United States Patent [19]

Jansson

[11] **3,923,053**

[45] **Dec. 2, 1975**

[54] **RESPIRATORY PROTECTIVE DEVICE**

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[22] Filed: **July 29, 1974**

[21] Appl. No.: **492,740**

[52] **U.S. Cl.** **128/142;** 128/145.8; 128/202

[51] **Int. Cl.²** **A61M 16/00**

[58] **Field of Search** 128/142, 142.2, 142.3, 128/145.5, 145.6, 145.7, 145.8, 188, 202, 203

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[57] **ABSTRACT**

A respiratory protective device is disclosed. The device is of a type which may be used in a noxious environment, such as a firefighting environment. The invention is characterized by a vented chamber of substantially fixed volume, two compliant breathing bags in the chamber, each having a filled volume in the chamber substantially equal to the chamber volume, a valving system to effect alternate normally prolonged use of the breathing bags, a source of oxygen-rich gas, and a scrubber to remove carbon dioxide from the gas. A unique scrubber apparatus is incorporated in preferred embodiments.

13 Claims, 3 Drawing Figures

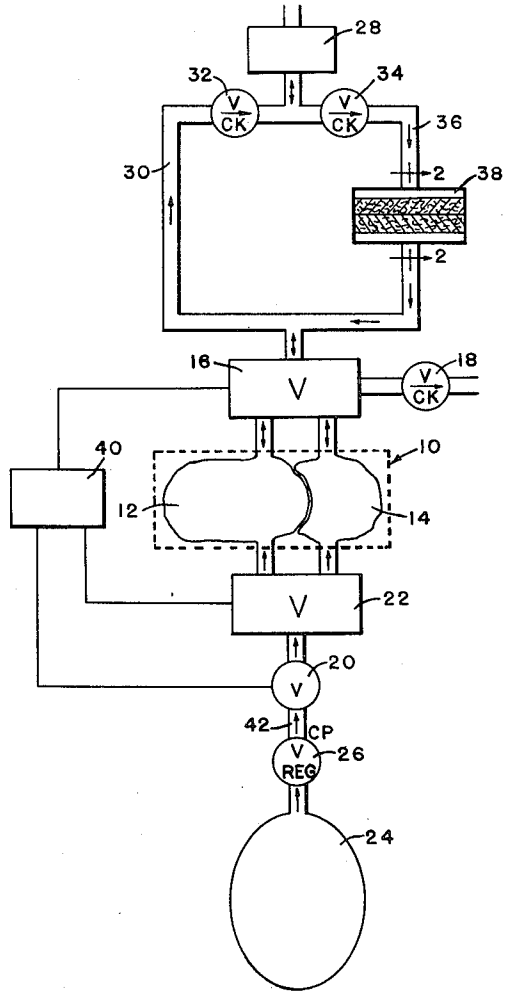


FIG. 1

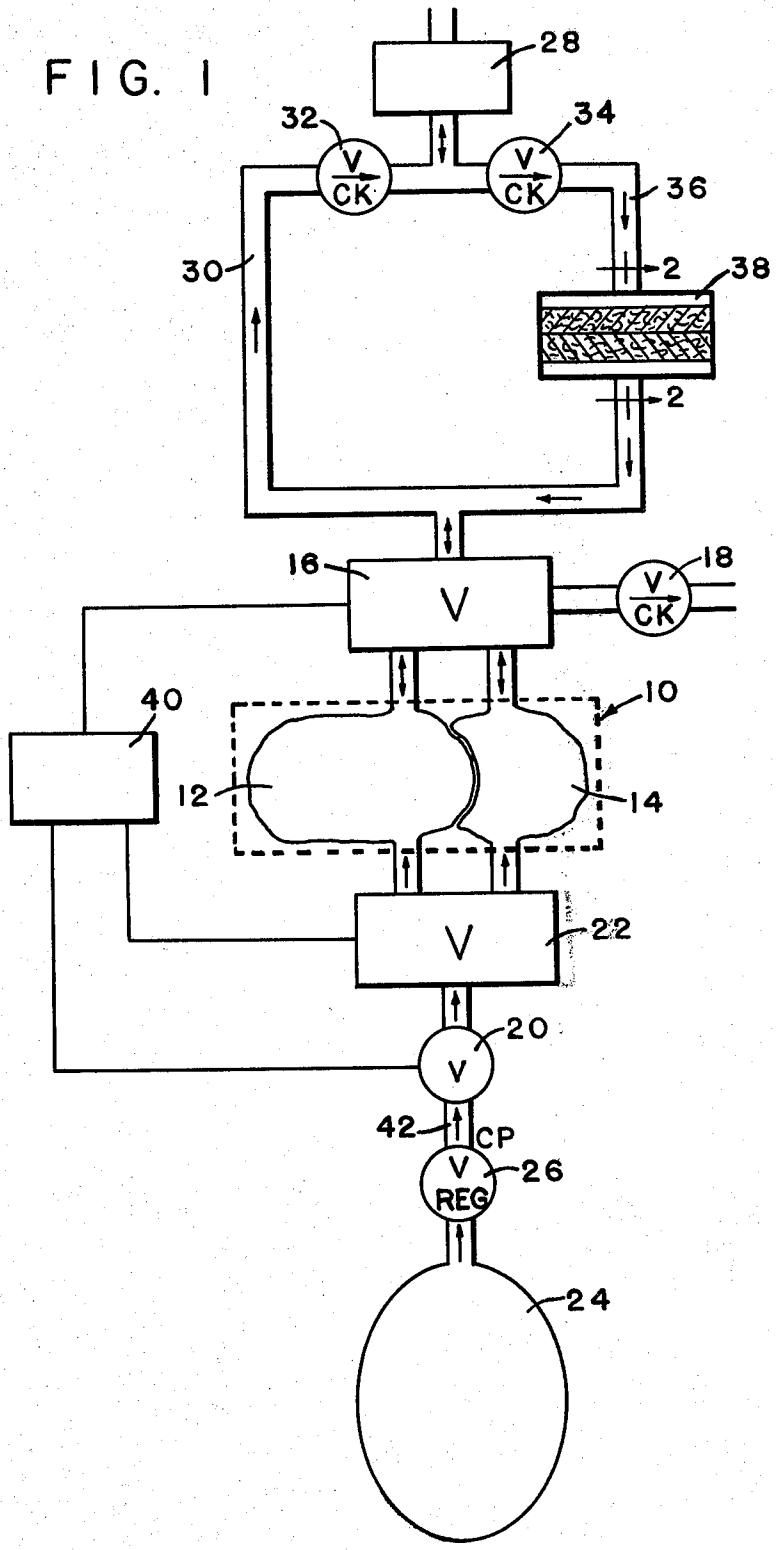

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FIG. 2

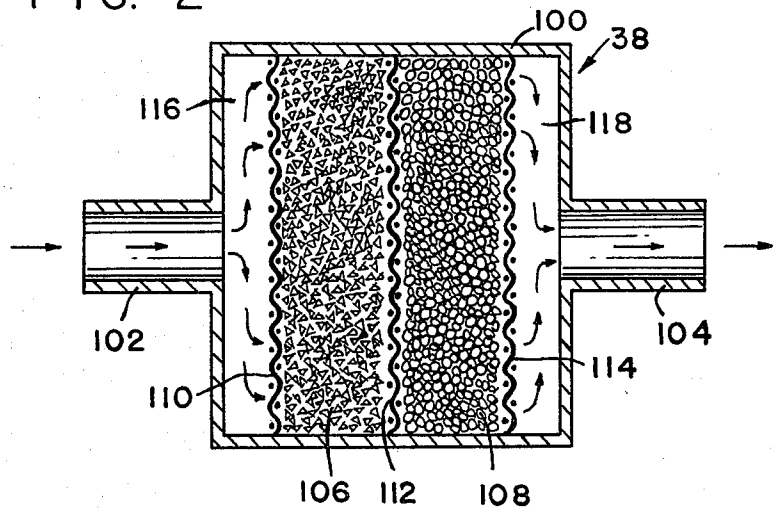
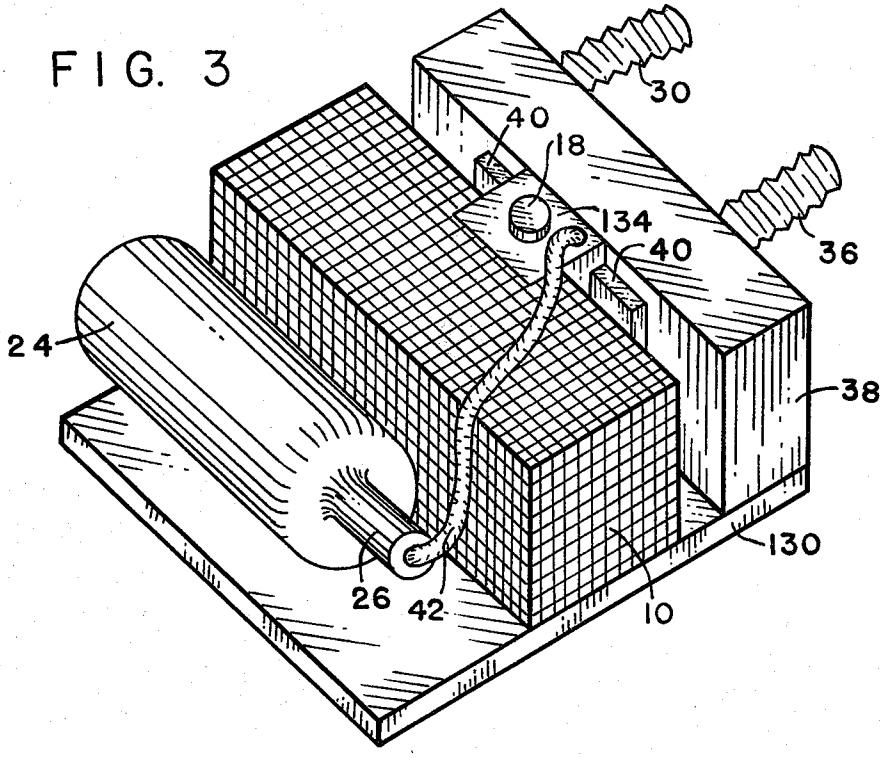

100
38
116
118
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104
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106
112
108

FIG. 3


30
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134
40
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24
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130
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42
10

RESPIRATORY PROTECTIVE DEVICE

The invention described herein was made in the performance of work under N.A.S.A Contract No. NAS 12-2265 and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958 (72 Stat. 435; 42 U.S.C. 2457).

BACKGROUND OF THE INVENTION

This invention relates to the field of breathing apparatus and particularly relates to respiratory protective systems such as are used by firefighters. This invention will be described with particular referernce to systems usable by firefighters. However, it is to be understood that this invention is applicable to other fields, such as where protection from noxious environments is necessary. The description in terms of firefighters' equipment and problems is merely for purposes of convenience.

In recent years, more and more people have become aware of the dangers involved in firefighting and of the need for improvement in the area of protection for firefighters. There is increasing interest in research and development in areas such as the identification of the environment to which the firefighter is exposed, new and improved methods and equipment for firefighting, and new safety and protection equipment for the firefighter.

According to a recent set of statistics, firefighting can be called one of the most dangerous occupations. Firemen are exposed to stresses of many kinds including extreme temperature conditions (both heat and cold), physical stresses caused by the difficult working environment of a fire, emotional stresses of being in a dangerous environment, and additional environmental stresses caused by particulate, gaseous, and vapor combustion products.

