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(54) **GILL-TYPE BREATHING EQUIPMENT**

(57) **Abstract:**

My invention relates to equipment for underwater swimming, observing, construction work, salvage, fishing, geologic prospecting, marine scientific studies, underwater sports, photography, or other activities underwater, and particularly includes the provision for means for extracting dissolved oxygen from the water for breathing purposes, and also includes means for dissipating carbon dioxide from the lungs into the water, providing results for the diver similar to those provided for fishes by their gills. The invention provides both a process and special apparatus for carrying out the process whereby a person's exhaled breath is rehabilitated, by purification and replenishment with oxygen, to render it suitable for rebreathing.

This relates to one of the oldest dreams of mankind. Throughout human history men have enviously watched the fishes swim serenely at various depths in streams, lakes, and in the oceans, "breathing" by use of their gills, and men have longed for some way to devise gills, or their equivalent, for themselves. In the centuries of development and use of underwater swimming and diving equipment, no one before has attempted and succeeded in providing any equivalent to fishes' gills, whereby dissolved oxygen is extracted from the water, and whereby carbon dioxide, one of the waste products of metabolism, is disposed of by passing in into solution in the water.

The basic principles of science, employing the laws of partial pressures of gases, as they operate in fishes' gills, in human lungs, and in this invention providing Gill-Type Breathing Equipment for man, are fully explained

and in extensive detail in my United States Patent No.

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3,228,394 issued January 11, 1966. The aforesaid United States Patent will "teach" the principles of this new art, and this extensive discussion will not be needlessly repeated here.

It will be sufficient to state here that the following "Objects" summarize this invention.

A major object of this invention is to rehabilitate a person's exhaled breath to render it suitable for re-breathing.

Another object is to extract dissolved oxygen from water and add this extracted oxygen to the exhaled breath.

Another object is to extract carbon dioxide from the exhaled breath and dispose of it by dissolving it in water, to purify the exhaled breath.

Another object is to accomplish the above objects by means of diving equipment worn or used by a person.

Another object is to accomplish the above objects for personnel in a submarine, or other underwater vessel.

Another object is to accomplish the above objects in underwater living spaces, work spaces, or housings of any type, and with apparatus of all types, whether movable or stationary.

Another object of the invention is to utilize gas permeable membranes of continuous materials (non-porous).

Another object of the invention is to utilize a different class of gas permeable materials, containing direct gas-to-water interfaces, which class, for example, may include microporous materials.

Another object of the invention is to utilize gas-to-water interfaces which may include bubbling exhaled breath through water to extract oxygen therefrom and add the oxygen to the exhaled breath and dissolve the carbon dioxide in water.

Another object, in some applications of the invention, is to substantially equalize the partial pressure of the exhaled inert gas and the partial pressure of the same gas dissolved in water so that no substantial net migration or loss of the inert gas will occur out through the permeable membrane.

Another object of the invention, in applications where the exhaled gases are at pressures greater than one atmospheric pressure in order to balance water pressures at depths, is to reduce the pressure of the exhaled gases in a gas exchange unit until the partial pressure of the inert exhaled gas is at substantially the same pressure [redacted] quantity of exhaled inert gas will be lost.

Another object of the invention is to provide various types of elements and apparatus for carrying out this new process for rehabilitating exhaled breath.

Other objects and advantages will be apparent during the course of the following description.

membrane of any kind of suitable material, as preferred by the user, and if a large enough area of it is exposed to the water, in accordance with the principles to be more fully described hereinafter, this will provide oxygen for rebreathing. One of the most oxygen and carbon dioxide permeable materials currently available is silicone rubber, and this will be used to illustrate the principles of the invention, but this example is not limiting.

Another class of barrier materials is the microporous sheetings, including such sheetings as microporous polyethylene, and others frequently used as microporous filters. These may be treated, where necessary, to render them water repellant, thus providing direct gas-to-water interfaces through their pores while acting as a barrier to keep out water.

When preferred, barrier materials may be made very thin, a process having been recently announced for making sheet materials only 6 microns thick. Also, where preferred, thin materials may be reinforced by a network of stronger material to provide mechanical strength with improved tear strength, bursting strength, and abrasion resistance.

With whatever materials or apparatus are used, it shall be understood that the purposes of this invention will be fulfilled by the extraction of dissolved oxygen from the water to ANY extent for breathing purposes, and for a time any greater than a person can hold his breath, and/or the same for the extraction of carbon dioxide from the exhaled breath and dissolving this in water.

To provide water flow across the surface of the gill units, a slow swimming movement through the water will be fully adequate, which is the same principle used by thousands of fishes. For a detailed discussion of this, with calculations, see my United States Patent. However, a pump or any suitable means may be used to provide adequate flow of water across or through the gas exchange means. The indications are that a current flow (usually present in most parts of the ocean) or a slow swimming speed of one foot per second (very easily maintained with swim fins) down to perhaps as little as an inch per second could provide adequate water circulation.

