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(19) (CA) APPLICATION FOR CANADIAN PATENT (12)

(54) Underwater Breathing Apparatus

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ABSTRACT

This invention relates to a breathing apparatus used in diving. The breathing apparatus is constructed from an underwater propelling device D having attached thereto an assembly consisting of a gas exchange module A containing hollow fibers (1) and having a gas inlet (2) and a gas outlet (3), an air reservoir (8) having an inlet (6) and an outlet (7), and a mouthpiece C having a gas outlet (11) provided with a valve opening only during exhalation and a gas inlet (10) provided with a valve opening only during inhalation, said gas exchange module A, said air reservoir B and said mouthpiece C being connected in series so that the inlet of each of them communicates with the outlet of another.

This breathing apparatus can exhibit improved gas exchange capability because the water around the hollow fibers (1) is easily replaced when the breathing apparatus, together with the underwater propelling device D, is moved through the water.

A portable breathing apparatus is also disclosed which is constructed similar to the above assembly and can be carried on the back of a diver instead of being attached to the underwater propelling device.

DESCRIPTION

UNDERWATER BREATHING APPARATUS

Technical Field

This invention relates to a breathing apparatus equipped with propelling means which apparatus can be used in diving for a long period of time.

This invention also relates to a portable breathing apparatus which can be used in diving by being attached to the body of the diver.

Background Art

In the air, human beings usually breathe in air having an oxygen concentration of about 20.8% by volume and a carbon dioxide concentration of about 0.03% by volume, as inhaled breath, and breathe out a gaseous mixture having an oxygen concentration of about 16.4% by volume and a carbon dioxide concentration of about 4.1% by volume, as exhaled breath.

Underwater breathing apparatus have long been known which bring the respired air into contact with water through the medium of a membrane so as to expel the carbon dioxide present in the breath exhaled from the lungs and introduce oxygen dissolved in the water into the exhaled breath for the purpose of oxygenating it.

For example, an underwater structure providing a residence space for man under water is disclosed in Japanese Patent Publication No. 35488/'81. Moreover, breathing apparatus (artificial gills) used by being attached to the body of the diver in place of an oxygen cylinder are disclosed in Japanese Patent Publication No. 14589/'67, Japanese Patent Publication No. 37956/'75, U.S. Pat. 3,228,394 and U.S. Pat. 3,318,306. In these artificial gills, a gas exchange membrane formed of silicone rubber is used and its thickness is of the order of 100 μm.

In underwater breathing apparatus using such a gas exchange membrane, its oxygen permeation rate is governed by the membrane resistance produced at the interface between the membrane and the water, provided that the oxygen permeation rate within the membrane is greater than a certain value. Accordingly, in order to enhance the oxygen permeation rate, it is necessary to reduce the thickness of the boundary layer.

However, in the case of an artificial gill with which the diver carries its gas exchange membrane module on his back and moves under water by his own efforts, it is impossible to enhance the speed of the water flow along the membrane surfaces. Accordingly, the membrane resistance cannot be reduced to such an extent as to provide a satisfactorily high oxygen permeation rate of the membrane module. For this reason, a very large membrane area is required to achieve a proper amount of gas exchange, so that it has been inevitable to employ a large-sized membrane module.

Moreover, since the diver must move under water by his own efforts, a large amount of energy consumption and hence oxygen consumption is required. Thus, the diving time and the sphere of action under water have been limited.

Disclosure of the Invention

It is an object of the present invention to provide a breathing apparatus equipped with propelling means which enables the diver to remain under water for a longer period of time.

It is another object of the present invention to provide a portable underwater breathing apparatus which is compact in size and has excellent gas exchange efficiency.

According to one aspect of the present invention, there is provided a breathing apparatus equipped with underwater propelling means comprising an underwater propelling device D having attached thereto an assembly consisting of a gas exchange module A containing hollow fibers and having a gas inlet and a gas outlet, an air reservoir B having an inlet and an outlet, and a mouthpiece

C having a gas outlet provided with a valve opening only during exhalation and a gas inlet provided with a valve opening only during inhalation, the gas exchange module A, the air reservoir B and the mouthpiece C being connected in series so that the inlet of each of them communicates with the outlet of another.

