Jan. 11, 1966 W. A. AYRES 3,228,394
GILL-TYPE UNDERWATER BREATHING EQUIPMENT
AND METHODS FOR REOXYGENATING
EXHALED BREATH
Filed Nov. 30, 1962 6 Sheets-Sheet 1

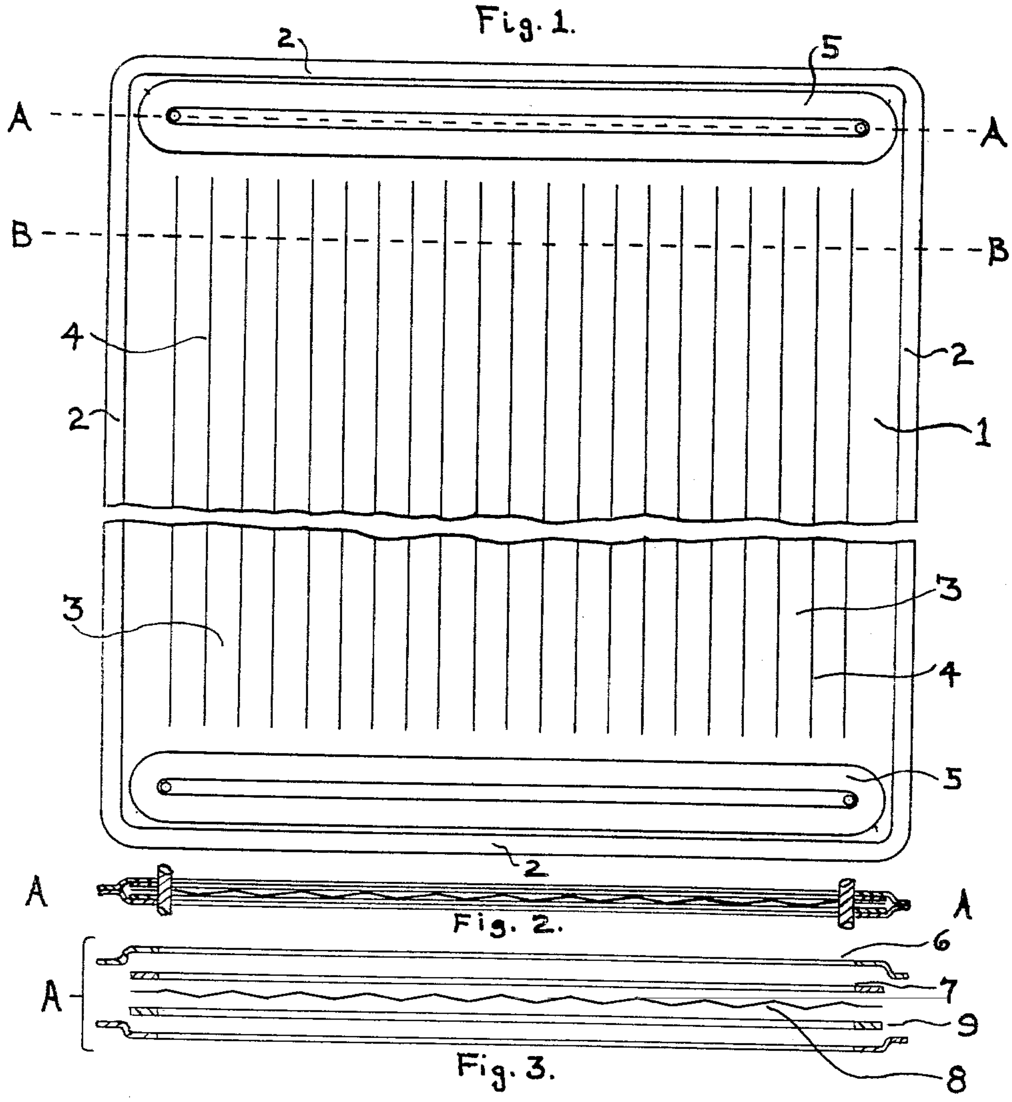

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Fig. 4.

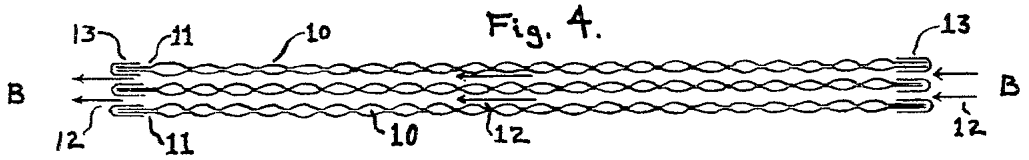


Fig. 5.

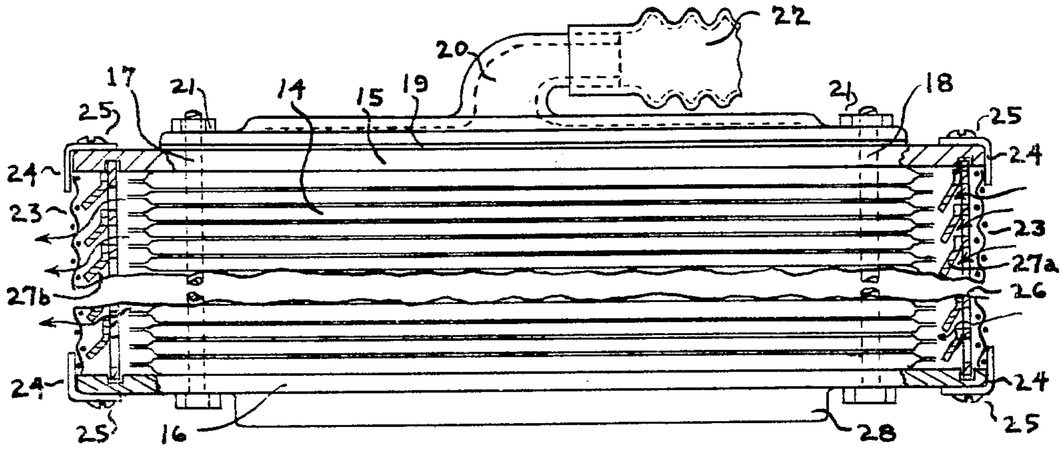


Fig. 6.