Figure 1 is a fragmentary plan view of a gill unit or module, a considerable number of which are assembled and are appropriately interconnected to form the gas exchange unit whereby exhaled breath in the inside of each gill unit is replenished by passing carbon dioxide out through the adjacent membrane into the surrounding water, and passing dissolved oxygen from the water through the membrane into the exhaled breath within the gill unit, and then back to the person for rebreathing.

Figure 2 is an edge elevation of Fig. 1, partly in section along the line A-A, and looking in the direction of the arrow.

Figure 3 is a fragmentary plan view of assembled gill units of Fig. 1, showing also connected breathing conduit hoses, and in addition showing means for guiding exhaled breath through a zig zag path back and forth through the gill units in a series-parallel connection pattern, to assure both maximum circulation of exhaled breath relative to the membrane, and to provide a fully adequate cross

section of the breathing circuit to assure easy and comfortable breathing. The number and size used, as in Fig. 3, is a matter of design choice for the individual user and partly depends also upon the membrane or barrier chosen, and the number shown herein is only to illustrate a method of construction and interconnection.

Figure 4 is a fragmentary side elevation of Fig. 3 showing a construction for a pipe manifold connecting gill unit ports in parallel and connecting these to a breathing hose.

Figure 5 is a fragmentary plan view, partly in section, of a complete gill-type diving equipment for an individual, including gill unit assembly, connecting hoses, breather bag, snorkle, mouth piece, safety automatic valve, and reserve air and buoyancy control.

Figure 6 is a cross sectional view showing the construction of the safety automatic valve of Fig. 5.

Figure 7 is a process diagram for methods of rehabilitating the exhaled air of one or more persons in a submarine or under water vessel, or other housing, work space, or living space or apparatus.

Figure 8 is a diagrammatic cross sectional view of an alternative type of gas exchange unit, providing direct gas-to-water interfaces by bubbling exhaled breath through water.

Figure 9 is a diagrammatic representation of an underwater housing or work space where the air pressure is kept equal to the outside water pressure so that divers can come and go through the air-to-water interface in the entrance built into the under side of the housing, and also live continuously at the outside sea pressure without having to go through decompression between work periods. Fig. 9 also shows how the exhaled air could be reduced to atmospheric pressure (15 lbs. per sq. in.) in the gas exchange unit so that the nitrogen of the exhaled air would not be lost, although the needed oxygen would be obtained and the poisonous carbon dioxide would be disposed of into the water.

In the accompanying drawings, it is to be understood that the parts are not necessarily shown to scale, it being believed more important to provide for a clear understanding of the principles of the invention.

The soundness of these principles has been proved by successful tests, repeated for witnesses and for photographing, where I demonstrated test equipment I had designed and built, whereby, for over an hour at a time, I exhaled into and inhaled from a closed breathing circuit where my exhaled breath had carbon dioxide extracted from it and this was dissolved in sea water, and where dissolved oxygen was extracted from the sea water and replenished my exhaled breath, and I rebreathed such exhaled air over and over again.

In Fig. 1, and Fig. 2, the gill module or unit, shown generally as 20, comprises an inner core 21, along and through which exhaled breath may readily flow, and which may be made of stiff sheet material perforated with many holes and then corrugated as shown; supporting screen elements 22-22; which in turn support the gas permeable barrier or membrane material 23-23 (which may be reinforced silicone rubber); bound around the edges with stiff channel members 24-24; with resiliant port connecting members 25-25 (which may be rubber washers) cemented to the permeable membrane with the membrane material and the screens 22 and core 21 cut away within the centers of the washers, as shown in Fig. 2; and spacer members (which may be rubber washers cemented to the permeable membrane preferably not cut away in their centers); and with all edges, channels, ports, etc. sealed with appropriate material to prevent any leakage when assembled and submerged in water.

It is desirable, although not essential, to secure the screen elements 22-22 to the core 21 at spaced intervals throughout the area, and also to secure the membrane barrier 23 to the screen elements 22 so that the permeable membrane will stay supported and in contact with the core 21. This securing may be done by cementing, or any other preferred means.

In Fig. 3 the method of assembly and connecting the gill units is shown. A plurality of gill units 20-20 are stacked together with separator elements 26-26 (which may be additional washers cemented to the port washers 25-25) to provide adequate space for the flow of water between the gill elements. Threaded rod members 27-27 are passed through the cut out portions of the port members 25-25 (see Figs. 1 and 2) and through the pipe manifolds 28-28 (Fig. 3) and are drawn tightly together and secured by nuts 29-29. Discs 30-30 made of sheet rubber (or other preferred material) with holes that fit tightly the rods 29-29 constitute flow guide members for the flow of the exhaled breath through the gill units 20-20. By locating the flow guide members to block and guide the flow of exhaled breath, various different paths of flow through the gill unit assembly can be provided. Various arrangements can be tried for preferred results. Fig. 3 shows a series-parallel flow pattern. Exhaled breath coming in through hose 31 flows into the two gill units shown at the right, and from there on as shown by the arrows, being guided by members 30-30 until the rehabilitated breath passes out hose 32 on its way back to the person to be rebreathed.

