Exhibit 1

Plaintiff's Complaint for Patent Infringement and Breach of Contract Injunctive Relief and Jury Trial Requested

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Delp, II

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[54] **OXYGEN ENRICHED AIR GENERATION SYSTEM**

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[58] **Field of Search** 95/8, 12, 14, 23, 95/45, 47, 54; 96/4, 7, 8, 10; 55/210, 218, 267–269

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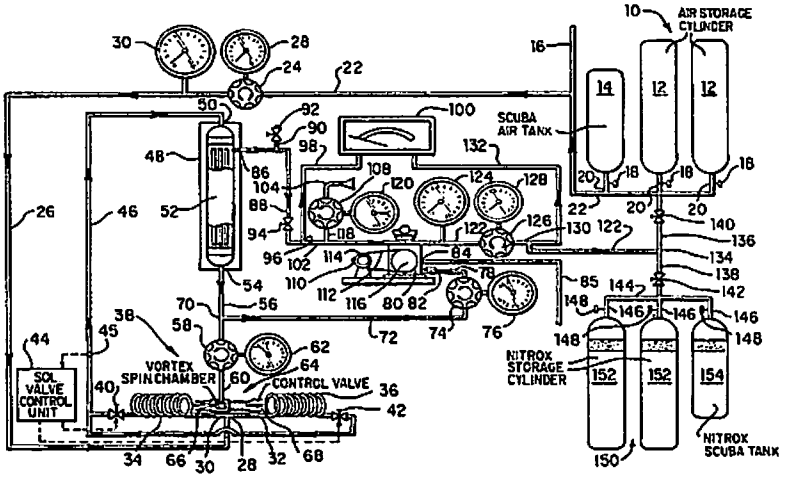
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[57] **ABSTRACT**

A system for generating oxygen enriched air includes a compressed air supply for supplying compressed air and a permeable membrane gas separation system for separating a nitrogen gas component and an oxygen enriched air component from the compressed air. An oxygen analyzer is provided to detect an oxygen concentration in the oxygen enriched air component. The nitrogen gas component is divided, by a vortex tube, into a cold gas stream and a hot gas stream, and solenoid valves are actuated to modify a flow path of the compressed air through the cold gas stream and the hot gas stream in order to selectively heat and cool the compressed air. The oxygen enriched air is then selectively distributed for further use.