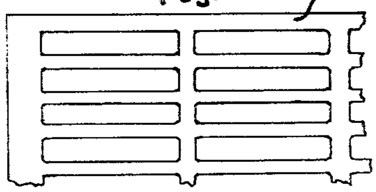


Fig. 7.

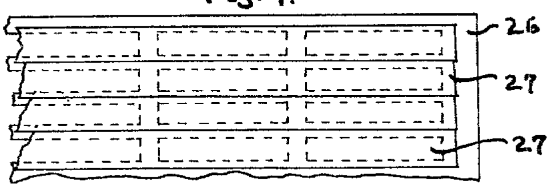
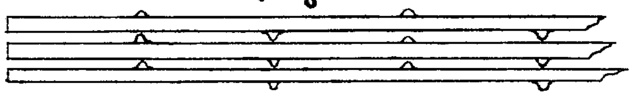


Fig. 8



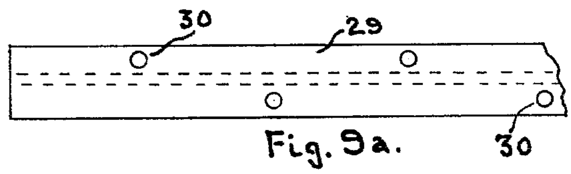


Fig. 9a.

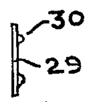


Fig. 9b.

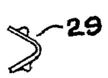


Fig. 9c.

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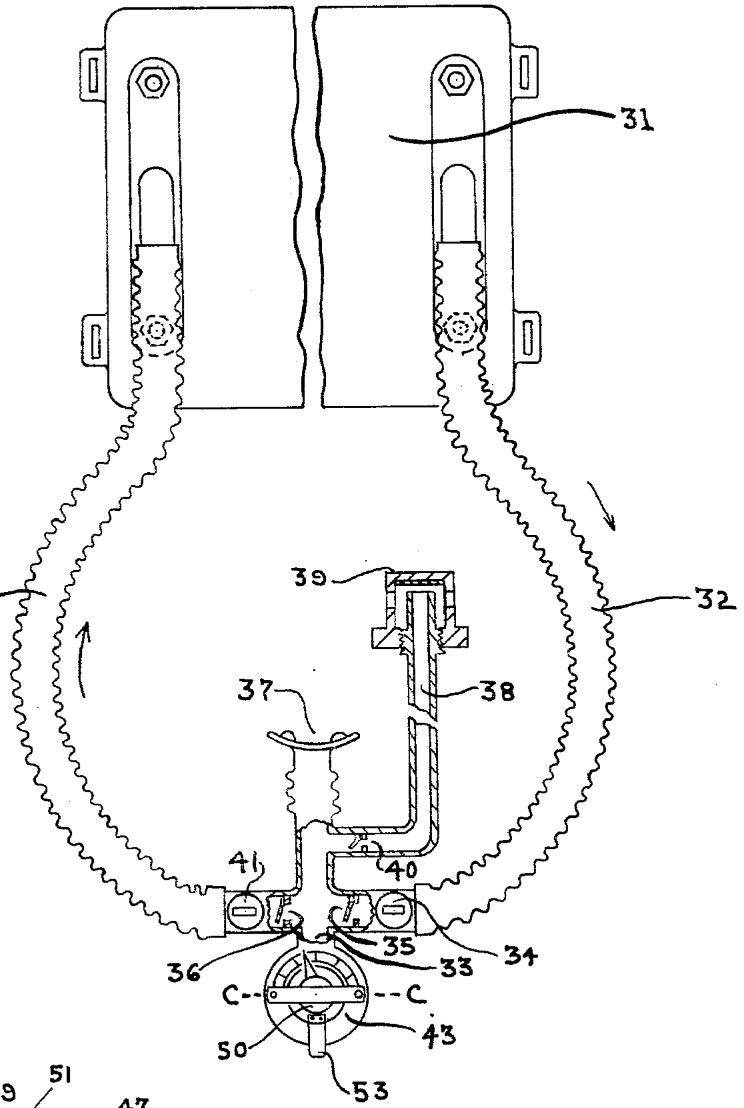
Fig. 10.



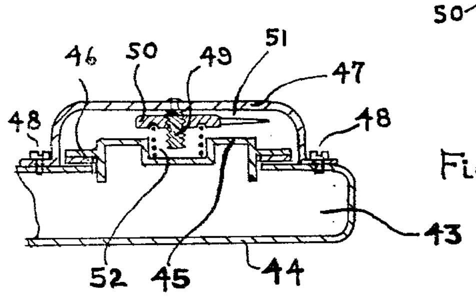


Fig 11.

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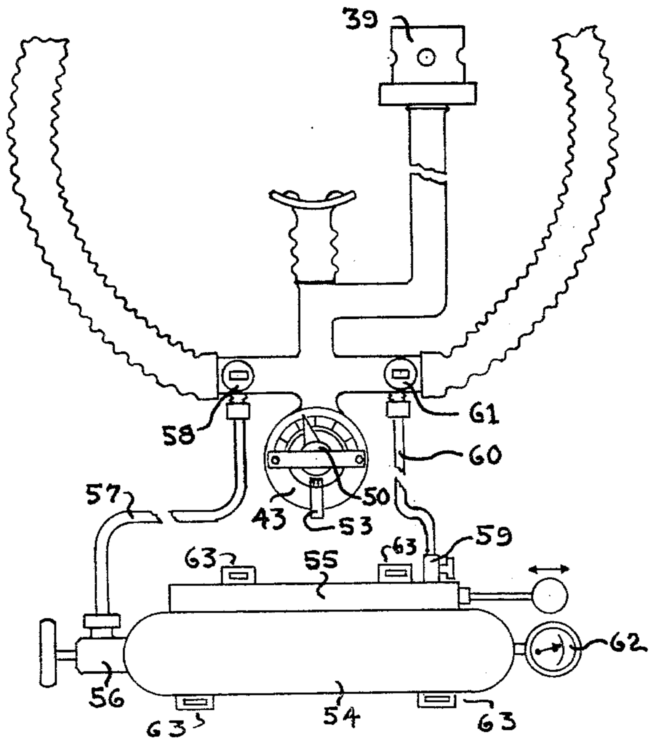

Fig. 12.