According to another aspect of the present invention, there is provided a portable breathing apparatus comprising a gas exchange module A containing hollow fibers and having a gas inlet and a gas outlet, an air reservoir B having an inlet and an outlet, a mouthpiece C having a gas outlet provided with a valve [illegible] with a valve opening only during inhalation, a carrier E for carrying the air reservoir B thereon, and fastening belts F for fastening the gas exchange module A and the air reservoir B, the gas exchange module A, the air reservoir B and the mouthpiece C being connected in series so that the inlet of each of them communicates with the outlet of another.

appearance of the breathing apparatus equipped with underwater propelling means;

Fig. 2 is a schematic sectional view taken along line X-X' in Fig. 1, illustrating the gas exchange module as viewed in the direction of the arrows;

Fig. 3 is an enlarged schematic sectional view of the gas exchange module illustrated in Fig. 2, most of the hollow fibers being not shown;

Fig. 4 is a perspective view of a gas exchange module A in which the perforated container has a double truncated-conical construction;

Fig. 5 is a schematic side elevation view of a gas exchange module A of double cylindrical construction having a baffle plate provided therein, most of the hollow fibers being not shown;

Fig. 6 is a schematic rear elevation view of the gas exchange module A illustrated in Fig. 5; and

Figs. 7 and 8 are schematic side elevation views of a gas exchange module A in which two fixing members are tied together with plate-like supporting members.

Fig. 9 is a schematic view of a portable breathing apparatus in accordance with the present invention.

Best Mode for Carrying Out the Invention

Basically, a breathing apparatus equipped with propelling means in accordance with the present invention comprises an underwater propelling device D to which an assembly consisting of a gas exchange module A, an air reservoir B and a mouthpiece C is attached.

Gas exchange module A consists of a large number of hollow fibers disposed in a bundle; two fixing members for fixing the opposite ends of the hollow fibers while leaving them open; a perforated container having its opposite ends joined to the respective fixing members and containing the hollow fibers therein, or supporting members having their opposite ends joined to the respective fixing members and thereby holding the fixing members at a predetermined distance from each other; a gas entry section joined to one of the fixing members, communicating with the internal bores of said hollow fibers, and having an inlet for the inflow of gas; and a gas exit section joined to the other of the fixing members, communicating the internal bores of said hollow fibers, and having an outlet for the outflow of gas.

In the breathing apparatus with propelling means illustrated in Fig. 1, the gas exchange module A is disposed at the back of underwater propelling device D, and the air reservoir B and the mouthpiece C are disposed along the side of underwater propelling device D. In this figure, reference numeral 1 denotes the hollow fibers, 2 denotes the gas inlet of the gas exchange module, 3 denotes the gas outlet thereof, 4 [illegible] denotes a fixing member, 5 denotes a perforated container, 6 denotes the gas inlet of the air reservoir, 7 denotes the gas outlet thereof, 8 denotes an expansible hose [illegible] of the mouthpiece, 10 denotes the gas inlet of the mouthpiece, 11 denotes the gas outlet thereof, 12 denotes the main body of the underwater propelling device, 13 denotes a control handle, 14 denotes a screw, 15 denotes a power switch, 16 denotes an air reservoir fastening belt, 17 denotes a mouthpiece fastening belt, and 18 denotes a water entry port for the screw.

perforated container(s) is to facilitate the flow, movement or replacement of water around the hollow fibers. Thus, the perforated containers serve to protect the hollow fibers and also to maintain the overall physical structure of gas exchange module A.

Preferably, the gas exchange modules are disposed at positions where the water around the hollow fibers can be replaced easily and, moreover, where the water flow produced by the revolution of screw 14 of the underwater propelling device can be utilized positively. However, consideration should preferably be given to the fact that, if the gas exchange modules are disposed at positions where the water flow produced by the screw directly strikes on them (i.e., right behind the screw), the propulsive force will be reduced. For example, the gas exchange modules may be disposed behind the screw in such a manner as to cylindrically surround the water flow produced by the screw, as shown in Fig. 2. This permits the water around the hollow fibers to be easily replaced without reducing the propulsive force of the screw. Alternatively, the gas exchange modules may be disposed at the water entry port 18 provided in front of the screw.