Fig. 4 shows how a manifold and hose looks when viewing the assembly of Fig. 3 from the side. The pipe manifolds (which may be metal) provide excellent mechanical strength and support for that end of the gill assembly. The other end is stiffened and supported by passing the threaded rods 27-27 through the metal strip members 32-32, which also provide closure for the ports of the first and last gill units. Similar members 33-33 may be used in conjunction with the manifolds 28-28, but in this case care must be taken to provide adequate air passageways around the clearance hole for the threaded rod, but inside the rubber washers. This has proved quite adequate. It has been found helpful to cement various of the washers (as preferred) to the surfaces with which they are to mate, before assembly.

In Fig. 5 the gill unit assembly of Figs. 3 and 4 is shown generally at 34, and this is connected with the rest of the system by exhalation hose 31 and inhalation hose 32, the flow being shown by the arrows. The mouthpiece 35 is connected so that exhaled breath can flow through a check valve 36 and into the expandable breather bag 37 and through the manually operable valve 38 (shown in the open position) and into the hose 31. The breather bag is any preferred type of flexible waterproof bag, such as is commonly used in rebreather diving equipment.

[illegible]

the breathing circuit. This bag preferably is located hose 32, through valve 43, through the mouthpiece 35, and into the diver's lungs. This is the normal breathing cycle.

Because the breather bag 37 is sensitive to sea pressure, it changes its volumetric capacity at different depths, becoming smaller with increased depth. This also reduces buoyancy of the total equipment (in common with all breather bag recirculating diving equipments). To compensate for this, and to provide the additional useful feature of "buoyancy control" special features have been added to the system. For example, if you want to carry up to the surface something you have found at a depth, it could save much swimming effort if you could adjust your equipment to have positive buoyancy and "float" up. Also, this added equipment can be controlled for negative buoyancy when desired.

The snorkle 38, mouthpiece 35, and total breathing circuit are connected by flexible high pressure hoses 44 and 45 to the hand pump 46, and the reserve tank 47. A manually operable valve 48 connects the hose 44 to the intake side of the hand pump 46. There is also an automatic check valve (not shown) between the valve 48 and the inlet side of the pump 46. The pump 46 is preferably the double action type, pumping when the handle is moved in either direction. While the diver is at the surface, before submerging, and with the snorkle open (or the mouthpiece not in his mouth) the diver opens valve 48 and then pumps as much air as he wishes into the reserve tank, as indicated by the pressure gauge 49 -- perhaps 100 p.s.i. gauge pressure. This he can do very easily wherever he is (anywhere in the world) and with no other equipment required. Contrast this with the compressed air scuba equipment usually requiring 2700 pounds p.s.i. gauge pressure, special compressors, and special precautions to prevent the compressor from adding toxic elements to the air compressed. In most of the world compressed air scuba diving isn't feasible simply because the high pressure compressed air (purified) isn't available in those localities. Even where available, it is expensive, and every tankfull costs money. In contrast, when using this gill-type diving equipment, the cost for air is zero, and you can go anywhere to dive, without worrying about availability of local compressed air stations, or (more expensive still) buying and taking along your own scuba compressor and fuel. Also, you can dive, with the gill-type equipment, as many times as you wish per day with no added expense.

The diver, having filled his tank, can close the snorkle cap 40 and submerge. As he goes deeper, the increased sea pressure diminishes the volume of the breather bag 37. When he wishes, the diver can open slightly the manual needle valve 50, to allow some of the compressed air from the tank 47 to enter the breathing circuit and increase the volume of breather bag 37. He can exactly compensate for the added depth of water and resume neutral buoyancy, or he can purposely over compensate and have positive buoyancy, or he can [illegible] doing so by opening valve 48 and pumping air from the breathing circuit back into the reserve tank 47, keeping the air there until it is wanted again. With this equipment there is no need to waste that air. This provides [redacted] added efficiency.

The safety automatic valve 51 is shown in Figs. 5 and 6. If a diver has been swimming at depth and returns to the surface, it is vitally important for him to exhale as he ascends, or to breathe continuously which includes exhalation, so that upon reaching the surface, he doesn't "explosively exhale" hemorrhaging the lung tissues, sometimes followed by death. The valve 51 is constructed [redacted] circuit pressure as a diver ascends, even if he forgets about it, so that he can continue breathing automatically diminished pressures as he ascends, and thus avoid hemorrhaging.

A second important use for this valve is for expelling leaked water in the breathing system. Note that this valve is located substantially below the mouthpiece and the prime circulating path for the breathed air, so that even a considerable quantity of leaked water could be accumulated here before interfering uncomfortably with pointer 56. This knob with pointer is threaded onto threaded stud 57, which is mounted in the support member 58, which in turn is secured to the valve body by screws [redacted] cover 54.

When the diver wants to expel water which may have leaked into the breathing system and may have accumulated in the lower portion of valve body 52, he can readily do this by taking an extra deep breath, turning "off" valve 38 and exhaling sharply while slightly lifting the handle 60, thus tilting the cover 54 and providing an exit opening along its lower edge. The diver would then turn valve 38 back to the "on" position, as shown in Fig. 5. Then he can replace the air used for "blowing" out the water by "cracking" the needle valve 50 and then reclosing it.