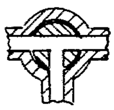

Fig. 13.

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GILL-TYPE UNDERWATER BREATHING EQUIPMENT
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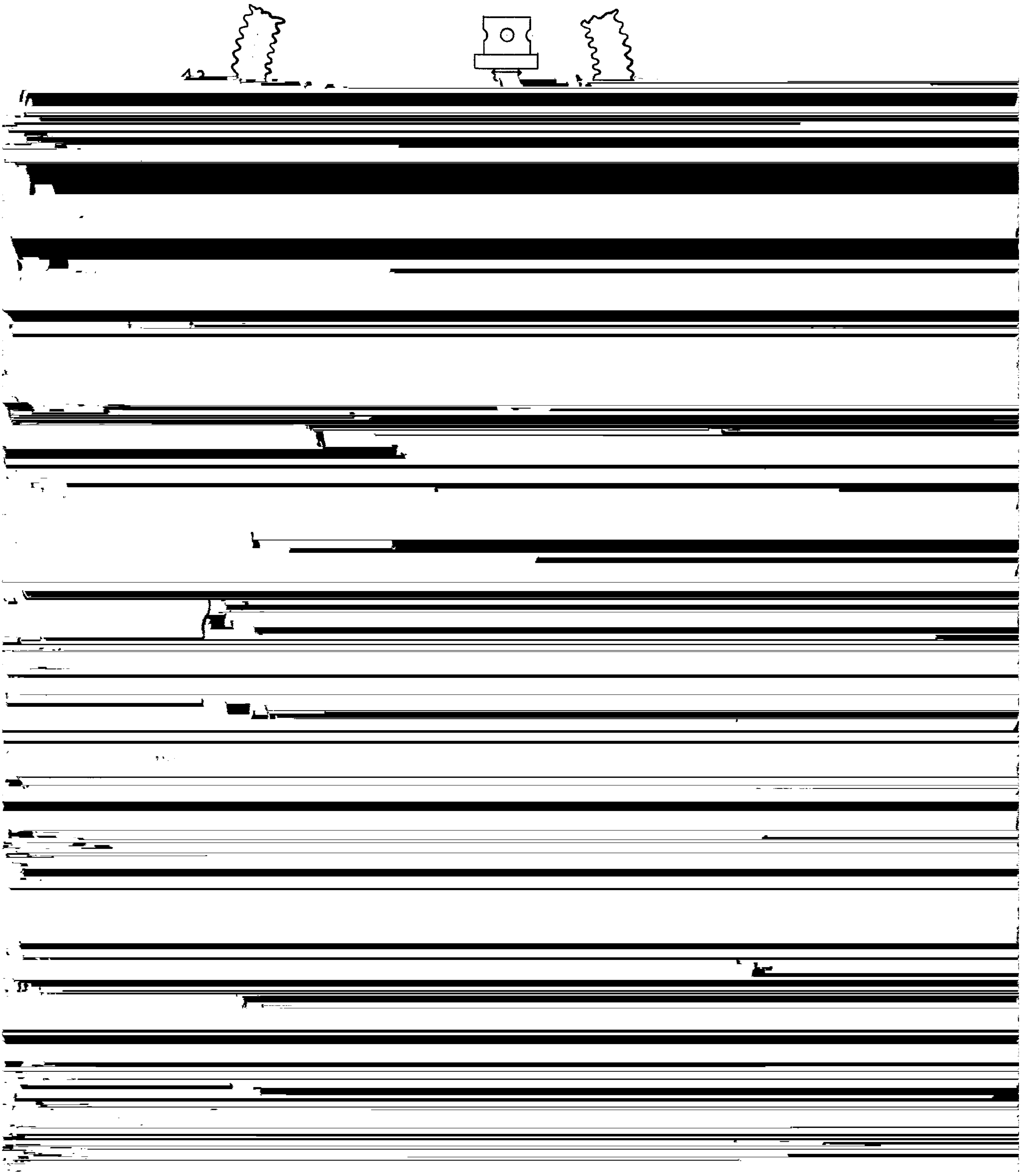

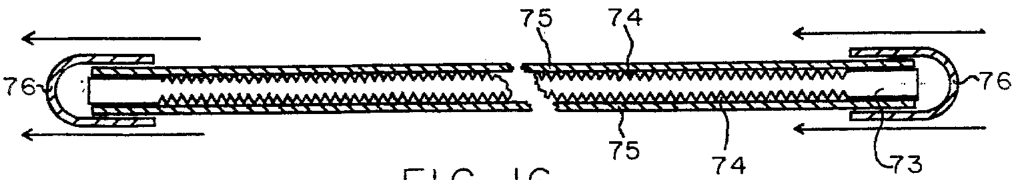

FIG. 16.

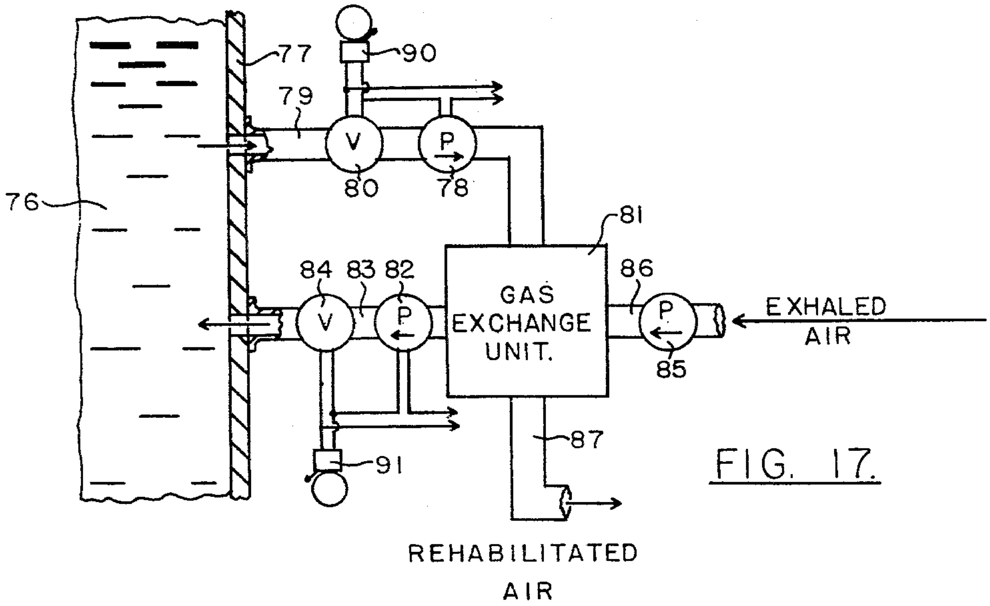

FIG. 17.