33 Claims, 1 Drawing Sheet



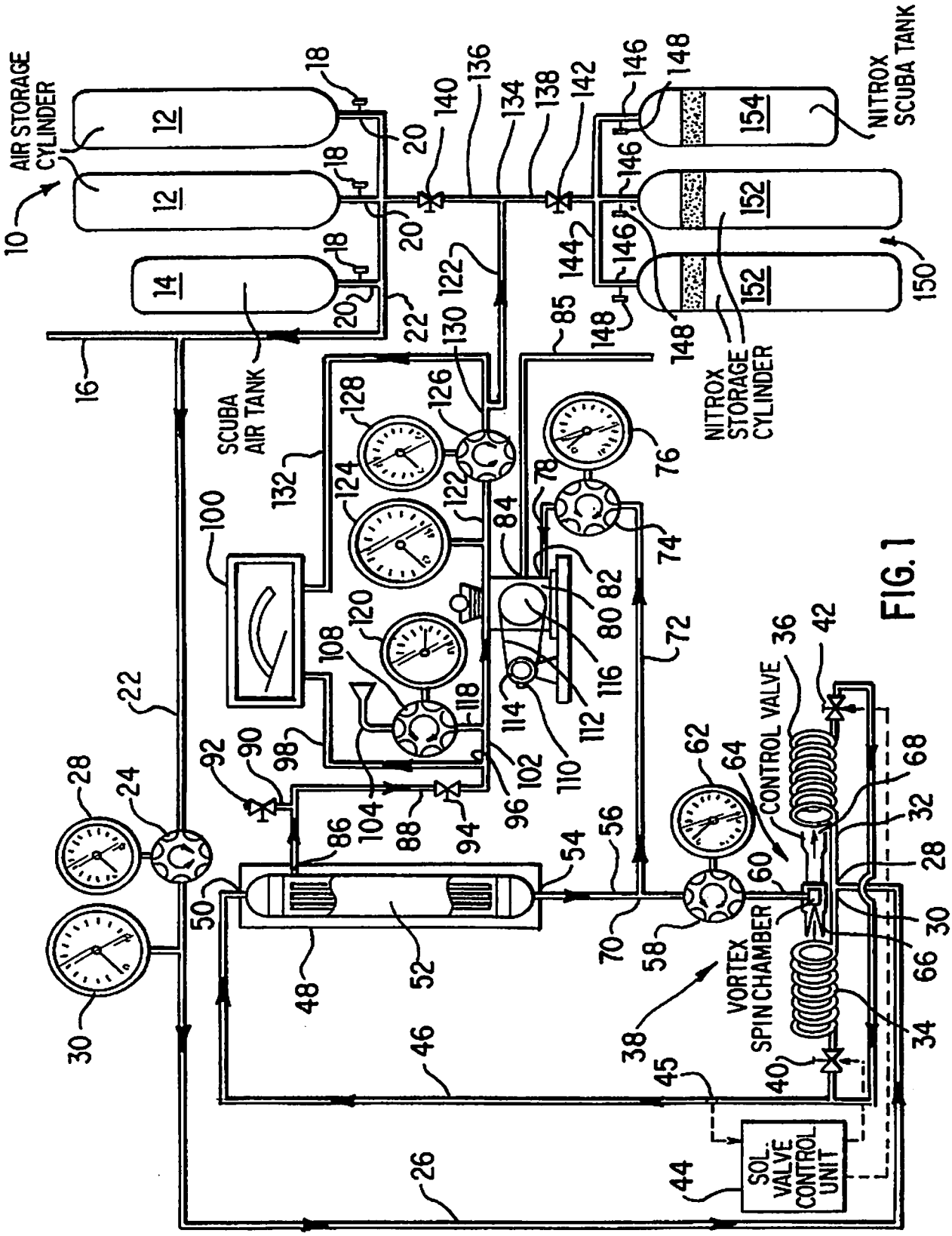

AIR STORAGE CYLINDER
NITROX SCUBA TANK
SCUBA AIR TANK
NITROX STORAGE CYLINDER
CONTROL VALVE
VORTEX SPIN CHAMBER
SOL. VALVE CONTROL UNIT

FIG. 1

OXYGEN ENRICHED AIR GENERATION SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a particular type of oxygen enriched air generation system. A permeable membrane oxygen enriched air and nitrogen gas separation device is utilized. Although the system is particularly suitable for use by dive shops for filling scuba tanks or other types of oxygen enriched air storage vessels, applications in areas such as firefighting, climbing, flight, veterinary, medical and dental treatments, welding, etc., are apparent.

2. Description of Related Art

One known system for producing a mixture of oxygen enriched air and ambient air is disclosed in U.S. Pat. No. 4,860,803 to Wells. In this system, oxygen is injected into a stream of ambient air in order to produce an oxygen enriched air mixture. The mixture is compressed and delivered to storage or scuba cylinders for use in diving or other applications. According to this system, however, a source of oxygen appropriate for injection into the ambient air stream is needed and, therefore, a great deal of caution is required, during generation of the oxygen enriched air mixture, to avoid explosions and other problems typically associated with the use of oxygen.

SUMMARY OF THE INVENTION

It is one object of this invention to provide a suitable alternative system for generating an oxygen enriched air mixture, suitable for breathing purposes, which does not require the use of oxygen supplied from a separate oxygen source.

It is another object of this invention to provide a system which generates a gas stream which may be used by a suitable element, such as a vortex tube, to adjust the oxygen concentration of the oxygen enriched air mixture.

It is a further object of this invention to divert some of the gas stream produced so that the portion of the gas stream diverted may be used for inerting purposes such as, for example, to inert the crankcase of a compressor so that the compressor may be a standard oil-lubricated compressor rather than an oil-free compressor.

According to the present invention, these and other objects are accomplished by the provision of a system for generating oxygen enriched air which includes a compressed air supply for supplying compressed air and a permeable membrane gas separation system for separating a nitrogen gas component and an oxygen enriched air component from the compressed air. An oxygen analyzer is provided to detect an oxygen concentration in the oxygen enriched air component. The nitrogen gas component is divided, by a vortex tube, into a cold gas stream and a hot gas stream, and solenoid valves are actuated to modify a flow path of the compressed air through the cold gas stream and the hot gas stream in order to selectively heat and cool the compressed air. The oxygen enriched air is then selectively distributed for further use. A compressed oxygen enriched air storage assembly, a compressor, a compressor feed line supplying the oxygen enriched air component to a compressor inlet and an outlet line interconnecting a compressor outlet to the compressed oxygen enriched air storage assembly are provided.

The solenoid valves are used to modify the flow path of the compressed air by alternate opening and closing thereof so that the compressed air is selectively heated and cooled by the gas streams to adjust the oxygen concentration of the oxygen enriched air component to a desired oxygen concentration. An ambient air feed line admits ambient air into the compressor feed line so as to mix with the oxygen enriched air component. A regulating valve is used to regulate the amount of ambient air admitted into the compressor feed line and also permits adjustment of the oxygen concentration.

