phase.

A wide variety of materials can be used for fabrication of members. The material must be quite impermeable to gasses and must be chemically and physically stable to the gas with which it is to be employed. Plastics such as nylon and polyethylene; metals such as aluminum and iron, ceramics such as glass and other silicates and the like are useful with consideration of corrosion resistance, temperature limitations and the like being adjusted to the environment in which the members are to operate. The member should be non-volatile in the gaseous environment and the gas should be relatively insoluble in the member. By "relatively insoluble" it is intended to mean that the gas will not dissolve in the member to an extent sufficient to cause it to swell to an extent to weaken the member or to change the size or shape of the openings to an extent to impair their function.

Equations 1 and 2 may be further understood by reference to Figure 7 where member 156 has a first side referred to as side i in the drawing and a second side referred to as side ii. The absolute effusional resistance from side i to side ii is referred to both in Equation (1) and in the drawings by R_i and the absolute effusional resistance in the reverse direction is referred to as R_{ii} . From R_i and R_{ii} the mean absolute effusional resistance coefficient, ξ , may be calculated as shown in Equation (3) above.

Member 156 may be fabricated from a wide variety of materials, such as polyethylene, polypropylene, poly urethane, polycarbonates, nylon, polymethylmethacrylate, rubber, cellulose, modified celluloses, metals such as copper, iron, aluminum, zinc and tin; ceramics, minerals, and composites of various organic and inorganic materials.

Since the member may be very thin, it is appropriate in many instances that it be supported by an inert base. The base must permit the relatively free flow of the gas. As shown in Figure 8, a coarse gas-



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porous base 158 is affixed to member 157. The support may be any inert, porous substance such as sintered glass. The member may be double supported as shown in Figure 9 where member 160 is supported by bases 161 and 162.

While the use of the member of the present invention has been discussed as being particularly useful in the neck of the flask, the invention has far greater application. The member may be used in any conduit which is relatively gas impermeable. The member or members are positioned in a gas-impervious conduit and sealed around the edges so that the gas does not pass between the member and the conduit.

These asymmetric members as 156 in Figure 7, 131 in Figure 5, or 160 in Figure 9 in which the mean absolute effusional resistance coefficient, ξ , is greater than 10^{-4} and less than 2.0 under certain specified conditions of gas composition, pressure and temperature, may be used for the circulation, of a gas between the tanks 170 and 171 in Figure 10. Such a member is shown as 172 in Figure 10 where it is sealed, gas tight, inside a conduit 173 connecting tanks 170 and 171. The conduit 174 provides for the return circulation. Figure 10 shows the use of a single member. A plurality such as five members may be used in series in conduit 173 of Figure 10. The number of members may be large such as 50, 300 or 2,500.

Figure 11 illustrates how this device may be used as a circulator to induce circulation of air 181 or other gas in an enclosure such as a room or a tank 180. A conduit with gas impervious walls, 182 extends from top to bottom of the room 180. Affixed and sealed air tight thereto are three asymmetric members 183, 184 and 185 in which the mean absolute effusional resistance coefficient, ξ , is greater than 10^{-4} and less than 2.0, for air at ambient temperature and atmospheric pressure. These members, 183, 184 and 185 are all ordered in the same direction and urge the circulation of the air upwardly in the



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direction of the arrows inwardly into entrance 187 and out of exit 186.

5 The present embodiments of this invention are thus to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims therefore are intended to be embraced therein.



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CLAIMS

1. A gas circulating system comprising: at least one member of a relatively gas impermeable material positionable within a gas impervious conduit and attachable to said conduit in such a manner as to form a gas-tight seal across the conduit, and said member has a thickness of less than about 3 millimeters and greater than about 0.001 micron, and contains a multiplicity of tapered holes passing from one surface of the member to the other surface of the member, wherein a substantial majority of the holes are aligned so that they have their smaller openings on the first surface of the member and their larger openings on the second surface of the member and wherein the distance across the smaller openings is less than three times the mean free path of the molecules of the gas which is to be employed with said gas circulating system and larger than the minimum diameter of said gas molecules, and wherein the member is both chemically and physically stable to the gas which is to be employed with said gas circulating system, and where the material of said member is relatively non-volatile under the conditions of temperature and gas pressure which are to be employed with said gas circulating system, and wherein the mean absolute effusional resistance coefficient, ξ is greater than 10^{-4} and less than 2.0 in the gas to be circulated, and whereby when said member is positioned within a conduit to form a gas tight seal across the conduit and said conduit is filled with said gas, the gas is urged through said member and said conduit.