There are two significant constituents of the combustion atmosphere which are known to justify the need for respiratory protection. The presence of elevated levels of carbon monoxide in the fire environment is a constant hazard to firemen. Carbon monoxide is dangerous because of the following property. Hemoglobin, the compound in blood which absorbs oxygen for use throughout the body, combines with carbon monoxide to form carboxyhemoglobin, thereby keeping that hemoglobin from combining with oxygen. The affinity of hemoglobin for carbon monoxide is 200 – 300 times that of its affinity for oxygen. For example, a typical one liter breath of air contains 800 milliliters of nitrogen and 200 milliliters of oxygen. In the course of its stay in the lungs, about 20 – 40 milliliters of oxygen are absorbed and some carbon dioxide is added. However, if that liter of air had contained only one milliliter of carbon monoxide (0.1%), this small amount of carbon monoxide could effectively keep a good part of the necesary oxygen from being absorbed during that breath. It is, therefore, easy to understand why carbon monoxide is such a dangerous contaminant.

The second important characteristic of the combustion atmosphere is its depressed level of oxygen. Large amounts of oxygen are consumed in a fire, thereby creating a shortage of oxygen for breathing. Normal air contains approximately 20% oxygen and about 16% is considered to be a minimum level of oxygen acceptable for respiration. Consequently, even if all noxious contaminants in the fire atmosphere could be filtered and/or absorbed from the air before breathing, such air would not contain an adequate concentration of oxygen. Therefore, the firefighter must carry some type of oxygen supply with him into a fire.

In the prior art, there are two basic types of respirator systems for use by firefighters. One is a compressed air system and the other is an oxygen rebreather system.

A compressed air system consists of a large compressed air tank with a demand regulator which provides air to a mask during inhalation. The two major problems of this type of system are excessive total weight and short operating time.

An oxygen rebreather system includes a significantly smaller tank containing pure oxygen in the gaseous or liquid state. The remainder of the system consists of a breathing bag, a chemical scrubber for removing carbon dioxide, and a mask for delivering oxygen to the user. Initially, the breathing bag is filled and the wearer inhales directly from the breathing bag and exhales through the carbon dioxide scrubber back into the breathing bag. The only nitrogen in the system is that which is present initially, and this is soon lost through a safety valve on the bag which prevents the bag from inflating as the oxygen is slowly leaked into it. Thus the concentration of oxygen in the mask is approximately 100% throughout most of the operating time. There are several problems with this system. The most significant of these is the safety hazard caused by having almost pure oxygen in the space around the man's face, especially if the mask is accidentally knocked out of position in a fire. Furthermore, for very prolonged use, pure or very high oxygen concentration in inhaled gas is physiologically dangerous to man. Other problems include the impedance to breathing and the high temperature of the inhaled gas caused by the chemical reactions of the scrubber material.

BRIEF SUMMARY OF THE INVENTION

The new respirator system provides a lightweight, longer-lasting respiratory protective system which, at the same time, provides the firefighter with gas containing a safer level of oxygen, when compared with present compressed air and rebreather systems. Furthermore, the novel scrubber provides cooler operation than typical oxygen rebreather scrubbers.

The respiratory protective device of my invention includes a chamber of substantially fixed volume and two alternatively active compliant breathing bags contained therein, each having a volume substantially equal to the chamber volume. The respirator of my invention has a source of oxygen-rich gas and a valving system to effect alternate, normally prolonged, use of the breathing bags. A scrubber is used to remove carbon dioxide from the exhaled air. A preferred embodiment includes a scrubber, described hereinafter, which delivers cool gas to the user. The scrubber is situated in a breathing conduit loop which, at any time, also includes the active breathing bag therein. Such conduit loop forms a means to deliver gas from the system to the user, such as a mask or a mouthpiece and one or more lengths of flexible hose.

The system embraces the idea of rebreathing oxygen-rich gas from a breathing bag until the gas has a concentration of oxygen low enough to necessitate discarding the gas. This "old" gas is then vented to the atmosphere, and a fresh volume of gas is supplied. Each breath lowers the concentration of oxygen until a lower limit is reached. Two similar, compliant bags are used.