The oxygen analyzer is interconnected with the outlet line to permit monitoring of the oxygen concentration of a mixture of ambient air and the oxygen enriched air component in the outlet line. The system includes an oxygen enriched air supply line and at least one valve provided in the oxygen enriched air supply line to regulate flow of the mixture into appropriate containers for storing the mixture. The oxygen analyzer, or another oxygen analyzer, is also interconnected with an outlet of the permeable membrane gas separation system to permit monitoring of the oxygen concentration of the oxygen enriched air component passing through the outlet. A valve is used to selectively eliminate admission of the oxygen enriched air component into the compressor feed line so that only ambient air passes through the outlet line and the air supply can be recharged. Finally, a branch line for diverting some of the nitrogen gas component to a crankcase of the compressor, in order to reduce any possibility of explosion, is provided.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1, the only drawing figure provided, illustrates the overall structure of an oxygen enriched air generation system according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A compressed air supply is provided by an assembly **10** of one or more storage vessels. Such storage vessels may include one or more conventional, removable, compressed air storage cylinders **12**. Other sources of compressed air, such as a known, oil-free, high pressure compressor (not shown) connected to an alternative compressed air supply branch line **16**, may be provided if desired. If a compressor is not attached to the branch line **16**, then the branch line **16** may be capped.

A flow control valve **18** is provided in each branch line **20** connecting an air storage cylinder **12** to a high pressure feed air line **22**. A self-contained underwater breathing apparatus (scuba) air tank **14** may also be removably connected to the high pressure feed air line **22**, also by a branch line **20** having a flow control valve **18** therein, for reasons which will become apparent. The compressed air is stored in the storage vessels at an initial pressure of anywhere in the range of 3000–6000 p.s.i.g. and, therefore, supplied to the high pressure feed air line **22** at such a pressure. Air flow through the line **22**, and air or gas flow through each of the other lines shown in the drawing figure, occurs in the directions indicated by arrows.

The high pressure air feed line **22** leads from each of the branch lines **16** and **20** to a conventional pressure regulator controlled, by operation of a rotatable knob **24**, so as to reduce the pressure of the air supplied by the feed line **22**. The pressure regulator is used to reduce the pressure of the compressed air passing into the low pressure feed air line **26**

so that it is lower than approximately 600 p.s.i.g. and, typically, in the range of 50–250 p.s.i.g. Air pressure in the low pressure feed air line **26** is monitored by a low pressure side pressure gauge **28** which indicates the air pressure, in p.s.i.g., for example, in the line **26**. A flow meter **30** is used to monitor the rate of air flow in the low pressure feed air line **26** and indicates the air flow rate in standard cubic feet per minute (SCFM), for example.

The low pressure feed air line **26** leads to a junction **28** from which a pair of heat exchanger lines **30** and **32** branch off. A portion of the line **30** defines a first coil **34**, while a portion of the line **32** defines a second coil **36**. As will become clear, the first coil **34** defines a cold coil of a heating and cooling heat exchanger, generally designated **38**, while the second coil **36** defines a hot coil of the heat exchanger **38**.

At the outlet of the first coil **34**, a first thermostatically operated ON-OFF solenoid valve **40** is disposed. A second thermostatically operated ON-OFF solenoid valve **42** is similarly disposed at the outlet of the second coil **36**. Each of the solenoid valves **40** and **42** is conventional in construction and is alternatively energized and de-energized by a conventional thermostatically operated control unit **44**. Input may be provided to the control unit **44**, for example, by a temperature sensor **45** or a plurality of such sensors. The control unit, otherwise, could be manually adjusted based on temperature readings obtained from an appropriately located thermometer, if desired. The solenoid valves are controlled by the unit **44** so that when the valve **40** is open to permit compressed air flow through the line **30** and the first coil **34**, the valve **42** is closed to prevent compressed air flow through the line **32** and the second coil **36** and when the valve **42** is open to permit compressed air flow through the line **32** and the second coil **36**, the valve **40** is closed to prevent compressed air flow through the line **30** and the first coil **34**. Alternate opening and closing, i.e. "cycling" of the solenoid valves at variable cycling or oscillation periods is permitted by the control unit **44**. Consequently, if more compressed air is to pass through the first coil **34** than through the second coil **36**, then, for every on-off cycle period, the first solenoid valve **40** is controlled by the unit **44** so that it is open for a longer time than the second solenoid valve **42**. If more compressed air is to pass through the second coil **36** than through the first coil **34**, then, for every on-off cycle period, the second solenoid valve **42** is controlled by the unit **44** so that it is open for a longer time than the first solenoid valve **40**. If the same amount of compressed air is to pass through the coils **34** and **36**, then the solenoid valves **40** and **42** are opened for equal times. Finally, if compressed air is to flow only through the first coil **34**, then only the valve **40** is opened by the control unit, while if compressed air is to flow only through the second coil **36**, then only the valve **42** is opened; no valve cycling or oscillating occurs in these particular situations. The solenoid valves **40** and **42**, therefore, form flow modifying means for modifying a flow path of the compressed air.