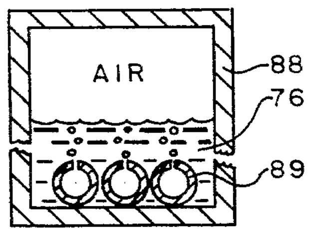

FIG. 18.

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United States Patent Office

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3,228,394

GILL-TYPE UNDERWATER BREATHING EQUIPMENT AND METHODS FOR REOXYGENATING EXHALED BREATH

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Filed Nov. 30, 1962, Ser. No. 242,046
18 Claims. (Cl. 128—142)

This is a continuation in part of my pending patent application, now expired, titled Gill-Type Diving Equipment, Serial No. 570,492, filed March 9, 1956.

My invention relates to equipment for underwater swimming, exploration, construction work, salvage, geologic prospecting, marine scientific studies, under water sports, photography, etc., such activities being carried on by the aid of breathing equipment being attached to the person (as "scuba") or alternatively as breathing equipment carried in underwater vessels, or in non-propelled work regions or housing spaces such as diving bells, underwater "domes," etc.; this invention particularly including methods and apparatus for rehabilitating exhaled air by extracting from it poisonous carbon dioxide and dis-

In all types of diving equipment heretofore, no one else has provided means for utilizing the dissolved oxygen in the water for respiration. That is the fundamental aim of this invention.

Extensive study of authoritative technical literature in various related fields has been one important part of the development of this invention. The following have proved to be useful sources of information on various aspects of the physiology, the physics, and the chemistry of respiration in men and in various other animals, especially including fishes; and various facts cited by them are used in this invention:

Cooperative Animal Physiology, by Clifford Ladd Prosser, and others; Anatomy of the Chordates, by Charles R. Weichert; Studies of the Structure and Development of Vertebrates, by Edwin S. Goodrich; Human Physiology, by Bernardo Housay; A History of Fishes, by John R. Norman; A Guide to the Study of Fishes, by David Star Jordan; The Study of Fishes, by Albert C. L. Gunther; Biological Physics and Chemistry of the Sea Water, by W. B. Harvey; Men and the Chemical Elements, by J. Newton Friend; Encyclopedia of permeable membranes. The series of pressure gradients for oxygen are as follows:

As stated by W. H. Harvey in Biological Chemistry and Physics of Sea Water, "The surface layers of the sea are nearly at equilibrium with the air in regard to both of these gases (oxygen and nitrogen). The weight or volume at N.T.P. (normal temperature and pressure) of dissolved oxygen per liter of water varies with the temperature of the water, but the pressure is usually in the neighborhood of 159 mm. (of mercury—Hg), as it is in water saturated with air at normal barometric pressure." From this, it is established that we start with oxygen dissolved in fresh water or sea water at approximately 159 mm. of Hg pressure.

As will be described in detail later, our equipment will include a substantial area of man-made permeable membrane material permeable to both oxygen and carbon dioxide. One side of this membrane material will be immersed in and in direct contact with the fresh water or sea water in which the user is submerged. The other side of the gas permeable membrane material will form part of the breathing circuit of the equipment which leads directly into the user's lungs. For the next step, we find in Comparative Animal Physiology, by C. L. Prosser, the following information: "In the lungs of men, the blood is exposed to oxygen at a partial pressure of approximately 100 mm. of Hg (in alveolar air). When the blood leaves the lungs it carries 19 volumes percent of oxygen at 80 mm. of Hg and 96% of its hemoglobin is saturated. In the capillaries the blood passes thru tissues (elsewhere in the body) where the oxygen pressure is low (5 to 30 mm. Hg). Here 25%–30% of the oxygen is unloaded, and venous blood returning to the heart carries 14 volumes percent of oxygen at about 40 mm. of Hg pressure." The information in this quotation is important because it establishes the approximate partial pressure of oxygen in the venous blood returning to the lungs in man, as being 40 mm. of Hg. According to the laws of gaseous diffusion we are utilizing, any oxygen pressure higher than 40 mm. of Hg in the lungs will cause oxygen to migrate thru the lung membrane and reoxygenate the venous blood. The higher the oxygen pressure in the lungs above 40 mm., the faster this reoxygenation will take place.

In our system, we will provide fresh water or sea water having dissolved oxygen at approximately 159 mm. of Hg pressure. This oxygen will pass thru the permeable membrane we provide, probably with a slight drop in pressure. We note, from the data quoted, that the pressure of oxygen going from alveolar air in the lungs thru the lung membrane and into the blood stream drops ap-

Also, 100 mm. of oxygen in the alveolar air is all that is necessary for ordinary breathing of air directly.

The other basic requirement is that the system dispose of the CO_2 of the exhaled air. In Comparative Animal Physiology by C. L. Prosser and others, we find this information: "The CO_2 in the blood of men for arterial blood is at a pressure of from 40–42 mm. of Hg, and for venous blood is at a pressure of 45–47 mm. As compared with this, the CO_2 pressure in sea water is 0.23 mm. of Hg." We are concerned with the venous blood—at 45–47 mm. of Hg. Its pressure relative to the 0.23 mm. of Hg in sea water provides a tremendous pressure gradient—the higher pressure is over 18,000% greater than the lower pressure. There is no question that CO_2 from the venous blood would migrate thru the lung membrane into the breathing circuit of the apparatus and then thru the man-made permeable membrane into the sea water where it would be dissolved.