While the active bag is being filled the inactive bag is vented. These simultaneous filling and venting operations can be done conveniently by constraining the volume of the two bags in a single, stiff, vented enclosure the size of one bag. The expansion of the bag being filled contracts the inactive bag to push the "old" gas through a passive valve to the atmosphere. The volume of fresh gas is preferably less than the constraining volume of the enclosure (often referred to herein as a "chamber"), thus partially venting the inactive bag to the atmosphere. The advantage of this partial filling is that the peak concentration of oxygen in gas being breathed may be lower than the concentration of oxygen in the oxygen-rich supply source.

The unique scrubber apparatus disclosed provides cooler system operation and lower impedance to breathing than the prior art. Molecular sieve material is used to remove the carbon dioxide from the exhaled gas since this material produces significantly lower heat than the commonly used material, soda lime. Both soda lime and the molecular sieve material also remove water and, in doing so, produce a considerable amount of heat. Therefore, a desiccant, such as $CaSO_4$ is used upstream of the molecular sieve material to remove the water with very much less heat generated, providing a scrubber with considerably cooler operation than typical rebreather scrubbers today. In addition, large cross-sectional area and lower depth of material keep flow velocity in the scrubber low, thus lowering the breathing impedance of the scrubber.

The advantages of this respiratory protective device are that it provides a lightweight, longer-lasting, and more compact system than a simple compressed air device and provides safer and cooler operation than a pure oxygen rebreather.

A primary object of this invention, therefore, is to provide a system which overcomes the aforementioned problems.

Another object of this invention is to provide a lightweight, compact respirator.

Another object of this invention is to provide a respirator which can be used for longer periods of time without replenishment of the supply of breathing gas.

Still another object of this invention is to provide a respirator which operates at a safe level of oxygen concentration.

A further object of this invention is to provide a respiratory protective device which operates at a cool temperature with a minimum of breathing effort.

These and other important objects of the invention will become apparent from the following description and drawings showing preferred embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a functional schematic of the respiratory protective device which will be used to describe the design and operation of the new system.

FIG. **2** is an enlarged sectional view of the scrubber used in the embodiment of FIG. **1** taken along section **2—2** as shown in FIG. **1.**

FIG. **3** is a perspective view illustrating the compactness of a preferred embodiment of this invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Throughout the figures, like numerals are used for identification of like elements and parts.

A preferred embodiment of this invention is illustrated by the schematic drawing of FIG. **1.** The respirator of FIG. **1** includes a vented bag chamber **10** having a substantially fixed volume. The chamber has walls through which the surrounding atmosphere can pass freely. An example of the type of material out of which the walls are made is common window screen. However, any material having sufficient strength and enough holes over a major portion of the chamber to allow free passage of the surrounding atmosphere is suitable for construction of chamber **10.** Bag chamber **10** houses breathing bags **12** and **14.** The volume of the bags **12** and **14** is constrained by the chamber **10** so that when either bag is full, its volume is substantially equal to the volume of chamber **10.** "Substantially equal" does not necessarily imply close to 100% of chamber volume, though this is preferred. The term, however, does imply enough filled volume for bag interaction. Breathing bags **12** and **14** are extremely compliant, meaning that adding gas to increase the volume of the bags does not increase the pressure of the gas in the bags. (Mathematically, (dP/dV) is equal to or very close to zero, where (dP/dV) is the derivative of the gas pressure in the bag with respect to the volume of the bag). Examples of materials that can be used for breathing bags are neoprene sheeting and common polyethylene sheeting. Other suitable materials will be obvious to those skilled in the art to whom this invention has been disclosed. Therefore, chamber **10** constrains bags **12** and **14** in a way such that if bag **12** is filled with gas, the filling process will force the gas in bag **14** to be expelled, and vice versa. Bags **12** and **14** are connected to tank **24,** which contains a compressed supply of oxygen-rich gas, through valve means **22,** valve **20,** and constant pressure regulator **26.** Valve means **22** can be switched into two modes, either connecting bag **12** to valve **20** or connecting bag **14** to valve **20.** Valve **20** is open for a short period of time to allow gas from tank **24** through regulator **26** to fill one of the breathing bags. Control of valve means **22** and valve **20** is accomplished by a controller **40.** Valve means **22,** valve **20,** and the control means form a means to open the source of breathing gas (tank **24**) to alternately fill bags **12** and **14** with a quantity of breathing gas. The detailed description of the function of controller **40** will be given hereinafter. The respirator of FIG. **1** further includes a breathing conduit loop having a breathing conduit **30,** an inhalation check valve **32,** a mask **28** for delivery of the gas to the user, an exhalation check valve **34,** a breathing conduit **36,** a chemical scrubber **38,** and a valve means **16** to which both bags are connected. Valve means **16** can be switched into two modes, either connecting bag **12** into the breathing conduit loop and bag **14** to the atmosphere through a check valve **18** or connecting bag **14** into the breathing conduit loop and bag **12** to the atmosphere through check valve **18.** Valve means **16,** check valve **18,** and the control means form a means to alternately vent bags **12** and **14** as the activated bag is being filled. Means for delivery of the gas to the user can also be a mouthpiece, complete helmet, or other suitable device in place of mask **28.** Therefore, the breathing gas is fed to and from mask **28** from either bag **12** or bag **14** by the breathing conduit loop. Valve means **16** is also controlled by controller **40,** described hereinafter. Valve means **16** and the control means form a means to alternately activate bags **12** and **14** for breathing.