Compressed low pressure feed air exits the heat exchanger **38** through a supply line **46**. The supply line **46** passes the compressed low pressure feed air to a compressed air inlet port **50** of a standard, known, commercially available, permeable membrane, oxygen enriched air (NITROX) and nitrogen gas separation system **48**; such a gas separation system **48** is preferably of the type using a membrane cartridge **52** and is readily available from any of a number of companies. U.S. Pat. Nos. 4,894,068 and 5,226,931 describe such separation systems. The knob **24** is used to control the pressure of the air in the low pressure feed air line **26** so that this pressure and the corresponding rate of air flow are appropriate for, and meet the specifications of, the particular gas separation system **48** ultimately selected. Typical pressures are in the 50–250 p.s.i.g. range as mentioned previously.

A nitrogen gas (N_2) component separated from the compressed low pressure feed air supplied through the port **50** passes from the system **48** through an exit port **54** and into a N_2 carrying line **56**. The N_2 carried by the line **56** primarily passes to a conventional pressure regulator controlled, by operation of a rotatable knob **58**, so that the pressure of the N_2 is reduced before entering compressed gas supply line **60** of the heat exchanger **38**. The pressure of the N_2 is monitored by a N_2 supply line pressure gauge **62** and dropped by the regulator so that it is somewhere in the range of approximately 80–100 p.s.i.g. and appropriate for supply to the spin chamber of a known and commercially available vortex tube **64** which forms another part of the heat exchanger **38**. Vortex tubes of this type are available from EXAIR corporation of Cincinnati, Ohio, for example. The vortex tube **64** operates to divide the nitrogen gas component into a cold nitrogen gas stream and a hot nitrogen gas stream. More specifically, cold N_2 leaves the vortex tube **64** through a cold gas exhaust **66**, which is directed towards the first coil **34**, while hot N_2 leaves the vortex tube **64** through a hot gas exhaust **68**, which is directed towards the second coil **36**. In this manner, heat is supplied to the compressed air which is directed through the heat exchanger line **32** and the second coil **36**, while heat is taken away from the compressed air which is directed through the heat exchanger line **30** and the first coil **34**. Appropriate operation of the solenoid valves **40** and **42** by the control unit **44** permits selective heating and cooling, i.e. "temperature conditioning" of the compressed low pressure feed air passing through the heat exchanger **38** and the supply line **46** so that the temperature is appropriate for, and meets the specifications of, the particular separation system **48** selected.

After the N_2 has been used in the heat exchanger **38** for heating or cooling, it may be collected and stored for other uses if desired. Otherwise, the N_2 may be exhausted to the atmosphere as waste gas.

Some of the N_2 carried by the line **56** is diverted, at a junction **70**, through a branch line **72**. The branch line **72** leads to a conventional pressure regulator, controlled by a knob **74**, which reduces the pressure of the N_2 passing into a compressor crankcase supply line **78** to somewhere in the range of approximately 1–3 p.s.i.g. Flow rates of the N_2 through the supply line **78** are about 1–3 liters per minute, which amount to approximately 1%, or less, of the N_2 leaving the exit port **54** of the system **48**. The supply line **78** feeds into a standard crankcase vent **82**, which otherwise would be open to the atmosphere, of a standard, oil-lubricated, high pressure compressor **80**. Operation of the compressor **80** is described later. The N_2 supplied by the line **78** passes through the crankcase and exits through an exhaust port **84**, provided in the crankcase, into a crankcase exhaust line **85** leading to the atmosphere. In this manner, the crankcase of the compressor **80** is inerted by the N_2 supplied in order to reduce any possibility of explosion. This permits the use of the standard, oil-lubricated compressor **80** rather than an oil-free compressor.

A directly breathable, oxygen enriched air (NITROX) component separated from the compressed low pressure feed air supplied through the port **50** passes from the separation system **48** through an oxygen enriched air exhaust port **86** and into a low pressure oxygen enriched air feed line **88**. The oxygen enriched air passing through the

port 86 is a breathable mixture which may be supplied for direct inhalation. Accordingly, an optional branch line 90, leading from the feed line 88, may be provided. The oxygen enriched air can be diverted through the line 90 for any of a variety of non-diving applications. Pressure in the feed line 88 is typically quite low, i.e. in the 0.5–5 p.s.i.g. range. A conventional flow control valve 92 may be used to open and close off the optional branch line 90. A conventional flow control valve 94 is also disposed in the feed line 88 so that the flow of oxygen enriched air through the feed line 88 can be permitted, shut off and regulated.