The soundness of these principles has been proved by successful tests, repeated for witnesses and for photographing, where I demonstrated test equipment I designed and built, whereby, for a substantial period of time, I exhaled into and inhaled from a closed breathing circuit where my exhaled breath and CO_2 extracted from it and was dissolved in sea water, and where dissolved oxygen was extracted from the sea water and replenished my exhaled breath, and I rebreathed such rehabilitated air over and over again.

A principal object of this invention is to extract dissolved oxygen from the water and add it to the exhaled breath, and extract CO_2 from the breath and dissolve it in the water, and return the oxygen enriched and purified breath for rebreathing.

A further object is to provide means whereby the pressure of the air breathed by the user is automatically made equal at all times to the pressure of the sea water, even though the water pressure varies greatly because of the different depths at which the user may be submerged.

Another object of the invention is to provide means, in one form of the apparatus, whereby if the swimmer enters polluted water, or water containing insufficient dissolved oxygen, he will not be injured or killed, as often happens to fish in such circumstances, but will be able to partly or entirely switch to a reserve supply of breathable gas until he returns to water of normal composition.

Another object of the invention is to provide a unit which we shall call a "Gill Respirator," the function of which will be to recondition exhaled air thru disposing of excess CO_2 by dissolving it in the water in which the user is immersed, and also by extracting dissolved oxygen from said exhaled air and dissolving it in the water in which the person is submerged.

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

FIGURE 1 is a plan view of a gill respirator element.

FIGURE 2 is a cross section of FIGURE 1, taken along the line A—A, showing the construction of a spacer element adapted to pass air from a main supply thru the individual channels of a gill element.

FIGURE 3 is an exploded view of the elements in FIGURE 2, provided to show that construction more clearly.

FIGURE 4 is a cross section of FIGURE 1 taken along the line B—B, and includes similar cross sections of two additional gill respirator units showing their arrangement when assembled.

FIGURE 5 shows a side elevation partly in fragmentary cross section, showing the assembled gill respirator unit.

FIGURE 6 shows a perforated member used in construction of valve means which are part of the gill respirator unit.

FIGURE 7 shows a fragmentary view of such a perforated member with the rubber valve flaps cemented in place.

FIGURE 8 shows a fragmentary enlarged view of edge stiffener members, arranged in the position they occupy in the assembled gill respirator unit.

FIGURE 9A shows a portion of one stiffener member flat, before it is bent and installed.

FIGURE 9B shows an end view of this same strip.

FIGURE 9C shows how the strip is bent prior to being installed.

FIGURE 10 shows a plan view of an assembled gill

a large number of such individual elements in order to provide a large number of square feet of surface of gas permeable membrances thru which oxygen from the water surrounding the driver may pass into the air breathing circuit and, at the same time, carbon dioxide may pass from the air breathing circuit into the sea water where it will be dissolved.

Permeable membranes for the gill respirator elements may be made from any one of a variety of materials. The one selected should have a preferred combination of qualities such as the ability to pass oxygen, ability to pass carbon dioxide, low absorption of water, reasonable dimensional stability, good mechanical strength (particularly tear strength), good characteristics for being sealed or cemented to itself or to other materials either by heat or adhesive or other appropriate means, and reasonable cost. The first requirement is that the material chosen should have good ability to pass oxygen and CO_2.

In response to our inquiry, written to E. I. Du Pont de Nemours & Co., Inc., their polychemicals department sent us a copy of an article titled "Permeability of Polymeric Films to Gases" by V. L. Simril and A. Hershberger, published in the July issue of "Modern Plastics." This is a technical report of studies made of "The permeabilities of 21 polymeric films to oxygen, hydrogen, carbon dioxide, nitrogen, ammonia . . . etc." In this article, "all gas permeability data obtained in this study are reported here in terms of the permeability constant P which is defined as the number of moles of gas passing thru one square centimeter of film, one centimeter thick, per second per centimeter Hg vapor pressure difference across the film." Several of these materials show high permeability factors which are expressed as are given in the following table of permeability coefficients.

Membrane	CO	O_2	CO_2
Polyvinyl chloride	1.2	--------	12
Polyethylene	2.5	4.1	18
Cellulose acetate butyrate	3.2	--------	35
Tetrafluoroethylene (Teflon)	5.8	--------	--------
Natural rubber	18	32	163
Silicone rubber	375	650	3,400
N.P. Pormax (microporous plastic)	13–16,000	--------	--------
E. P. Pormax	15–25,000	--------	--------
Micro-Pormax	22–40,000	--------	--------

From this, it will be seen that various different materials may be used as the gas permeable membrane and this invention specifically includes any suitable membrane material.

This invention also includes a structure employing no membrane at all, as illustrated by the following. There are a number of instances in nature where various living creatures utilize the migration of dissolved oxygen in water into an air space provided by a submerged air bubble, trapped under water, without the use of any permeable membrane or anything comparable to it. Also, in these same situations, CO_2 given off by the living creature passes from the air space into the surrounding water where it is dissolved without any permeable membrane being employed.

For example, in an article entitled "Insect Breathing" generally the same order of magnitude. In contrast to this permeable material, "porous" materials are discontinuous, having openings, pores, interstices (as between paper or cloth fibers) or other discontinuities of cross section, such pores usually being thousands or millions of times larger than the gas atoms we are concerned with. Either permeable or porous materials can be used for this invention, but different factors are involved.