Another use for the reserve air tank is as follows. In providing a gas permeable membrane to pass out carbon dioxide from the breathing system into the water, and to also pass dissolved oxygen from the water into the breathing system, this membrane also will pass out some of the inactive nitrogen we breathe. Helpfully, the permeation of nitrogen is only about half as fast as it is for oxygen. There is no significant problem here for diving in shallow water. However, as we dive deeper we increase the pressure of the gases in the breathing circuit to balance the increased outside sea pressure. This also increases the partial pressures of the gases in the breathing circuit and gill units. This makes no difference to us in getting rid of carbon dioxide, and in obtaining the oxygen we need, but we will lose some nitrogen, and at an increasing rate as we dive deeper. This can be compensated for by opening needle valve 50 and letting some of the compressed air stored in the tank out into the breathing circuit. Tests on a silicone rubber membrane, using specially built instruments, have shown that we can expect to dive, for example, to 66 to 99 feet for half an hour with quite moderate p.s.i. gauge pressures using a quite feasibly small reserve tank. More stored pressure or a larger tank would enable us to go deeper or for a longer time. Since we are told that approximately 80% of all the diving done is in less than 25 feet of water, the above considerations indicate very practical equipment.

In submarines, and in any underwater housing or work spaces or apparatus where there is normal atmospheric pressure, this gill-type breathing equipment will have no loss of nitrogen at all because the naturally dissolved nitrogen in the water will be at the same partial pressure as the nitrogen in the gill units, and so migration or loss of nitrogen will not occur.

Fig. 7 is a process diagram showing how the gill-type breathing equipment can be applied to a submarine or similar other underwater housing or work space. In Fig. 7, 61 represents the outside (sea) water held out by the submarine hull 62 with water being passed in through valve 63, by pump 64, and being pumped through the gas exchange unit 65; and then being pumped by pump 66, out through valve 67, and out through the hull 62. Also, exhaled breath is pumped by pump 68 through the gas exchange unit and back to the personnel for rebreathing. The gas exchange unit 65 can be of the type shown in Figs. 1, 2, 3 and 4 or it can be of any other preferred type.

Fig. 8 shows an alternative type wherein a housing 69 contains the circulating water and has submerged conduits with fine apertures through which the exhaled air is pumped, the bubbles rising through the water providing direct gas-to-water interfaces with the rehabilitated air accumulating at the top of the housing and being passed back to the personnel for rebreathing.

In applications like the submarine application, where the air pressure is at or near normal atmospheric pressure, the water pressure and air pressure are equalized after the water is pumped inside the hull, since water does not expand or contract appreciably with change of pressure. Fig. 7 shows optional alarm systems actuated if any of the water pumps or valves of the water circuit fail.

In Fig. 9, 70 represents a housing or other work or living space where the atmosphere is kept at the same pressure as the outside water pressure, and where the divers go in and out through the entrance 71 built into the underside of the housing 70. The valves 63 and 67 and pumps 64 and 66 correspond to those shown in the submarine of Fig. 7, for circulating water from outside the enclosure and through the gas exchange unit. However, in the submarine, the water pressure was reduced to the pressure of the exhaled breath by merely pumping the water into the submarine, where the air normally is kept at approximately one atmosphere of pressure. In contrast, in the underwater housing of Fig. 9, the atmosphere would be at two atmospheres of pressure at 33 feet of water depth, and at proportionally greater pressures at greater depths. The method to be used in such a case is to reduce the pressure of the exhaled air within the gas exchange unit, so that the partial pressure of its nitrogen will be substantially equal to the partial pressure of the naturally dissolved nitrogen in the water, whereupon substantially no nitrogen will be lost through the permeable membranes. In Fig. 9, valve 69 is so constructed and adjusted that, in conjunction with pump 68, the gaseous pressure of the exhaled air contained within the gas exchange unit 65 is held at substantially one atmosphere of pressure. Then the above discussed partial pressure conditions are maintained, and no substantial loss of nitrogen results, while at the same time the needed oxygen is obtained and the carbon dioxide is disposed of by dissolving it in the water.

In the claims it is to be understood that the term "gas permeable material, membrane, barrier, element," etc., includes both or either continuous materials, such as silicone rubber, etc., or alternatively porous materials including microporous plastics, or any material or barrier containing a very large number or small openings, providing gas-to-water interfaces.

It is to be understood that the descriptions herein are illustrative and not limiting and that all other equivalents are likewise included.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of reoxygenating the exhaled breath of a person, wherein a substantially liquid-impervious oxygen-permeable membrane is utilized, comprising the steps of moving the exhaled breath to and in contact with one side of the liquid-impervious oxygen-permeable membrane disposing the other side of the liquid-impervious oxygen-permeable membrane in contact with water containing dissolved oxygen to extract dissolved oxygen from said water through the membrane, and adding said dissolved oxygen to said exhaled breath while excluding water, and moving said reoxygenated breath to the person for rebreathing.