Fig. 4 is a schematic perspective view of a gas exchange module A in which the perforated container has a double truncated-conical construction. In this gas exchange module A, the diameter of the cone decreases gradually in the direction of the water flow, allowing the water flow produced by the screw to replace the water around the hollow fiber more easily than the gas exchange module of double cylindrical construction. The degree of reduction of the diameter of the cone may be suitably varied according to the intensity of the water flow from the screw, and other factors.

In the gas exchange module A illustrated in Fig. 5, a baffle plate 21 for disturbing the water flow is provided at the outlet for the propelling water flow. By providing the gas exchange module A of double cylindrical or double truncated-conical construction with such a baffle plate, the water around the hollow fibers can be replaced more easily.

In the above-described gas exchange modules A, the hollow fibers are housed in the perforated container(s). However, supporting members 22 may be used in place of the perforated container(s). Supporting members 22 serve to hold the fixing members 4 and 4' at a prdetermined distance from each other, and usually comprise a plurality of bars or plates fixed to the outer peripheries of the two fixing members. In order to prevent the hollow fibers from being damaged, the surfaces and side faces of the supporting members should preferably be finished smoothly. The supporting members may have any other configuration.

In the gas exchange module A illustrated in Figs. 7 and 8, the length of hollow fibers 1 is about 15% longer than the distance between the two fixing members 4 and 4', and six supporting members are equidistantly disposed on the outer peripheries of the fixing members. Figs. 7 and 8 shows the states of the hollow fibers when underwater propelling device D is stopped and operated, respectively. When it is [redacted]

water around the hollow fibers can be replaced easily. Moreover, when the length of the hollow fibers is 1 to 50% longer than the distance between the two fixing members 4 and 4' as shown in these figures, the gas exchange efficiency can further be enhanced because the hollow fibers are shaken under the influence of the water flow.

In the gas exchange module A shown in Figs. 7 and 8, the left and right fixing members have different sizes. However, it is to be understood that a gas (non-porous membrane) or a microporous membrane.

Any of various well-known membrane materials can be used in the present invention. Useful materials for the formation of homogeneous membranes include silicone rubber type polymers such as dimethylpolysiloxane and copolymers of silicone and polycarbonate; olefin polymers such as poly-4-methylpentene-1 and low-density polyethylene; perfluoroalkyl type fluorine-containing polymers; cellulose-based polymers such as ethyl cellulose; polyphenylene oxides; poly-4-vinylpyridine; copolymers composed of monomers constituting the foregoing polymers; and mixtures thereof. Useful materials for the formation of microporous membranes are hydrophobic polymers including polyolefins such as polyethylene, polypropylene, poly-3-methylbutene-1 and poly-4-methylpentene-1; fluorine-containing polymers such as polyvinylidene fluoride and polytetrafluoroethylene; polystyrene and polyether ketones.

Where a homogeneous membrane is used, its oxygen permeation rate at the time of passage of oxygen under water is governed by the film resistance, provided that its oxygen permeation rate as measured by the passage of air in the air is not less than about 10^{-5} $cm^3(STP)/cm^2 \cdot sec \cdot cmHg$. Accordingly, the oxygen permeation rate of the homogeneous membrane should preferably have a value as described above.

In order to meet this requirement, the membrane thickness must be about 30 μm or less even for silicone rubber that is known to have the highest oxygen permeation rate. For copolymers of silicone and polycarbonate, it is necessary to reduce the membrane thickness to 6 μm or less.

In any event, homogeneous membranes must be made very thin. To this end, the membrane forming the hollow fibers preferably have a three-layer structure in which inner and outer porous membrane layers are disposed on both sides of an intermediate homogeneous membrane layer. Membranes having such a three-layer structure can be formed by a process involving melt spinning and subsequent stretching treatment, as disclosed in U.S. Pat. 4,713,292.

On the other hand, where a microporous membrane is used, its pore size may be suitably chosen with consideration for both the water pressure (or depth) at which the breathing apparatus is to be used, and the gas permeation rate of the membrane.

Air reservoir B is disposed on the outlet or inlet side of mouthpiece C and have the function of storing exhaled or reoxygenated breath temporarily. Accordingly, air reservoir B preferably has a construction which can expand and contract during breathing, such as a bellows-like or expansible hose construction.