Certain well known previous experience indicates that one method of extracting oxygen without using a permeable membrane would be to use a closely woven material, such as cloth, or to use wet strength paper, or perhaps very fine wire screening, or perhaps sheet metal or plastic perforated with a very large number of very small holes. In the old fashioned "water wings" for swimming, use was made of ordinary woven cloth which, when saturated with water, prevented the air from going out thru the pores between the fibers, even though the water wings were subjected to very considerable pressure due to the weight of the person being supported in the water. The fundamental force involved in this situation is the surface tension of the water, which becomes comparatively quite high when the dimensions of the openings involved become very small. The surface tension in this case caused the water saturating the cloth to bridge the gaps between the cloth fibers so tenaciously that even the weight of a large person in the water was not sufficient to disrupt this water film. Another example is the experiment which

allow $\frac{3}{16}$″ water space between each of the gill respirator elements. Then, a gill respirator assembly containing a 12″ stack of 18″ by 18″ elements would have 48 such units and would provide approximately 216 sq. ft. of gas permeable membrane exposed to the surrounding water.

an extremely promising set of possibilities since the number of square-foot-seconds for a gill respirator unit of quite moderate size, 18″ by 18″ by 12″, appears to provide 600% more square-foot-seconds for reoxygenation [illegible] tainer and on the rib cage of the diver, the diver's chest muscles are again effective in expanding the lungs for inhalation, whereupon the flexible container of air is correspondingly compressed. Upon exhalation, the reverse occurs. The muscles of the chest contract the rib cage applying a slightly greater pressure to the air contained in it and the exhaled air passes to the flexible container which expands by a corresponding amount. Since the outside water presses equally on the flexible air container and upon the rib cage of the diver, his muscles can become fully effective in the ordinary breathing movements. Also, because his air container has a flexible structure, the air contained in the breathing circuit at all times is at precisely the same pressure as the outside water for the simple reason that the outside water compresses a flexible container of air until the pressure of the air inside is at equilibrium with the pressure of the water. It will be noted that in all three forms of the invention disclosed in this patent application, these essential principles are embodied.

In regard to the gill respirator elements in particular, the air passageways formed by the parallel lines of heat sealing are normally quite flat ovals in cross section. As the diver exhales and additional air flows into the breathing circuit thereby, the slight added air pressure will cause these passage ways to become more rounded ovals in shape, thereby increasing their volumetric capacity. Conversely, when the diver inhales and air is withdrawn from the breathing circuit, the water pressure on the outside of the permeable membranes of the gill respirator elements will cause these parallel passage ways to assume a more flattened oval shape, thereby decreasing their volumetric capacity. In this simple way, the

[illegible]

providing oxygen and CO_2 exchange with the water, also provide for the breathing circuit a flexible element having

plurality of gill respirator elements 14 are stacked together between an upper end plate 15 and a lower end plate 16. These gill elements are held in register and the whole unit is held together by the tie bolts 17 and 18 which pass up thru the bottom of end plate 18, thru the opposite ends of the elongated openings of the subassemblies 5, shown in FIG. 1, up thru the upper end plate 15, thru the water tight gasket 19, and thru the respirator unit air conduit 20. The tie bolts 17 and 18 are held securely in place by the nuts 21, 21, as shown.

Refer to FIG. 10 which is a plan view of the assembled gill respirator unit. Here it will be seen that two of the respirator unit air conduits 20 are used in the parallel fashion shown. It should be understood that when a series of gill respirator units 1, of FIG. 1, are piled in a stack in register, and to this stack are added the end plates 15 and 16 and two respirator air conduits 20 are also employed as shown in FIG. 10, then air passage ways are provided as follows. Air may be supplied by a flexible hose connection as 22 in FIG. 5, and will pass through the respirator unit air conduit 20 which leads to the elongated opening provided by the stack of separators 5 of the gill respirator elements 1 of FIG. 1; air can move down thru the central opening of the stacked elements 5 and also can move in a parallel fashion thru the passage ways provided by the corrugated separator 8 of each of the subassemblies and thence thru the parallel channels formed in the permeable membranes. The air then flows out thru the corrugated elements 8 of the subassemblies 5 at the other end of the gill respirator elements 1 and flows upwardly thru the elongated openings of the stack of elements 5 and back out thru the second

[illegible]

flexible air hose.

It is desirable to cause new water to flow frequently water flowing thru the gills of big fish have never been measured.

However, I have developed a way of making a useful approximation for our purposes. At the outdoor shark run at the Seaquarium it is readily possible to get within a few feet of the sharks. I studied nurse sharks there which (I was told) weighed approximately 400 pounds, as a basis for making a conservative comparison with a 175 pound man. They swam, much of the time, at approximately 1 ft. per second. It could easily be seen that they were not working their jaws in breathing, but as is common with sharks, with mouth slightly open were depending entirely upon their forward movement to pass water thru their gills. Also the gill slits did not periodically distend in a breathing rhythm, but instead maintained constant apertures.

All the water going over the gill membranes necessarily comes out of the gill slits, so all we need to do is estimate the flow at that point. This flow will be the total cross sectional area of the gill openings times the rate of flow, this flow being approximately equal to the speed of the fish thru the water. The gill slits averaged approximately 3 inches long, with an average opening of approximately 3/16" width, and these nurse sharks had 4 gill slits per side, making a total of eight. The total gill slit cross sectional area therefore was approximately 3" (height) times 3/16" (width) times 4 (gill slits per side) times 2 (sides), equalling a total of 4½ sq. in. cross section of water flow.

At the swimming speed of 1 ft. per second, and 4½ sq. in. of water flow, this equals 54 cubic inches of water per second, which equals approximately 14 gallons per minute.

This 14 gallons a minute is for a 400 pound shark. It might be a fraction of this for a 175 pound man.

Now compare this 14 gallons a minute for the 400 lb. shark with what we could readily provide for the man, swimming (with swim fins) at the same very slow rate of 1 ft. per second.

We have previously described a gill unit having a frontal area 18" wide by 12" high. The 48 gill units were planned at 1/16" thick each with 3/16" spaces between. The total cross sectional area of water flow will therefore be 47 spaces times 18" wide times 3/16" high, which totals slightly over 158 sq. in. of water flow. (Note the shark had only 4.5 sq. in. of water flow). With the gill unit having approximately 158 sq. in. of water flow, at a speed of 1 ft. per second we would have approximately 492 gallons flowing across the gill surfaces per minute. This obviously is far more than necessary. Then, from another point of view, calculating what reduced speed would provide the same flow as for the 400 lb. shark, we find that approximately ⅓ of an inch per second would do it.

This is such an extremely low speed that most bodies of water probably have at least this much water movement as their natural state, without a person having to swim at all, most of the time. However, a great many fish swim all their lives to circulate water over the gill surfaces. The nurse shark swims most of the time, but can also stop, and then pumping action thru the gills is observable.

Similarly, both methods for passing water over the gill units are provided in this invention. Swimming action will continuously hold open the valves (to be described below), while this will be supplemented by pumping action when not swimming.