2. The system as claimed in Claim 1, wherein said member is a sheet of relatively gas impermeable material.

3. The system as claimed in Claim 1, wherein the tapered holes are uniform and the angular dimension between the opposite sides of the holes are between 2° and 150° .

4. The system as claimed in Claim 3, wherein said angle is about 10° .

5. The system as claimed in Claim 1, wherein said tapered holes are conical in shape.

6. The system as claimed in Claim 1, wherein said



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system has one of said members.

7. The system as claimed in Claim 1, wherein said system has a plurality of said members.

8. The system as claimed in Claim 7, wherein said system has five of said members.

9. The system as claimed in Claim 1, wherein the members of said system have a thickness of about 0.02 millimeters.

10. The system as claimed in Claim 1, wherein the mean absolute effusional resistance coefficient, ξ is approximately 0.1.

11. The system as claimed in Claim 5, wherein said tapered holes are flared at the end with the larger opening, wherein the angle between the opposite sides of the flare where it meets the surface of the member is between 10° and 180° .

12. The system as claimed in Claim 11, wherein said angle is about 150° .

13. The system as claimed in Claim 1 designed for use in air, wherein the mean distance across the opening at the smaller end of the hole is about 0.002 microns.

14. The system as claimed in Claim 1, wherein said member is supported by a coarse gas-pervious base on one side.

15. The system as claimed in Claim 14, wherein said member is supported by a coarse gas-pervious base on both sides thereof.

16. The system as claimed in Claim 13, wherein said coarse gas-pervious base is sintered glass.

17. The system as claimed in Claim 1, wherein said holes are irregular, generally tapered holes.

18. The system of Claim 17, wherein the irregular, generally tapered holes are not uniform, and the average mean value of the angular dimension between the opposite sides of the holes is between 2° and 150° .

19. The system of Claim 18 wherein the average mean value of the said angular dimension is about 10° .

20. The system of Claim 17 wherein said irregular, generally tapered holes are in addition flared at the end



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with the larger opening wherein the average mean value of the angle between the opposite sides of the flare where the flare meets the surface of the member is between 10° and 180° .

21. The system as claimed in Claim 20, wherein the average mean value of the said angle is about 150° .

22. The system of Claim 1, wherein said member has a thickness of about 0.002 millimeters.

23. The system as claimed in Claim 1, wherein said holes comprise a multiplicity of highly interconnected and branched holes which pass from said first surface of the member to said second surface of the member, and wherein the average mean diameter of the openings of the holes on the first surface are smaller than the average mean diameter of the openings of the holes on the second surface and wherein the average mean diameter of the holes inside of the member are of an intermediary average mean diameter between the average mean diameters of the openings of the holes on the two opposite sides of the member, and wherein the solid material of the member consists of one relatively gas impervious continuous phase through which the network of holes pass, and wherein the average mean diameter of the openings of the holes in the first surface is greater than the average mean diameter of the molecules of the gas which is to be employed with said gas circulating system and less than three times the mean free path of the said gas molecules under the operating conditions of said gas circulating system.

24. The system as claimed in Claim 1, including a gas to be circulated through said system.

25. The system as claimed in Claim 24, wherein the gas is air.

26. The system as claimed in Claim 24, wherein the gas is nitrogen.

27. The system as claimed in Claim 24, wherein the gas is carbon dioxide.

28. The system as claimed in Claim 24, wherein the gas is hydrogen.

29. The system as claimed in Claim 24, wherein the



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gas is helium.