2. A method of reoxygenating the exhaled breath of a person, wherein a liquid impervious barrier member including a multiplicity of small holes is utilized, comprising the steps of moving the exhaled breath to and in contact with one side of said barrier member, disposing the other side of the liquid-impervious barrier member in contact with water containing dissolved oxygen to extract dissolved oxygen from said water, and adding said dissolved oxygen to said exhaled breath while excluding water, and moving said reoxygenated breath to the person for rebreathing.

3. The method of reoxygenating the exhaled breath of a person, comprising the steps of conducting the exhaled breath to water containing dissolved oxygen, bubbling said exhaled breath through said water whereby

dissolved oxygen is extracted from said water and is added to said exhaled breath, and conducting said reoxygenated breath back to the person for rebreathing.

4. The method of reoxygenating the exhaled breath of a person, comprising the steps of moving the exhaled breath to oxygen extraction means in contact with water containing dissolved oxygen, extracting dissolved oxygen from said water through the said extraction means and adding said extracted oxygen to the exhaled breath, and moving the reoxygenated breath back to the person for rebreathing.

5. The method of rehabilitating the exhaled breath of a person, wherein a substantially liquid impervious carbon dioxide-permeable membrane is utilized, comprising the steps of transferring the exhaled breath to and in contact with one side of the liquid-impervious carbon dioxide-permeable membrane, disposing the other side of the liquid-impervious carbon dioxide-permeable membrane in contact with water to extract a substantial portion of carbon dioxide from said exhaled breath and dissolving the extracted carbon dioxide in said water, adding oxygen to said exhaled breath from which a substantial portion of carbon dioxide has been extracted, and transferring the rehabilitated breath back to the person.

6. The method of rehabilitating the exhaled breath of a person, wherein a liquid-impervious barrier member including a multiplicity of small holes is utilized, comprising the steps of transferring the exhaled breath to and in contact with one side of the said barrier member, disposing the other side of said barrier member in contact with water to extract a substantial portion

of the carbon dioxide from the exhaled breath and dissolving the extracted carbon dioxide in said water, adding oxygen to the exhaled breath from which a substantial portion of carbon dioxide has been extracted, and transferring the rehabilitated breath back to the person.

7. The method of rehabilitating the exhaled breath of a person, comprising the steps of conducting the exhaled breath to water, bubbling said exhaled breath through said water to extract a substantial portion of carbon dioxide from said exhaled breath and dissolving the said carbon dioxide in said water, adding oxygen to said exhaled breath from which a substantial portion of carbon dioxide has been extracted, and conducting the rehabilitated breath back to the person.

8. In a process for providing a rebreathable atmosphere, the steps including transferring a person's exhaled breath to means adapted to extract oxygen from water containing dissolved oxygen and to extract carbon [illegible] from said exhaled breath and passing it to said

to equalize the pressure of the exhaled breath in the breathing circuit and the pressure of said water, passing gasses from the breathing circuit into a rigid container to reduce displacement and buoyancy of the diving equipment, passing gasses from the rigid container into the breathing circuit to increase displacement and buoyancy of the diving equipment, extracting oxygen from said water and mixing the extracted oxygen with the exhaled breath, and transferring the reoxygenated breath back to the person for rebreathing.

10. In maintaining a breathable atmosphere in a submarine where the outside water pressure is different from the inside air pressure, the method including the steps of conducting exhaled breath to water containing dissolved oxygen, equalizing the pressures of said water and said exhaled breath, extracting oxygen from said water and mixing the extracted oxygen with the exhaled breath, and conducting the reoxygenated breath back to the personnel of the submarine for rebreathing.

11. In maintaining a breathable atmosphere in a submarine where the outside water pressure is different from the inside air pressure, the method including the steps of conducting exhaled breath to water, equalizing the pressures of said water and said exhaled breath, extracting carbon dioxide from said exhaled breath and dissolving the extracted carbon dioxide in said water, adding oxygen to said exhaled breath, and conducting the mixed gasses to the personnel of the submarine for rebreathing.

12. In a process for providing a rebreathable atmosphere, the steps including transferring the exhaled breath of a person to means adapted to extract dissolved oxygen from water, extracting dissolved oxygen from water with said means and mixing the extracted oxygen with the breath to oxygen-enrich it, and transferring said oxygen-enriched breath back to the person for rebreathing.

13. Gill-type respirator equipment for underwater breathing including conduit means adapted to conduct the exhaled breath away from a person's face, a face piece in communication with said conduit means, a gas exchange unit connected to the conduit means and adapted to extract the dissolved oxygen from the surrounding water and mix said extracted oxygen with the exhaled breath, and gas return means connected to said gas exchange unit and adapted to conduct the reoxygenated breath back to the person's face for rebreathing.