The control means in this particular embodiment of the respirator of FIG. 1 contains a battery power supply and electronic circuitry in controller 40 and microswitches located in valve means 16 and 22. Details of a suitable control means will be obvious to a man skilled in the art to whom this invention has been disclosed. A wide variety of control means, including various types of apparatus, are suitable for use in this invention and such would be obvious. The control means also includes a means of determining the oxygen concentration in the breathing conduit loop, that is a means to determine when the concentration of oxygen is at a predetermined lowest tolerable level. This function can be done by several methods, some of which are as follows: a direct measurement of oxygen concentration using an oxygen sensor, a flow integrator to measure the total volume of inhaled gas and infer the oxygen concentration, approximate flow integration schemes to infer volume and thus oxygen concentration, or a timer from which an estimate of the oxygen concentration can be made. Several approximate flow integration schemes are possible, the simplest example of which is a breath counter. The reason for determining the oxygen concentration in the breathing conduit loop will be explained in the detailed description of the respirator system operation which follows. Methods and means to determine (measure or approximate) the oxygen concentration of the gas in the breathing conduit loop would be obvious to someone skilled in the art to which this invention has been disclosed.

FIG. 2 is an enlarged sectional view of the scrubber 38 of FIG. 1 illustrating a unique scrubber used in preferred embodiments of this invention. Scrubber 38 includes an airtight case 100, inlet port 102, outlet port 104, chemical material layers including an upstream scrubber material layer 106 and a downstream scrubber material layer 108, screens 110, 112 and 114, separating and/or isolating layers 106 and 108 and defining, with case 100, plenum chambers 116 and 118. Exhaled gas containing oxygen, carbon dioxide, water, and other gaseous components such as nitrogen, passes into the plenum chamber 116 through inlet port 102 in the direction indicated by the arrows. The first or upstream layer 106 is an efficient desiccant having a low K cal of desiccation, which removes water from the exhaled gas. A highly preferred such desiccant material is $CaSO_4$, commercially known as Drierite. The heat of desiccation of $CaSO_4$ is 2.7 cal per mole of H_2O, compared with about 40 k cal per mole of H_2O for the commonly used scrubber material, soda lime. "Low" heat of desiccation refers to a heat of desiccation substantially less than that of soda lime, normally no more than 20 k cal per mole of H_2O, and preferably much less. Other acceptable desiccant materials meeting the above criteria would be obvious to those skilled in the art and aware of this invention. The second or downstream layer 108 is molecular sieve material such as Union Carbide molecular sieve 5A ($Ca_{4.5}Na_3[(AlO_2)_{12}] \cdot 30\ H_2O$) which adsorbs both water and carbon dioxide, and has a low heat of carbon dioxide adsorption, about half of that of soda lime. The heat produced by the hydration of $CaSO_4$ is significantly less than that produced by the adsorption of water by the molecular sieve material. Thus, the total amount of heat produced by this new scrubber keeps the gas in the respirator significantly cooler than if existing scrubbers of the well-known type using soda lime were used. The large cross-sectional area of the scrubber provides a lower pressure drop across the scrubber for a given flow rate so that the breathing impedance of the respirator is low. The exhaled gas passes from plenum 116 through screens 110, 112, 114 and layers 106 and 108, into plenum 118 and out through port 104.