30. The system as claimed in Claim 24, wherein the gas is argon.

31. The system as claimed in Claim 24, wherein the gas is sulphur dioxide.

32. The system as claimed in Claim 24, wherein the gas is a perhalogenated hydrocarbon.

33. The system as claimed in Claim 32, wherein the gas is monochlorotrifluoromethane.

34. The system as claimed in Claim 32, wherein the gas is hexafluorocyclobutane.

35. The system as claimed in Claim 32, wherein the gas is dichlorodifluoromethane.

36. The system as claimed in Claim 32, wherein the gas is tetrafluoromethane.

37. The system as claimed in Claim 24, wherein the gas is water in the vapor state.



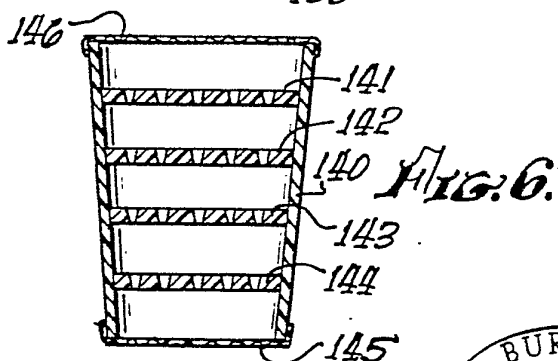
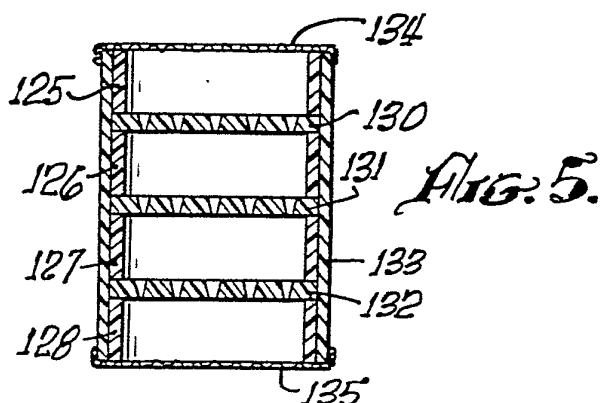
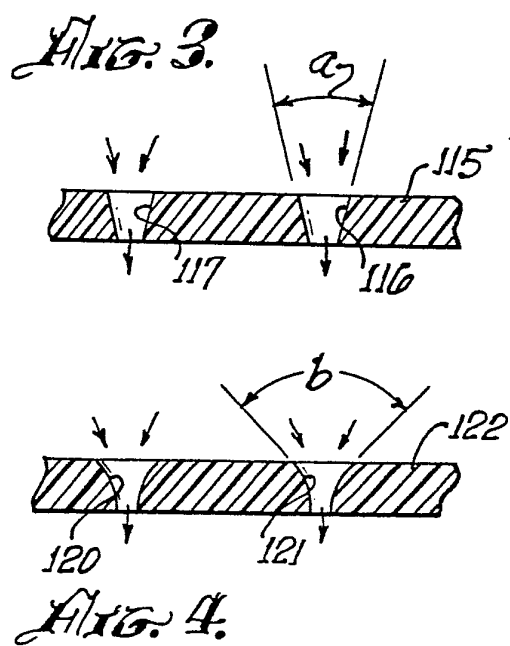
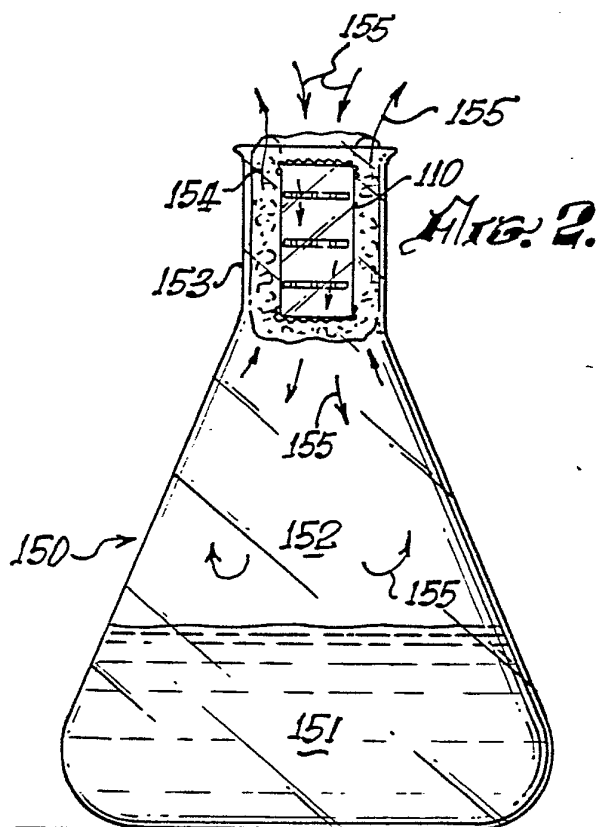
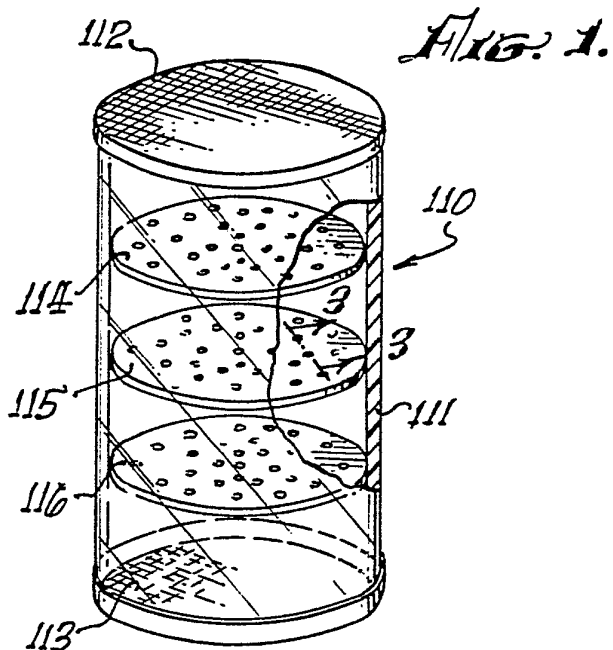