Among others, an air reservoir having a expansible hose construction may preferably be disposed between parts (for example, between the mouthpiece and the gas exchange module) because the air reservoir also serves as a connecting tube for carrying gas and can hence provide an apparatus of compact design. The air reservoir should preferably have an air storage capacity of about 0.5 to 20 liters in its normal state.

In order to minimize breathing resistance, it is preferable to permit breathing at the same pressure as the water pressure. Accordingly, air reservoir B is preferably formed of an elastic material which is easy of expansion and contraction. For example, rubbery materials such as silicone rubber, acrylic rubber and natural rubber may be used for air reservoir B.

Mouthpiece C has an outlet for discharging the air exhaled from the lungs of the diver to the air reservoir B (or gas exchange module A), an inlet for introducing (oxygenated) air to be inhaled from the gas exchange module A (or air reservoir B), and an aperture to be connected with the mouth of the diver. In order to allow the respired air to flow in one direction, the outlet is provided with a gas exit valve opening only during exhalation and the inlet is provided with a gas entry valve opening only during inhalation.

Underwater propelling device D comprises a main body, a power source (such as a battery) isolated from the water by the main body, a control handle 13, and a screw 14 for producing propulsive force. For this purpose, there may be used any of well-known underwater propelling devices.

In the breathing apparatus equipped with propelling means in accordance with the present invention, a water separator for removing water vapor may also be provided in order to prevent the exhaled breath saturated with water vapor from condensing in the gas flow path to form waterdrops.

Next, the portable breathing apparatus of the present invention, which is to be used in diving by being attached to the body of the diver, will be described with reference to Fig. 9.

Basically, the portable breathing apparatus of the present invention comprises a gas exhange module A, an air reservoir B, a mouthpiece C, a carrier E and fastening belts F, and is characterized by being constructed so that the gas exchange module A can be shaken by the expansion and contraction of air reservoir B.

Gas exchange module A and mouthpiece C can be any of those described previously for the breathing apparatus equipped with propelling means. However, gas exchange module A is preferably of a type in which the hollow fibers are housed within a perforated container or containers, because the hollow fibers are protected thereby.

Similarly, air reservoir B can be any of those described previously for the breathing apparatus equipped with propelling means. However, air reservoir B preferably has side walls of bellows-like construction as illustrated in Fig. 9, in order to facilitate shaking of the gas exchange module.

Carrier E serves to carry the air reservoir B and the gas exchange module A thereon and thereby attach them to the back of the diver. It comprises at least a plate or ladder to be applied to the back of the diver, and a pair of strands 24 for holding the carrier E on the diver's shoulder. No particular limitation is placed on the material of the carrier, and it may be made of a resin such as polyethylene or polypropylene.

Air reservoir B is fastened directly to the carrier E, and gas exchange module A is fastened to the carrier E through the medium of air reservoir B. By employing this fastening method, the motions of the air reservoir B alternately expanding and contracting during breathing can be transmitted to the gas exchange module A so as to move the gas exchange module A in the water and thereby enhance its gas exchange capability under water. Although no particular limitation is placed on the fastening means used for this purpose, the gas exchange module A and the air reservoir B are usually fastened together with fastening belts F. Air reservoir B and carrier E may be fastened together with the same fastening belts F as used for gas exchange module A and air reservoir B. In this case, however, the fastening belts should preferably be made of a highly elastic material such as silicone rubber or natural rubber, so that gas exchange module A can move in response to the motions of air reservoir B. In Fig. 9, reference numeral 24 denotes belts for fastening the air reservoir B to the carrier E, and 25 denots a hose.

If desired, gas exchange module A may be tied to the swim fins with strings so as to promote its shaking.

The breathing apparatus of the present invention are more specifically explained with reference to the following examples.

Example 1

Hollow fibers having an inner diameter of 200 μm and an oxygen permeation rate of 1.1×10^{-5} cm^3(STP)/cm^2·sec·cmHg were obtained by melt spinning and subsequent intermediate layer and a 20 μm thick porous outer layer. The polymeric material of the inner and outer layers was high-density polyethylene, and that of the intermediate layer was segmented polyurethane.