A small amount of the oxygen enriched air component flowing through the low pressure feed line 88 is diverted, at junction 96, through a sampling line 98. The sampling line 98 leads to a conventional oxygen analyzer 100 which detects and provides a reading of the oxygen concentration of the oxygen enriched air passing through the flow control valve 94 and into a compressor feed line 102 leading to the oil-lubricated, high pressure compressor 80. The analyzer shown can provide oxygen concentration readings anywhere in the range of 0% to 50%. The temperature of the compressed low pressure feed air in the supply line 46 influences the oxygen concentration of the oxygen enriched air passing from the system 48. Appropriate cycling of the solenoid valves 40 and 42, therefore, can be used to selectively heat and cool the feed air in the supply line and adjust this oxygen concentration. As is usual, the compressor 80 is operated by an electric or gasoline powered motor 110 interconnected with the compressor 80 by a belt 112 and pulleys 114 and 116.

An ambient air intake 104 leads to a conventional ambient air flow or pressure regulation valve controlled, by operation of a rotatable knob 108, so as to modify the flow and pressure of ambient air admitted into the compressor feed line 102 through an ambient air feed line 118. A pressure gauge 120 can be used to indicate the pressure in the feed line 118 which varies depending on the degree, between 0% and 100%, to which the air flow or pressure regulation valve is opened; as shown, the gauge 120 provides readings which could vary between −15 p.s.i.g. (partial vacuum) and 30 p.s.i.g.

Oxygen enriched air (NITROX) only, ambient air only, or a combination of oxygen enriched air and ambient air may be drawn through the compressor feed line 102 to a compressor inlet when the compressor 80 is operated; typically, a mixture of the oxygen enriched air and the ambient air is drawn into the compressor. Compressed oxygen enriched air, compressed ambient air or a compressed combination of oxygen enriched air and ambient air subsequently passes through a compressor outlet and into a high pressure side outlet line 122. A conventional flow meter 124 is used to monitor the rate of air flow through the line 122 and indicates such an air flow rate in SCFM. As shown, readings of 0–60 SCFM could be provided by the flow meter 124. The air pressure in the outlet line 122 is adjusted by a conventional pressure regulator, operated by a rotatable knob 126, to an appropriate pressure. The air pressure in the outlet line 122 is monitored by a pressure gauge 128 which is conventional in structure. The high pressure side air pressure is typically between 3000 and 6000 p.s.i.g. In the embodiment of the invention illustrated, keeping the high pressure side air pressure below 4000 p.s.i.g. is appropriate because of the capability of the pressure gauge 128.

At a junction 130, a high pressure side sampling line 132 diverts a small portion of the compressed oxygen enriched air, the compressed ambient air or the compressed combination thereof from the outlet line 122 to the analyzer 100 (or a completely separate and different oxygen analyzer if desired). A reading of the oxygen concentration of the air passing through the line 122, be it oxygen enriched, ambient or a combination of oxygen enriched and ambient, is thereby provided.

Air which has been compressed by the compressor 80 passes through the outlet line 122 to a junction 134 at which point the outlet line is divided into a first or ambient air supply line 136 and a second or oxygen enriched air supply line 138. A conventional flow regulating valve 140 is disposed in the line 136 to regulate the flow of ambient air therethrough, while a conventional flow regulating valve 142 is disposed in the line 138 to regulate the flow of oxygen enriched air therethrough. As is clear from the drawing figure, the air supply line 136 feeds into the high pressure feed air line 22. As a result, the air supply line 136 is able to supply compressed air to the line 22 and to each of the branch lines 20. Similarly, the oxygen enriched air supply line 138 feeds into a high pressure feed oxygen enriched air line 144 and any desired number of branch lines 146 associated therewith. Each branch line 146 includes a flow control valve 148, similar to the valves 18, to regulate the flow of oxygen enriched air into a compressed oxygen enriched air storage assembly 150 including one or more conventional and appropriately labeled NITROX storage vessels such as removable storage cylinders 152 or a removable NITROX scuba tank 154. Both assembly 10 and assembly 150 may be located either above water or under water. Applications other than for diving purposes, such as in firefighting, climbing, space or high altitude flight, veterinary, medical and dental treatments, welding, etc., are apparent.

A variety of operations can be performed by the system represented in FIG. 1. To provide an initial charge or a recharge to an air storage cylinder 12, or a plurality of such cylinders, or to charge a scuba air tank 14, the appropriate flow control valve or valves 18 is or are opened. The flow regulating valve 140 is opened while the flow regulating valve 142 is closed. The flow control valve 94 is closed to eliminate the admission or flow of oxygen enriched air into the feed line 102. The knob 108 is rotated to permit free flow of ambient air through the intake 104 and into the compressor feed line 102. The motor 110 is turned on to drive the compressor 80 and draw ambient air into the feed line 102. The air is compressed and then passed through the outlet line 122, the air supply line 136 and the appropriate branch line or lines 20 and into the appropriate air storage cylinder or cylinders 12 and/or scuba air tank or tanks 14.