14. Gill-type respirator equipment for underwater use including conduit means adapted to conduct the exhaled breath away from a person's face, a face piece in communication with said conduit means, a gas exchange unit connected to the conduit means and adapted to extract dissolved oxygen from the surrounding water and mix said extracted oxygen with the exhaled breath, variable volumetric means connected to the conduit means and adapted to be expanded to provide increased buoyancy for the equipment and adapted to be compressed to provide decreased buoyancy for the equipment, and gas return means connected to said gas exchange unit and adapted to conduct the reoxygenated breath back to the person's face for rebreathing.

15. In equipment for rehabilitating exhaled breath, the combination including a housing adapted to exclude water and provide a space for confining a person's exhaled breath, and means adapted to extract dissolved oxygen from water, said extracting means coacting with said exhaled breath and said water containing dissolved oxygen whereby dissolved oxygen is extracted from said water and is mixed with said exhaled breath to oxygen- [redacted]

16. In equipment in accordance with claim 15, wherein said means comprises a membrane formed of silicone rubber.

17. In a process for providing a rebreathable atmosphere where the gaseous pressure is greater than at sea level, the steps including enclosing exhaled breath in a means adapted to extract dissolved oxygen from water and at a gaseous pressure substantially equal to atmospheric pressure at sea level, extracting dissolved oxygen from water with said means, mixing the extracted oxygen with the breath to oxygen-enrich it, returning the oxygen-enriched breath to substantially the same pressure it had when exhaled, and transferring said oxygen-enriched breath to the person for rebreathing.

18. In a process for providing a rebreathable atmosphere where said atmosphere contains an inert gas, the steps including confining exhaled breath in means adapted to extract dissolved oxygen from water, substantially equalizing the partial pressure of the exhaled

oxygen extracting means, mixing the extracted oxygen with the exhaled breath to oxygen-enrich it, substantially equalizing the pressure of the oxygen-enriched breath with the pressure of the rebreathable atmosphere, and [redacted]

19. In equipment for rehabilitating exhaled breath, the combination [redacted]

24. In equipment in accordance with claim 15, wherein said means includes a gas exchange element having a large surface area compared to its cross section, which may be defined as having a thickness less than its width or length.

25. In equipment in accordance with claim 15, wherein said means includes a gas exchange membrane having thin portions adapted to promote gas permeation, and other stronger portions adapted to provide increased tear strength and abrasion resistance.

26. In equipment in accordance with claim 15, including construction of a gas exchange element having an inner core member providing a plurality of passageways through which exhaled breath may readily flow, perforated sheet material secured to the outside of said core member, and gas permeable membrane material supported by said perforated sheet material.

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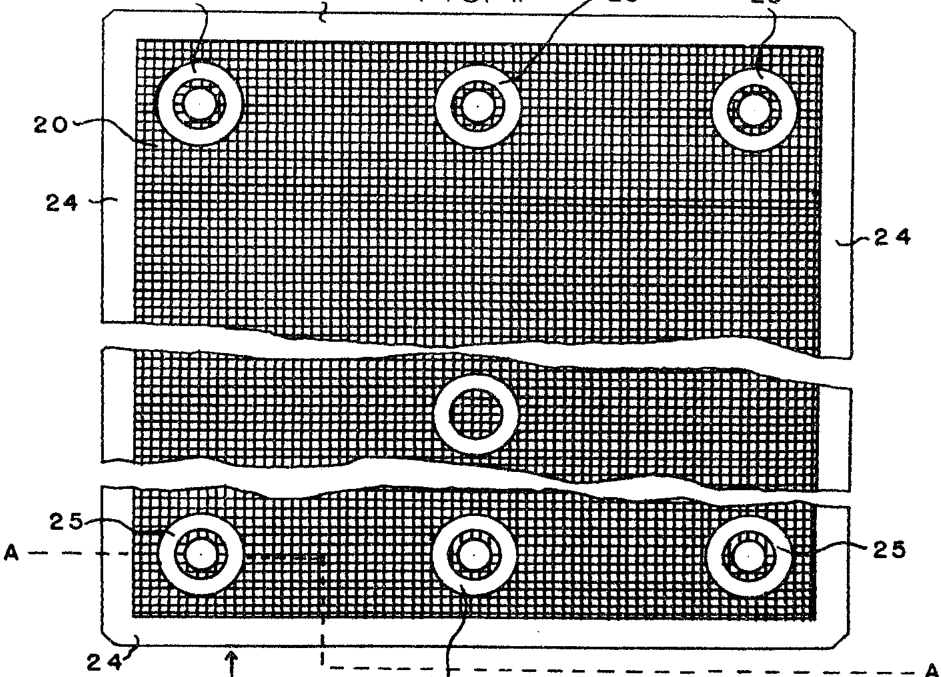
FIG. 1.