Fig. 7.

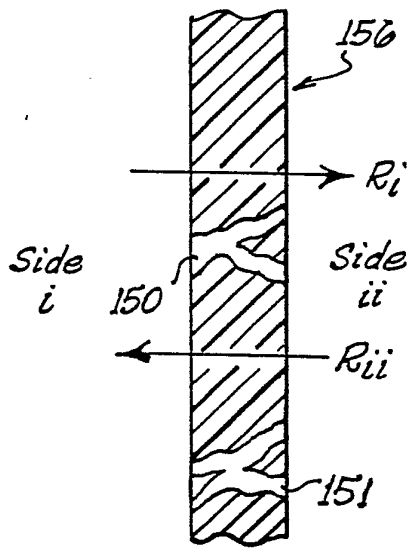


Fig. 8.

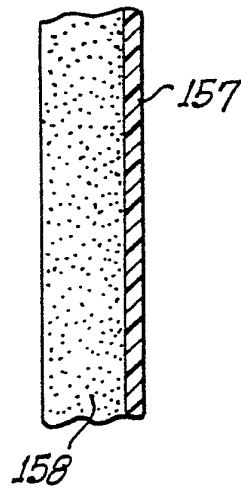


Fig. 9.

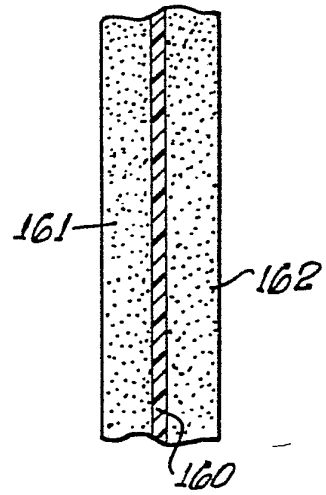


Fig. 10.