To provide an initial charge, or a recharge, to a NITROX storage cylinder 152, or a plurality of such cylinders, or to charge a NITROX scuba tank 154, the flow regulating valve 140 is closed, while the flow regulating valve 142 is opened. If it is provided, then the flow control valve 92 is closed. The flow control valve 94 is opened to permit free flow of oxygen enriched air into the feed line 102. The knob 108 may be rotated to cause the valve associated therewith to set the flow rate of ambient air through the intake 104 and into the feed line 102 to an initial value. The motor 110 is turned on to drive the compressor 80 and draw a mixture of both ambient and oxygen enriched air into the feed line 102. The air mixture is compressed and then passed through the outlet line 122, the oxygen enriched air supply line 138 and one or more of the branch lines 146. At this point, one or more of the branch lines 146 may be left open. The oxygen concentration of the ambient and compressed oxygen enriched air mixture passing through the outlet line 122 is detected by the oxygen analyzer 100 and, as a result, may be closely monitored during any oxygen concentration adjustment.

It has been found that various parameters influence the concentration of oxygen in the compressed oxygen enriched air passing through the outlet line **122**. These parameters include, for example, the temperature of the feed air in the supply line **46** mentioned previously, the pressure of the air in the low pressure feed air line **26** and, of course, the rate at which ambient air is admitted into the compressor feed line **102** through the ambient air intake **104**. The concentration of oxygen in the compressed oxygen enriched air passing through the high pressure outlet line **122**, therefore, can be modified to any desired concentration by adjustment of these parameters. Such an adjustment may be made by changing the setting of the pressure regulator knob **24**, the setting of the thermostatic control of the unit **44**, the setting of the air pressure regulation valve knob **108** or the settings of two or more of these elements. For diving applications, typically desired oxygen concentrations are 32% oxygen (NOAANITROX I) and 36% oxygen (NOAA NITROX II). The parameters obviously could be adjusted so that other concentrations of oxygen in the compressed air passing through the outlet line **122** are provided.

Once a suitable oxygen concentration adjustment of the compressed oxygen enriched air and ambient air mixture in the outlet line **122** has been performed, the appropriate NITROX storage cylinders **152** or NITROX scuba tanks **154** may be connected to the branch lines **146**. The flow control valves **148** may then be operated to admit the oxygen enriched air and ambient air mixture into the NITROX storage cylinders **152** and/or the NITROX scuba tanks **154**. Appropriate pressure regulation is provided by the knob **126** and the pressure gauge **128**.

If a diversion of oxygen enriched air through the optional branch line **90** is desired, then the flow control valve **92** is opened. The oxygen enriched air leaving the separation system **48** through the port **86** is then permitted to pass through the optional branch line **90** so that it may be used in any of a variety of non-diving applications. This oxygen enriched air is directly breathable. As mentioned previously, the pressure in the feed line **88** is usually quite low (in the 0.5 to 5 p.s.i.g. range) and, as a result, the flow of air through the branch line **90** occurs at a fairly low rate. The flow control valve **94** may be left open so that some of the air passing through the port **86** is also permitted to enter the sampling line **98** and, therefore, pass to the oxygen analyzer **100**. In this manner, the oxygen concentration of the oxygen enriched air exiting through the port **86** and flowing through the branch line **90** can be monitored. Thus, the flow control valve **92** and the flow regulating valves **140** and **142**, together with the other elements used to properly route the oxygen enriched air passing through the port **86**, form means for selectively distributing the oxygen enriched air component for further use.

Variations in the embodiment described above and represented in the drawing figure may occur to these skilled in the art. It is intended to protect any such variations which do not depart from the spirit of this invention by the following claims.

What is claimed is:

1. A system for generating oxygen enriched air comprising:

an air supply for supplying compressed air;

a permeable membrane gas separation system for separating a nitrogen gas component and an oxygen enriched air component from said compressed air;

means for detecting an oxygen concentration in said oxygen enriched air component;

means for dividing said nitrogen gas component into a cold gas stream and a hot gas stream;

flow modifying means for modifying a flow path of said compressed air through said cold gas stream and said hot gas stream to selectively heat and cool said compressed air; and

means for selectively distributing said oxygen enriched air component for further use.

2. A system as defined in claim **1**, and further comprising a compressed oxygen enriched air storage assembly, a compressor, a compressor feed line supplying said oxygen enriched air component to a compressor inlet and an outlet line interconnecting a compressor outlet to said compressed oxygen enriched air storage assembly.

3. A system as defined in claim **2**, wherein the flow modifying means comprises solenoid valves which modify said flow path of said compressed air by alternate opening and closing thereof so that the compressed air is selectively heated and cooled to adjust the oxygen concentration of the oxygen enriched air component to a desired oxygen concentration.

4. A system as defined in claim **3**, and further comprising an ambient air feed line for admitting ambient air into said compressor feed line so as to mix with said oxygen enriched air component and regulating means for regulating the amount of ambient air admitted into said compressor feed line to permit further adjustment of said oxygen concentration.