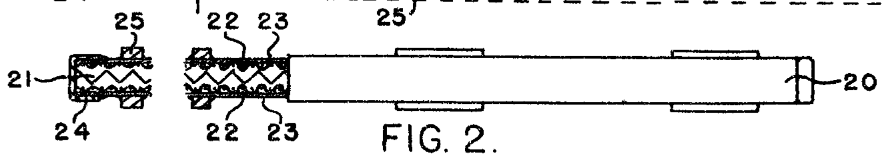
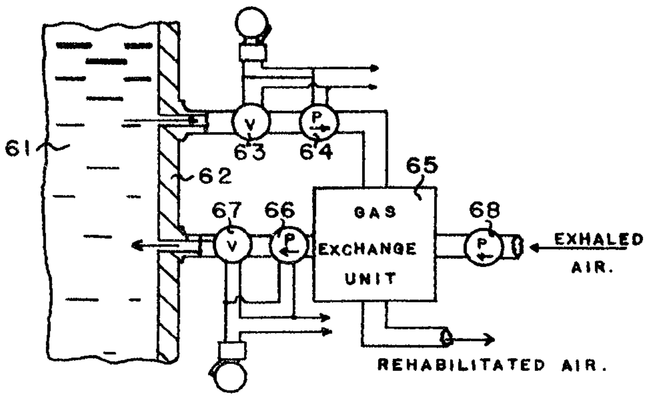


FIG. 2.

FIG. 7.



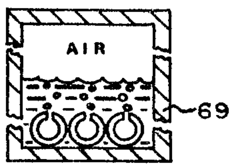


FIG. 8.

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FIG. 3.

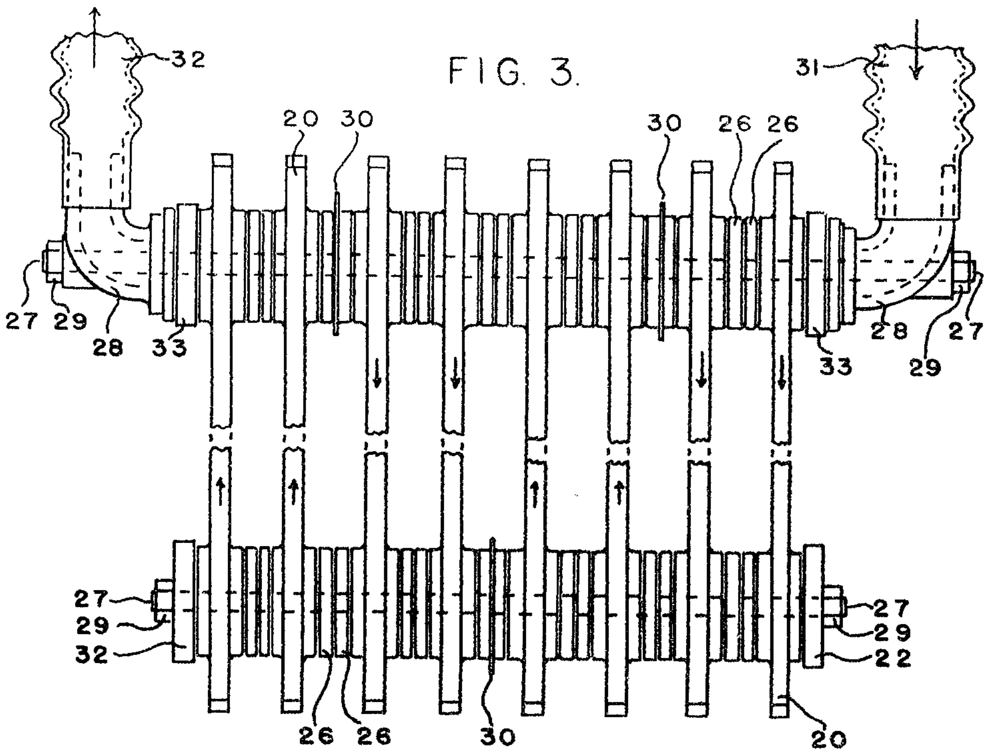
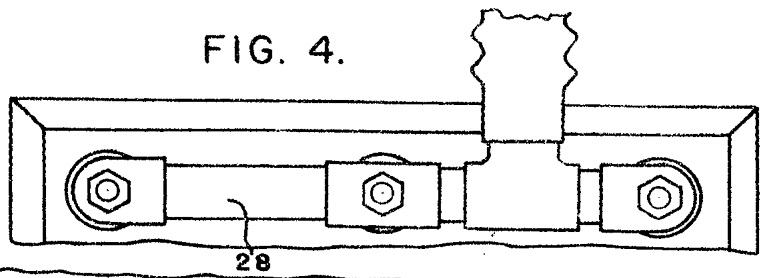


FIG. 4.



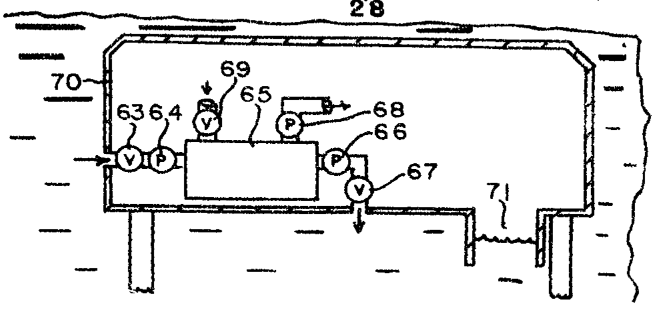


FIG. 9.