A typical cycle of operation of the respirator of FIG. 1 is as follows. For this description, the breath counting scheme will be used to estimate the oxygen concentration of the gas in the breathing conduit loop. The activated bag 12 contains oxygen-rich gas just after being filled. Bag 12 is, therefore, connected by valve means 16 to mask 28 by the breathing conduit loop. Valve means 16, while placing the activated bag 12 in the breathing conduit loop, also connects the deactivated bag 14 to the surrounding atmosphere through check valve 18 which allows gas to pass only from the deactivated bag 14 to the atmosphere. The user, wearing mask 28, inhales gas from bag 12 and exhales gas through scrubber 38 back into bag 12. The concentration of oxygen in bag 12 is lowered with each breath. Scrubber 38 chemically removes the carbon dioxide and water from the exhaled gas. The breath counter in controller 40 counts the number of breaths that the user has breathed from the bag 12 and when a predetermined number has been reached, controller 40 begins the switching sequence, which deactivates bag 12, activates bag 14, fills bag 14, and allows venting of bag 12 through check valve 18. When the controller 40 starts the switching sequence, valve means 16 places bag 14 into the breathing conduit loop and connects bag 12 to the atmosphere through check valve 18. Thus bag 12 and bag 14 have switched roles, bag 14 now being the activated bag and bag 12 the deactivated bag. Since the end of the previous switching sequence, valve 22 has been in a mode connecting valve 20 to bag 14. Immediately after the change of valve means 16, the controller 40 activates valve 20 for a preset short interval of time to allow a supply of oxygen-rich gas to pass from tank 24 through regulator 26, valve 20, and valve 22 into the newly-activated bag 14. The filling of bag 14 causes the expansion of bag 14 in the chamber 10, thus causing the contraction of bag 12 in the chamber 10 by the physical interaction of bags 12 and 14, expelling the gas in bag 12 through check valve 18 to the atmosphere. If the volume of the newly-filled activated bag 14 is less than the volume of the chamber 10, then some of the gas in bag 12 will remain to be used after the next switching sequence which will activate bag 12 and deactivate bag 14. When the controller 40 closes valve 20, controller 40 then activates valve 22 which changes to the mode connecting valve 20 to bag 12, ready for the next switching sequence. The user now breathes from the activated bag 14 in the breathing conduit loop and the breath counter counts the number of breaths from bag 14. The oxygen concentration of the gas in bag 14 decreases with each breath until the breath counter reaches the predetermined number, at which point the switching sequence is begun by controller 40. This switching sequence reverses the roles of bag 12 and bag 14 again, filling the newly-activated bag 12 and expelling gas from bag 14 in the same manner as the switching sequence described above. Similarly, valve 22 now switches to a mode connecting bag 14 to valve 20 for filling of bag 14 during the next switching sequence. The respirator continues to operate through repetitive cycles during the entire period of use, thus making very efficient use of the oxygen contained in supply source 24, while keeping a low oxygen concen-

tration in the gas breathed from the breathing conduit loop.