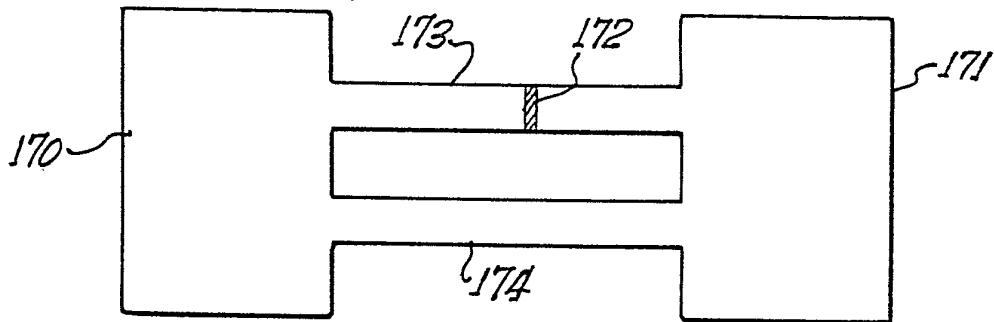
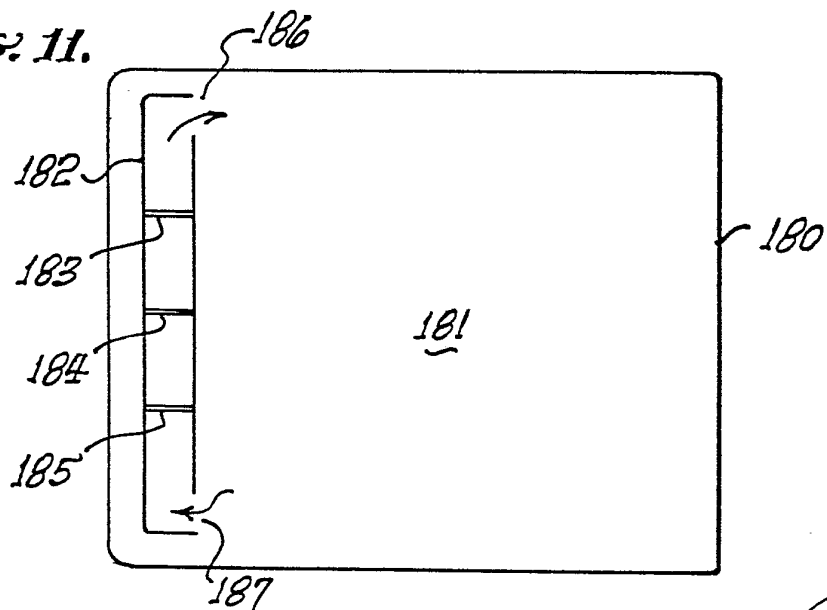


Fig. 11.



INTERNATIONAL SEARCH REPORT

International Application No PCT/US79/00107

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) *

According to International Patent Classification (IPC) or to both National Classification and IPC

Intl. Cl. F04B 39/00
US Cl. 417/572

417/572

II. FIELDS SEARCHED

Minimum Documentation Searched *

Classification System

Classification Symbols

US

417/53, 207, 572
73/23, 28

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched *

III. DOCUMENTS CONSIDERED TO BE RELEVANT **

Category *	Citation of Document, ** with indication, where appropriate, of the relevant passages **	Relevant to Claim No. **
X	US, A, 3,150,818, PUBLISHED 29 SEPTEMBER 1964, SCHUMACHER	1-37
X	US, A, 3,286,531, PUBLISHED 22 NOVEMBER 1966, SHAPIRO ET AL	1-37
A	US, A, 3,565,551, PUBLISHED 23 FEBRUARY 1971, HOBSON	1-37
A	US, A, 3,693,457, PUBLISHED 26 SEPTEMBER 1972, PILAT	1-37
A	US, A, 3,795,135, PUBLISHED 05 MARCH 1974, ANDERSEN	1-37
A	US, A, 3,837,762, PUBLISHED 24 SEPTEMBER 1974 LEE	1-37

* Special categories of cited documents: **

"A" document defining the general state of the art

"E" earlier document but published on or after the international filing date

"L" document cited for special reason other than those referred to in the other categories

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but on or after the priority date claimed

"T" later document published on or after the international filing date or priority date and not in conflict with the application, but cited to understand the principle or theory underlying the invention

"X" document of particular relevance

IV. CERTIFICATION

Date of the Actual Completion of the International Search *

Date of Mailing of this International Search Report *

18 OCTOBER 1979

31 OCT 1979

International Searching Authority *

Signature of Authorized Officer **

ISA/US

EDWARD LOOK

LEON R. GREGG