5. A system as defined in claim **4**, wherein said means for detecting the oxygen concentration is interconnected with said outlet line to permit monitoring of the oxygen concentration of a mixture of ambient air and the oxygen enriched air component in said outlet line.

6. A system as defined in claim **5**, and further comprising means for storing said mixture, wherein said means for selectively distributing said oxygen enriched air component for further use comprises an oxygen enriched air supply line and at least one valve provided in said oxygen enriched air supply line to regulate flow of said mixture into the means for storing said mixture.

7. A system as defined in claim **4**, and further comprising a valve for selectively eliminating admission of said oxygen enriched air component into said compressor feed line so that only ambient air passes through said outlet line and said air supply can be recharged.

8. A system as defined in claim **2**, wherein said means for detecting the oxygen concentration is interconnected with an outlet of said permeable membrane gas separation system to permit monitoring of the oxygen concentration of said oxygen enriched air component passing through said outlet.

9. A system as defined in claim **8**, wherein the flow modifying means comprises solenoid valves which modify said flow path of said compressed air by alternate opening and closing thereof so that the compressed air is selectively heated and cooled to adjust the oxygen concentration of the oxygen enriched air component to a desired oxygen concentration.

10. A system as defined in claim **9**, and further comprising an ambient air feed line for admitting ambient air into said compressor feed line so as to mix with said oxygen enriched air component and regulating means for regulating the amount of ambient air admitted into said compressor feed line to permit further adjustment of said oxygen concentration.

11. A system as defined in claim **10**, wherein said means for detecting the oxygen concentration is interconnected with said outlet line to permit monitoring of the oxygen

concentration of a mixture of ambient air and the oxygen enriched air component in said outlet line.

12. A system as defined in claim 11, and further comprising means for storing said mixture, wherein said means for selectively distributing said oxygen enriched air component for further use comprises an oxygen enriched air supply line and at least one valve provided in said oxygen enriched air supply line to regulate flow of said mixture into the means for storing said mixture.

13. A system as defined in claim 2, and further comprising means for diverting some of the nitrogen gas component to a crankcase of said compressor in order to reduce any possibility of explosion.

14. A system as defined in claim 13, wherein the flow modifying means comprises solenoid valves which modify said flow path of said compressed air by alternate opening and closing thereof so that the compressed air is selectively heated and cooled to adjust the oxygen concentration of the oxygen enriched air component to a desired oxygen concentration.

15. A system as defined in claim 14, and further comprising an ambient air feed line for admitting ambient air into said compressor feed line so as to mix with said oxygen enriched air component and regulating means for regulating the amount of ambient air admitted into said compressor feed line to permit further adjustment of said oxygen concentration.

16. A system as defined in claim 15, wherein said means for detecting the oxygen concentration is interconnected with said outlet line to permit monitoring of the oxygen concentration of a mixture of ambient air and the oxygen enriched air component in said outlet line.

17. A system as defined in claim 16, and further comprising means for storing said mixture, wherein said means for selectively distributing said oxygen enriched air component for further use comprises an oxygen enriched air supply line and at least one valve provided in said oxygen enriched air supply line to regulate flow of said mixture into the means for storing said mixture.

18. A system as defined in claim 15, and further comprising a valve for selectively eliminating admission of said oxygen enriched air component into said compressor feed line so that only ambient air passes through said outlet line and said air supply can be recharged.

19. A system as defined in claim 13, wherein said means for detecting the oxygen concentration is interconnected with an outlet of said permeable membrane gas separation system to permit monitoring of the oxygen concentration of said oxygen enriched air component passing through said outlet.

20. A system as defined in claim 2, wherein said compressor is an oil-lubricated compressor.

21. A system as defined in claim 1, wherein said means for dividing said nitrogen gas component includes a vortex tube.

22. A system as defined in claim 1, wherein the further use is breathing.

23. A system for generating oxygen enriched air comprising:

an air supply for supplying compressed air;

a permeable membrane gas separation system for separating a nitrogen gas component and an oxygen enriched air component from said compressed air;

means for detecting an oxygen concentration in said oxygen enriched air component;

means for selectively heating and cooling said compressed air as it passes between said air supply and said permeable membrane gas separation system; and

means for selectively distributing said oxygen enriched air component for further use.

24. A system as defined in claim 23, and further comprising a compressed oxygen enriched air storage assembly, a compressor, a compressor feed line supplying said oxygen enriched air component to a compressor inlet and an outlet line interconnecting a compressor outlet to said compressed oxygen enriched air storage assembly.

25. A system as defined in claim 24, and further comprising an ambient air feed line for admitting ambient air into said compressor feed line so as to mix with said oxygen enriched air component and regulating means for regulating the amount of ambient air admitted into said compressor feed line to permit further adjustment of said oxygen concentration.