FIG. 3 shows a preferred arrangement of the components of the respirator on a backpack base **130.** Scrubber **38** is the device shown in FIG. **2.** Valve means **16** and **22,** valve **20,** and check valve **18** are shown contained in a single valve package **134** with controller **40** placed next to valve package **134** for ease of wiring. Bag chamber **10** is mounted to valve package **134** so that bags **12** and **14,** not visible in FIG. **3,** can easily be connected to valve means **16** and **22.** Tank **24** and regulator **26** are mounted on the bottom of the base **130.** Conduits **30** and **36** connect the system to the mask **28** (not shown) with check valves **32** and **34** (also not shown) mounted in the mask **28.** High pressure conduit **42,** shown also in FIG. **1,** connects regulator **26** to valve **20** in valve package **134.** The components of the respirator of this invention may be placed in a compact, low-profile arrangement which is easily worn by a fire-fighter. The compact arrangement of the respirator of FIG. **3** may be worn easily by a man, either on his back or on his chest, or elsewhere. Other compact or distributed arrangements of the components of the respirator of this invention would be obvious to thos skilled in the art to whom this invention has been disclosed.

Various materials useful in the components of embodiments of this invention will be apparent to those skilled in the art to whom this invention has been disclosed.

While in the foregoing specification this invention has been described in relation to certain preferred embodiments, and many details have been set forth for purpose of illustration, it will be apparent to those skilled in the art that the invention is susceptible to additional embodiments and that certain of the details described herein can be varied considerably without departing from the spirit of the invention.

I claim:

1. A respirator comprising:

a source of oxygen-rich gas;

a chamber having a substantially fixed volume, said chamber being vented;

first and second compliant breathing bags within said chamber, each of said bags having a filled volume within said chamber substantially equal to the volume of the chamber;

means to alternately activate one of said bags for breathing;

means to open said source to fill said activated bag with a quantity of said gas; and

means to vent the other bag as said activated bag is filled, said other bag being contracted by expansion of said activated bag during filling.

2. The respirator of claim **1** further having a breathing conduit loop, said means to activate connecting said activated bag into said loop, said loop including a scrubber to remove carbon dioxide from exhaled gas.

3. The respirator of claim **2** wherein said scrubber comprises separate upstream and downstream chemical scrubber materials within said loop, said upstream scrubber material being an efficient desiccant having a low heat of desiccation and said downstream scrubber material being a molecular sieve which is adsorbent of carbon dioxide and having a low heat of adsorption, whereby scrubbed gas is not substantially heated.

4. The respirator of claim **1** wherein said quantity of said gas from said source filled into said activated bag is less than said filled volume.

5. The respirator of claim **2** wherein said quantity of said gas from said source filled into said activated bag is less than said filled volume.

6. The respirator of claim **1** wherein said means to activate includes means to determine when the concentration of oxygen is at a lowest tolerable level.

7. The respirator of claim **2** wherein said means to activate includes means to determine when the concentration of oxygen is at a lowest tolerable level.

8. In breathing apparatus of the type having a supply source of breathable gas and breathing bag means replenished by said source, the improvement comprising:

a chamber having a substantially fixed volume, said chamber being vented;

first and second alternately active compliant breathing bags within said chamber, each of said bags having a filled volume of sufficient extent within said chamber such that the filling of one bag causes physical interaction thereof with the other bag whereby said other bag is at least partially deflated;

means to alternately activate one of said bags for breathing, the other of said bags to be inactive until thereafter activated; and

means to determine when to switch bags.

9. The improvement of claim **8** wherein said supply source comprises a source of oxygen-rich gas.

10. The improvement of claim **9** further including means to open said source to fill said activated bag with a quantity of said gas, said quantity being less than said filled volume.

11. The improvement of claim **9** further having a breathing conduit loop, said first and second breathing bags being alternately connected into said loop, said loop including a scrubber to remove carbon dioxide from exhaled gas.

12. The improvement of claim **11** wherein said scrubber comprises separate upstream and downstream chemical scrubber materials within said loop, said upstream scrubber material being an efficient desiccant having a low heat of desiccation and said downstream scrubber material being a molecular sieve which is adsorbent of carbon dioxide and having a low heat of adsorption, whereby scrubbed gas is not substantially heated.

13. The improvement of claim **12** further including means to open said source to fill said activated bag with a quantity of said gas, said quantity being less than said filled volume.

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