A total of 24 gas exchange sub-modules were made by housing the above hollow fibers in perforated polycarbonate containers 5 having an inner diameter of 65 mm and an overall length of 450 mm. These gas exchange sub-modules were substantially uniformly disposed between netted members 19 and 20 having a double cylindrical construction to obtain a gas exchange module having a membrane area of 15 m^2. The air reservoir used in this example comprised an expansible hose made of natural rubber and having an internal volume of 4 liters in its normal state. Then, a breathing apparatus with underwater propelling means as illustrated in Fig. 1 was assembled by mounting the gas exchange module, the air reservoir and a mouthpiece to a commercially available underwater propelling device (Apollo Scooter AV-1; manufactured by Apollo Sports Co., Ltd.).

Using this breathing apparatus, a man weighing 70 kg was able to travel under water (about 5 m deep) at a speed of 2.0 km/hr for 60 minutes without encountering any difficulty in breathing.

Example 2

Hollow fibers having an inner diameter of 200 μm and an oxygen permeation rate of 4.1×10^{-4} cm^3(STP)/ cm^2·sec·cmHg were obtained by melt spinning and subsequent stretching treatment. The membrane forming the hollow fibers had a three-layer structure consisting of a 25 μm thick porous inner layer, a 0.1 μm thick non-porous intermediate layer and a 25 μm thick porous outer layer. The polymeric material of the inner and outer layers was poly-4-methylpentene-1, and that of the intermediate layer was a copolymer of silicone and polycarbonate.

Using the hollow fibers thus obtained, a breathing apparatus equipped with underwater propelling means similar to that of Example 1 was assembled.

Using this breathing apparatus, a man weighing 70 kg was able to travel under water (about 5 m deep) at a speed of 2.0 km/hr for 60 minutes without encountering any difficulty in breathing.

Example 3

A portable breathing apparatus as illustrated in Fig. 9 was assembled and its gas exchange capability under water was evaluated. Specifically, microporous hollow fibers formed of polypropylene and having an inner diameter of 200 μm, a membrane thickness of 25 μm, an average pore diameter of 0.2 μm and a porosity of 40%

were housed within perforated containers 5 made of polycarbonate to form a gas exchange module A having a membrane area of 15 m^2 and a capacity of 20 liters. In [illegible]

[illegible] bellows made of natural rubber and having a internal volume of 4 liters in its normal state, a carrier E made of high-density polyethylene, and fastening belts F made of silicone rubber.

This portable breathing apparatus was placed in a water tank measuring 100 cm (length) x 100 cm (width) x 60 cm (depth), with the carrier facing downward. While fresh tap water was being supplied to the tank at a rate of 100 liters per minute, a man weighing 70 kg held the mouthpiece C in his mouth and continued to breathe with this breathing apparatus for 30 minutes [illegible] fibers formed of polypropylene. Using this gas exchange module, a portable breathing apparatus was assembled in the same manner as in Example 3.

When the performance of this heating apparatus was evaluated in the same manner as in Example 3, almost similar results were obtained.

The breathing apparatus equipped with underwater propelling means in accordance with the present invention has excellent gas exchange capability because the water around the hollow fibers is easily replaced when the breathing apparatus, together with the underwater propelling means, is moved through the water. Especially where the gas exchange module is disposed around the water flow produced by the screw, more excellent gas exchange capability is achieved. Moreover, since the gas exchange module is fixed to the underwater propelling means, the diver can move with agility. Furthermore, since the underwater propelling means cuts down the diver's oxygen consumption required for underwater movements, it becomes possible to prolong the diving time and extend the sphere of action.

The portable breathing apparatus equipped with a carrier has much more excellent gas exchange efficiency than conventional breathing apparatus, because the water around the gas exchange module is easily replaced by expansion and contraction of the air reservoir.

Moreover, this apparatus requires no special power source and, therefore, enables the diver to remain under water for a long period of time.

CLAIMS

1. A breathing apparatus equipped with propelling means comprising an underwater propelling device D having attached thereto an assembly consisting of a gas exchange module A containing hollow fibers and having a gas inlet and a gas outlet, an air reservoir B having an inlet and an outlet, and a mouthpiece C having a gas outlet provided with a valve opening only during exhalation and a gas inlet provided with a valve opening only during inhalation, said gas exchange module A, said air reservoir B and said mouthpiece C being connected in series so that the inlet of each of them communicates with the outlet of another.