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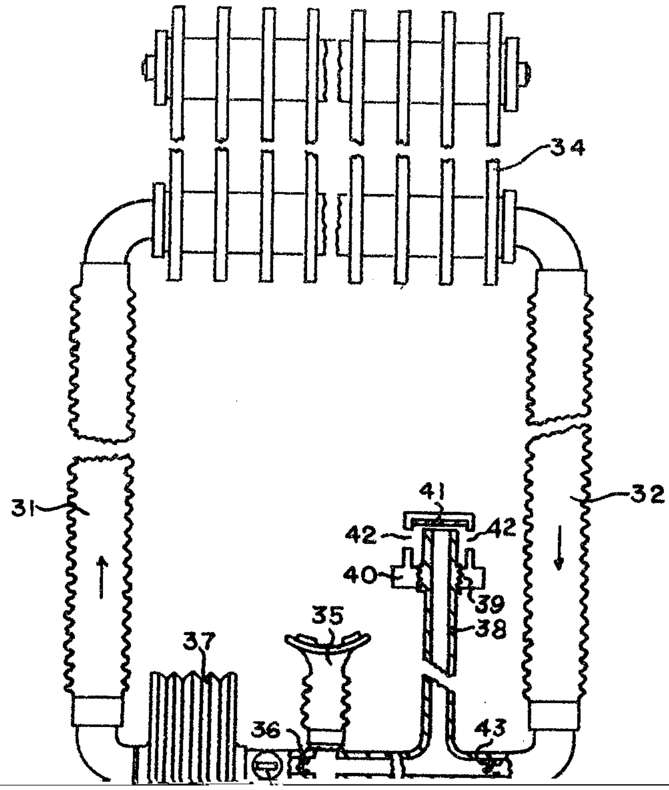
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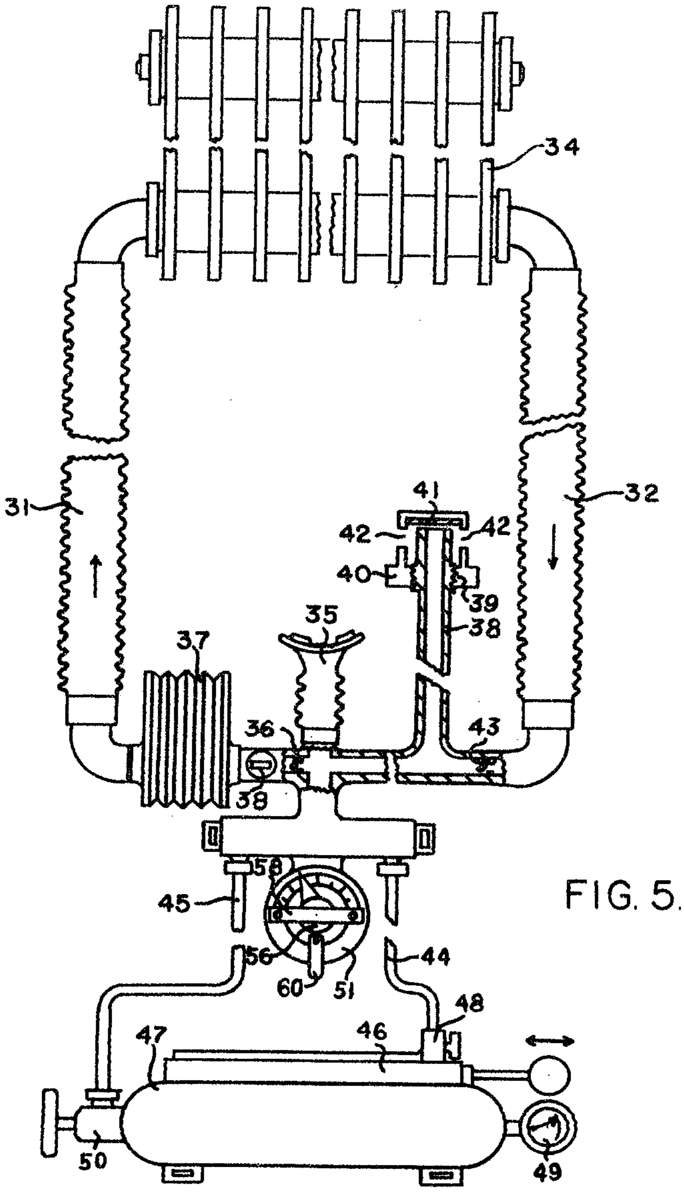

FIG. 5.

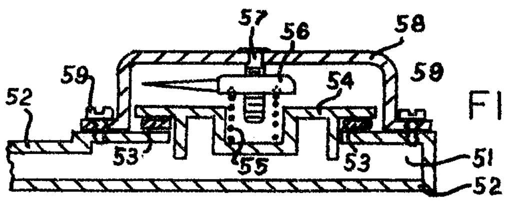

FIG. 6.

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