Referring to FIG. 5, water which has come thru the screen member **23** next passes thru a valve unit which is comprised of a perforated plate **26**, shown in FIGS. 5, 6, and 7, and a series of flexible rubber-like valve strips **27**, **27**, which are cemented along their upper edges to the perforated plate **26** and are mounted in an overlapping fashion resembling shingles. These valve strips are normally closed, but in FIG. 5 they are shown in a partially open position with water passing thru the spaces between them. At the right hand side of FIG. 5, after water passes thru the screen **23** into the perforated metal sheet **26** and the valve flaps **27*a***, it then passes along between the gill respirator elements and flows out thru the valve unit at the left and then out thru the screen at the left. Water pressure, when swimming, holds both sets of valves open continuously with water flowing right thru. When not swimming, the force which provides the pumping action is as follows. When the diver inhales and withdraws air from the breathing circuit, the volumetric capacity of the parallel channels in the gill respirator units is correspondingly reduced below the pressure of the outside water. The greater pressure of the water on the outside forces the valve flaps **27*b*** to close and the valve flaps **27*a*** to open, as shown at the right side of FIG. 5, so that with these open the water flows into the spaces between the gill respirator elements by an amount sufficient to make up for the volume of these elements which are reduced when the diver inhaled. Conversely, when the diver exhales, the volumetric capacity of the parallel passages of the respirator gill element increases, thereby increasing the pressure of the water between these elements to a point where this pressure is greater than the pressure of the water outside the respirator unit. The increase of pressure from the water on the inside causes the valve flaps **27*a*** to close and the valve flaps **27*b*** shown at the left side of FIG. 5, to open, thereby allowing water to flow outwardly and thru the screen until the pressure of the water remaining within the gill respirator unit equals the pressure of the air contained in the parallel passages of the permeable membrane units. In this way, with each inhalation by the diver, there is a flow of water into the front of the gill respirator unit, and with each exhalation by the diver there is a flow of water out thru the back of the gill respirator unit.

It is to be understood however, that any suitable means for moving water thru the gas exchange unit may be employed, as preferred. For example, an electric pump could be used, with a rechargeable storage battery for power; or the power might come from copper and zinc plates with sea water as the electrolyte forming a primary battery.

In FIG. 5, **28** is a sheet of sponge rubber or other resilient material, cemented to the bottom plate and intended to make the respirator unit more comfortable when worn by the diver.

FIGS. 8, 9A, 9B, and 9C show various details of an optional element which may be used or not as found preferable. If it is found that water flowing into the front of the respirator unit (at the right as shown in FIG. 5) tends to bend over the sealed edges of the thin flexible plastic of the gill respirator elements, and if such action tends to close off these channels unduly, then stiffener elements, described below, may be utilized to hold the edges of the respirator elements in a preferred spaced and separated relation.

FIG. 9A is a plan view of part of one of the stiffener elements **29**. This may be made of a thin strip of noncorrodable material, such as thin sheet brass, or stainless steel. It is shown in end elevation in FIG. 9B. This strip carries small rounded raised portions **30** which will serve as spacers. In the manufacturing process, each strip **29** will be bent as shown in FIG. 9C and will be laid along one of the heat sealed edges **2** of the gill respirator elements **1** of FIG. 1. Then the metal strip **29** will be bent closed so that it grips both sides of the heat sealed edge as shown at **13** in FIG. 4. When these strips have been added to the gill respirator elements **1** of FIG. 1 and these elements have been assembled in a stack, their edges will appear as shown in FIG. 8. Here it is clear that the raised portions **30** will act as spacer elements reliably separated, thereby providing adequate spaces for the passage of water therebetween.

FIG. 10 is a plan view of a complete underwater breathing system utilizing the previously described gill respirator unit. Part of this diagram is fragmentary, showing in cross section some of the construction of the breathing

water outside. If not, and if he should arrive at the surface with a considerable pressure of air in his lungs, and

The operation is as follows. While charging the equipment with air at the surface, as previously described in connection with the operation of the system shown in FIG. 10, the pump valve **59** may be opened and the hand pump **55** may be operated to take air from the breathing circuit and compress it in the small compressed air tank **54**. When the gill respirator unit and the breathing circuit has been fully charged with air at the surface, as previously described, and when the diver closes the snorkle valve **59** and submerges, if he goes down to an appreciable depth the air in the breathing circuit will become more compressed as the pressure of the water into which the diver descends increases. For example, if the diver descends to 33 ft. of depth, the pressure of the water doubles and the air in the breathing circuit also has its pressure doubled and, therefore, will have only half its former volume. This will reduce the buoyancy of the diver and

wear weight belts and to carry a number of weights on the belt in accordance with personal choice as to the buoyancy desired. If a diver using this equipment had chosen to wear enough weights on his weight belt to have neutral buoyancy at the surface, then as he descended and the additional water pressure compressed the air in the breathing circuit, he would have considerable negative buoyancy. If he wished to restore his neutral buoyancy with this equipment, he could do so while submerged by opening the hand operated valve **56** and carefully allowing enough compressed air from tank **54** to enter the breathing circuit to expand the gill respirator elements to their former size, thereby displacing the same amount of water as when at the surface. If he should allow too much compressed air into the breathing circuit for neutral buoyancy, so that his buoyancy became positive, he could correct this by opening the pump valve **59** and operating the hand pump **55** while under water, thereby pumping some of the air in the breathing circuit back into the compressed air tank **54**. Similarly, as he might choose to swim at various depths during his under water swimming, he can repeatedly obtain his desired buoyancy for the varying pressure conditions by opening valve **56** to increase buoyancy or by opening valve **59** and operating

the water out. The check valve will keep any water from coming in under any circumstances—a safety precaution.

The system shown in FIG. 14 is identical with that shown in FIG. 10 except that the shutoff valves **34** and **41** of FIG. 10 are replaced by proportioning valves **65** and **64** in FIG. 14.