2. A breathing apparatus as claimed in claim 1 wherein said gas exchange module A consists of a large number of hollow fibers disposed in a bundle; two fixing members for fixing the opposite ends of said hollow fibers while leaving them open; a perforated container having its opposite ends joined to the respective fixing members and containing said hollow fibers therein; a gas entry section joined to one of said fixing members, communicating with the internal bores of said hollow fibers, and having an inlet for the inflow of gas; and a gas exit section joined to the other of said fixing members, communicating with the internal bores

of said hollow fibers, and having an outlet for the outflow of gas.

3. A breathing apparatus as claimed in claim 2 wherein said perforated container of said gas exchange module A has a double cylindrical construction.

4. A breathing apparatus as claimed in claim 2 wherein said perforated container of said gas exchange module A has a double truncated-conical construction.

5. A breathing apparatus as claimed in claim 4 wherein said perforated container of said gas exchange module A is disposed so that the larger-diameter side of the double truncated-cone is close to the screw of said underwater propelling device and the smaller-diameter side of the double truncated-cone is remote.

7. A breathing apparatus as claimed in claim 6 wherein the membrane forming said hollow fibers has a gas permeation rate of not less than 10^{-5} cm^3(STP)/ $cm^2 \cdot sec \cdot cmHg$.

8. A breathing apparatus as claimed in claim 1 wherein said gas exchange module A consists of a large number of hollow fibers disposed in a bundle; two fixing members for fixing the opposite ends of said hollow fibers while leaving them open; supporting members having their opposite ends joined to the respective fixing members; a gas entry section joined to one of said fixing members, communicating with the internal bores of said hollow fibers, and having an inlet for the inflow of gas; and a gas exit section joined to the other of said fixing members, communicating with the internal bores of said hollow fibers, and having an outlet for the outflow of gas.

9. A breathing apparatus as claimed in claim 8 wherein the length of said hollow fibers is 1 to 50% longer than the distance between said two fixing members.

10. A breathing apparatus as claimed in claim 8 wherein the membrane forming said hollow fibers has a three-layer structure in which the inner and outer layers

are porous and the intermediate layer is non-porous.

11. A breathing apparatus as claimed in claim 10 wherein the membrane forming said hollow fibers has a gas permeation rate of not less than 10^{-5} cm^3 (STP)/ $cm^2 \cdot sec \cdot cmHg$.

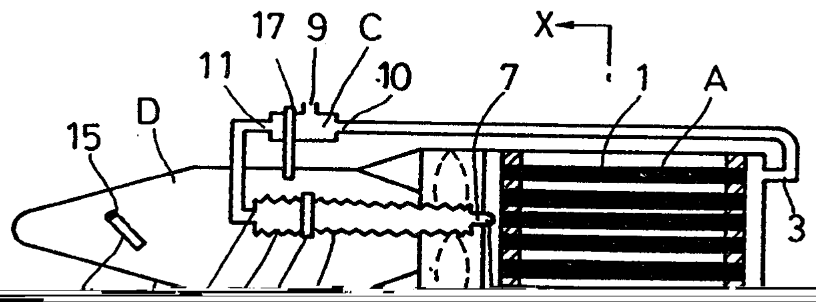
12. A portable breathing apparatus for use under water comprising a gas exchange module A containing hollow fibers and having a gas inlet and a gas outlet, an air reservoir B having an inlet and an outlet, a mouthpiece C having a gas outlet provided with a valve opening only during exhalation and a gas inlet provided with a valve opening only during inhalation, a carrier E for carrying said air reservoir B thereon, and fastening belts F for fastening said gas exchange module A and said air reservoir B, said gas exchange module A, said air reservoir B and said mounthpiece C being connected in series so that the inlet of each of them communicates with the outlet of another.

13. A portable breathing apparatus as claimed in claim 12 wherein said gas exchange module A consists of a large number of hollow fibers disposed in a bundle; two fixing members for fixing the opposite ends of said hollow fibers while leaving them open; a perforated

container having both ends joined to the respective fixing members and containing said hollow fibers therein; a gas entry section joined to one of said fixing members, communicating with the internal bores of said hollow fibers, and having an inlet for the inflow of gas; and a gas exit section joined to the other of said fixing members, communicating with the internal bores of said hollow fibers, and having an outlet for the outflow of gas.

14. A portable breathing apparatus as claimed in claim 13 wherein said air reservoir B has side walls of bellows-like construction, and said gas exchange module A is fastened to said carrier E through the medium of said air reservoir B.

FIG.1



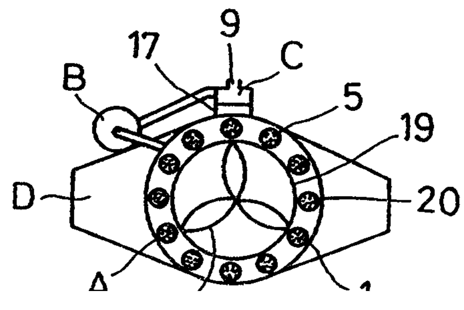


FIG.3

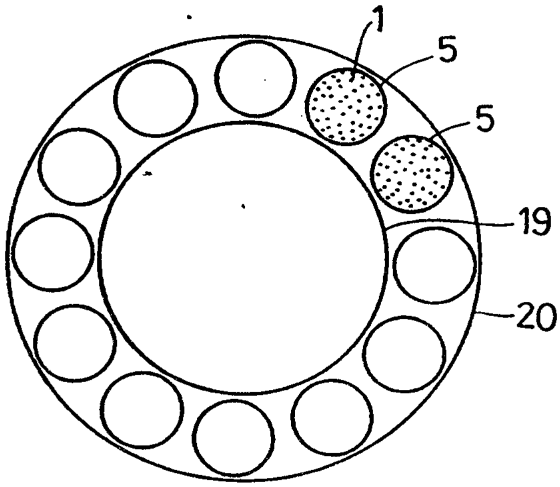


FIG.4

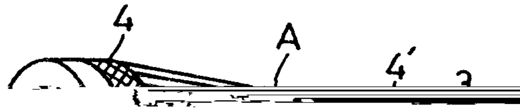


FIG. 5

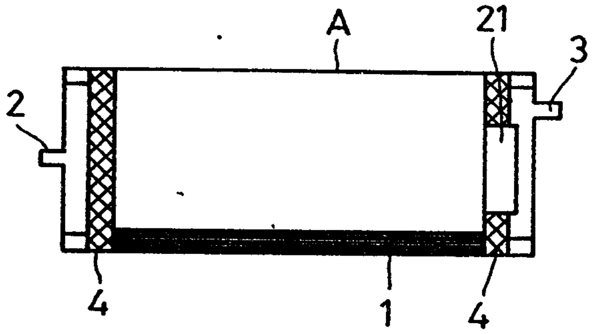


FIG. 6

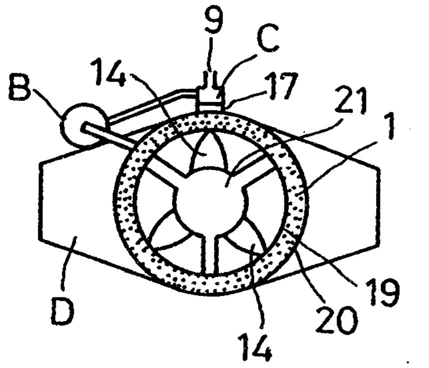


FIG. 7

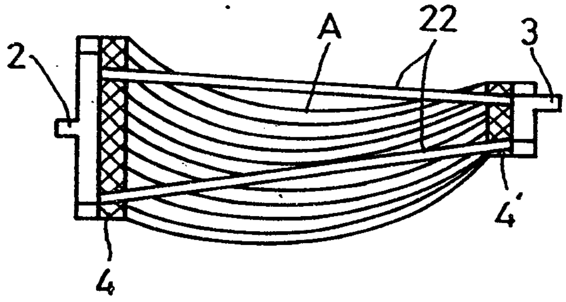


FIG. 8

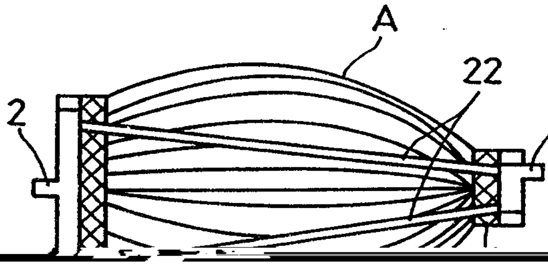


FIG. 9