FIG. 15 shows such a proportioning valve in cross section. It will be seen that the rotatable central part can be rotated clockwise or counterclockwise to completely close either branch of the valve or can be positioned to vary the proportioning of the air flowing in the two left branches of the valve, or can be rotated to shut off the flow of air altogether. The valves **64** and **65** are identical in operation. The air hoses **66** and **67** connect the proportioning valves **64** and **65** with a demand regulator **68** which is of well known type widely used in self contained under water breathing apparatus. This regulator **68** also

manually depressing the diaphragm of the demand regulator in order to pass air from the compressed air supply into the breathing circuit. **70** is a conventional tank of compressed air and is equipped with the lugs **71** which are provided for attaching a harness to be worn by the diver.

The primary purpose of the system shown in FIG. 14 is to provide the gill respirator unit for breathing under water most of the time, but to also provide an auxiliary compressed air supply which the diver may use if he gets into polluted water. Fish very frequently die when they enter polluted water because the toxic gases in such water go thru the gill membranes and enter the blood stream of the fish and there is no way the fish can prevent it. In contrast, in this system, we supply an improvement over anything the fish can make use of. The diver, as soon as he smells the toxic gases of polluted water, can turn the handle of the proportioning valve **64** clockwise so that his breathing circuit is connected only with the air hose **66** and can also turn the control handle of proportioning valve **65** counter clockwise so that his beathing system is connected only with hose **67**. Under these circumstances, the gill respirator unit breathing circuit is completely shut off from the diver and will remain inoperative. The diver gen is considered less useful because of the danger of oxygen poisoning at depths greater than 25 feet, unless used by persons well aware of the danger and extremely skilled in the use of oxygen under such conditions. In contrast, the compressed air equipment is regularly used at depths of 100, 200, and even 300 feet.

In connection with leaked water, in all three systems as shown in FIGS. 10, 12, and 14, the air exit valve **43** is purposely located directly below the air passage ways leading to the mouthpiece of face mask, so that leaked water will naturally flow down into the internal space provided by this valve and there will be far less likelihood that an inhaltion will suck water into the diver's lungs. Also, this is the best location for leaked water in connection with expelling it. In the system shown in FIG. 10, the diver may expel leaked water by first inhaling a deep breath, and then turning off valve **41**, and then expelling his breath sharply. The exhaled breath can only escape by unseating the diaphragm of air exit valve **43** and the air flowing out will carry the leaked water with it. The process may be repeated if necessary to expel all the leaked water.

In the system shown in FIG. 12, the same thing can be accomplished by closing valve **58** and exhaling sharply, or leaked water can be blown out by compressed air by opening valve **56** and passing enough air into the breathing circuit so that the pressure provided for by the setting of control knob **50** is exceeded and the valve **43** will open automatically, the air expelled thereby carrying out the leaked water also.

In FIG. 14, leaked water may be blown out by the exhaled breath of the diver by closing valve **65** and exhaling sharply, or by also turning valve **64** so that it connects only with hose **66**, and then operating button **69** which will release compressed air from tank **70** and blow out the leaked water.

FIG. 16 is a fragmentary enlarged cross sectional view, comparable to FIG. 4, but shows an alternative form of construction for a gill element. In this design, a central core member **73**, having a multiplicity of channels **74—74** formed in its opposite faces supports the permeable or porous membrane material **75—75**. Optional stiffener and spacing members **76—76** may be used, like those shown in FIGS. 9A, 9B, and 9C. Even though the channels **74—74** may be made quite small in size, the fact that

The exhaled breath of the person or persons submerged is pumped by pump **85** thru the conduit **86** into the gas exchange unit **81** and then out thru conduit **87** back to be rebreathed. The gas exchange unit **81** can consist of any of the previously discussed gas permeable or porous sheet materials used to form passage ways thru which the exhaled air is pumped, such units being bathed by the flowing water **76** whereby dissolved oxygen is extracted from the water and carbon dioxide is extracted from the exhaled breath, such extracted oxygen being added to the exhaled breath and carbon dioxide being passed off into the water, and the rehabilitated air being returned to the person or persons for rebreathing.

FIG. 18 shows an alternative form of gas exchange unit where the transference of carbon dioxide from air to water and of oxygen from the water to the air takes place directly across the air-to-water interfaces without any barrier material being used. The wall **88** of the gas exchange unit **81** is partially filled with the water **76**. Pipes or other gas conducting means **89** with spaced apertures cause the exhaled air to bubble up thru the water. These bubbles would preferably be very small and in enormous numbers so that the air is provided with a very large surface area (relative to its volume) in direct contact with the water for enhancing the gas exchange. FIG. 18 is not necessarily to scale, and its vertical height may be increased as much as desired to provide full gas exchange of the bubbles as they rise vertically thru the water.

There may be considerably greater pressure in the water **76** than in the inside of the vessel or housing **77**, with possible danger of flooding if the pumps should fail. As a safety feature, the pumps **78** and **82** and valves **80** and **84** (these valves preferably being of a type which can be actuated either manually or electrically) are interconnected so that at any time that the pumps **78** or **82** fall below their proper speed, or stop, the valves **80** and **84** will automatically close, thus assuring against flooding, and the alarms **90** or **91** will ring. This system will have an independent power supply from that driving the pumps **78** and **82**. The units on the pumps sensing their speed can be well known centrifugal governors, but connected to actuate the valves and alarms instead of being connected to control the speed of the pumps.

tact with one side of said barrier member, disposing the other side of the 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 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 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

ment and buoyancy of the diving equipment, passing gases 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 a process for providing a rebreathable atmosphere, the steps including transferring a person's exhaled breath to water containing dissolved oxygen, extracting dissolved oxygen from the water and mixing the extracted oxygen with the exhaled breath, obtaining additional oxygen from an auxiliary oxygen supply, and mixing the gas from the auxiliary supply in any desired proportion to the exhaled breath containing oxygen extracted from the water, and transferring the resulting mixed gases to the person 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 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.

12. 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 gases to the personnel of the submarine for rebreathing.

13. 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.

14. 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 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.

15. Gill-type respirator equipment for underwater use including conducting means adapted to convey the exhaled breath of a person away from the person, a gas exchange unit connected to said conducting means, said gas exchange unit adapted to extract dissolved oxygen from the water and to mix the extracted oxygen with the

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.

17. 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-enrich it for rebreathing.

18. In equipment in accordance with claim 17, wherein said means comprises a membrane formed of silicone rubber.

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