26. A system as defined in claim 25, wherein said means for detecting the oxygen concentration is interconnected with said outlet line to permit monitoring of the oxygen concentration of a mixture of ambient air and the oxygen enriched air component in said outlet line.

27. A system as defined in claim 26, and further comprising means for storing said mixture, wherein said means for selectively distributing said oxygen enriched air component for further use comprises an oxygen enriched air supply line and at least one valve provided in said oxygen enriched air supply line to regulate flow of said mixture into the means for storing said mixture.

28. A system as defined in claim 25, and further comprising a valve for selectively eliminating admission of said oxygen enriched air component into said compressor feed line so that only ambient air passes through said outlet line and said air supply can be recharged.

29. A system as defined in claim 24, wherein said means for detecting the oxygen concentration is interconnected with an outlet of said permeable membrane gas separation system to permit monitoring of the oxygen concentration of said oxygen enriched air component passing through said outlet.

30. A system as defined in claim 29, and further comprising an ambient air feed line for admitting ambient air into said compressor feed line so as to mix with said oxygen enriched air component and regulating means for regulating the amount of ambient air admitted into said compressor feed line to permit further adjustment of said oxygen concentration.

31. A system as defined in claim 30, and further comprising a valve for selectively eliminating admission of said oxygen enriched air component into said compressor feed line so that only ambient air passes through said outlet line and said air supply can be recharged.

32. A system as defined in claim 33, wherein said means for detecting the oxygen concentration is interconnected with an outlet of said permeable membrane gas separation system to permit monitoring of the oxygen concentration of said oxygen enriched air component passing through said outlet.

33. A system as defined in claim 23, and further comprising an ambient air feed line for mixing ambient air into said oxygen enriched air component and regulating means for regulating the amount of ambient air mixed into said oxygen enriched air component to permit further adjustment of said oxygen concentration.

* * * * *

Exhibit 2

Plaintiff's Complaint for Patent Infringement and Breach of Contract Injunctive Relief and Jury Trial Requested

US005858064A

United States Patent [19]

Delp, II

[11] **Patent Number: 5,858,064**

[45] **Date of Patent: Jan. 12, 1999**

[54] **OXYGEN ENRICHED AIR GENERATION SYSTEM**

[75] Inventor: **William H. Delp, II**, Lake Worth, Fla.

[73] Assignee: **Undersea Breathing Systems, Inc.**, Lake Worth, Fla.

[21] Appl. No.: **58,852**

[22] Filed: **Apr. 13, 1998**

Related U.S. Application Data

[63] Continuation of Ser. No. 822,141, Mar. 17, 1997, Pat. No. 5,766,308, which is a continuation of Ser. No. 518,020, Aug. 22, 1995, Pat. No. 5,611,845.

[51] **Int. Cl.**[6] **B01D 53/22**

[52] **U.S. Cl.** **95/12**; 95/8; 95/54

[58] **Field of Search** 95/8, 12, 54

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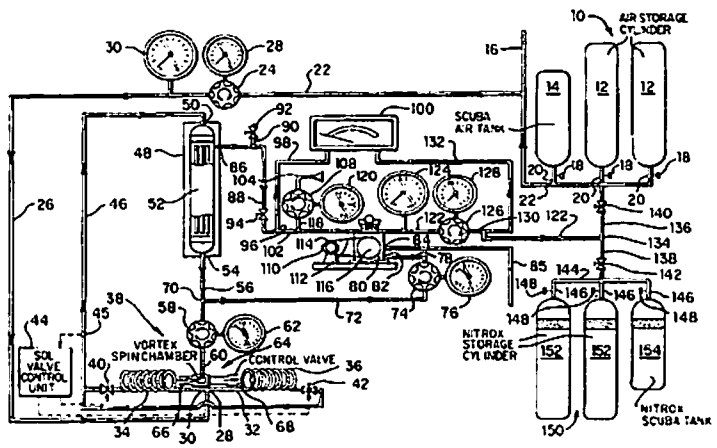
Primary Examiner—Robert Spitzer

Attorney, Agent, or Firm—Evenson, McKeown, Edwards & Lenahan, PLLC

[57] **ABSTRACT**

A system for generating oxygen enriched air includes a compressed air supply for supplying compressed air and a permeable membrane gas separation system for separating a nitrogen gas component and an oxygen enriched air component from the compressed air. An oxygen analyzer is provided to detect an oxygen concentration in the oxygen enriched air component. The nitrogen gas component is divided, by a vortex tube, into a cold gas stream and a hot gas stream, and solenoid valves are actuated to modify a flow path of the compressed air through the cold gas stream and the hot gas stream in order to selectively heat and cool the compressed air. The oxygen enriched air is then selectively distributed for further use.

10 Claims, 1 Drawing Sheet



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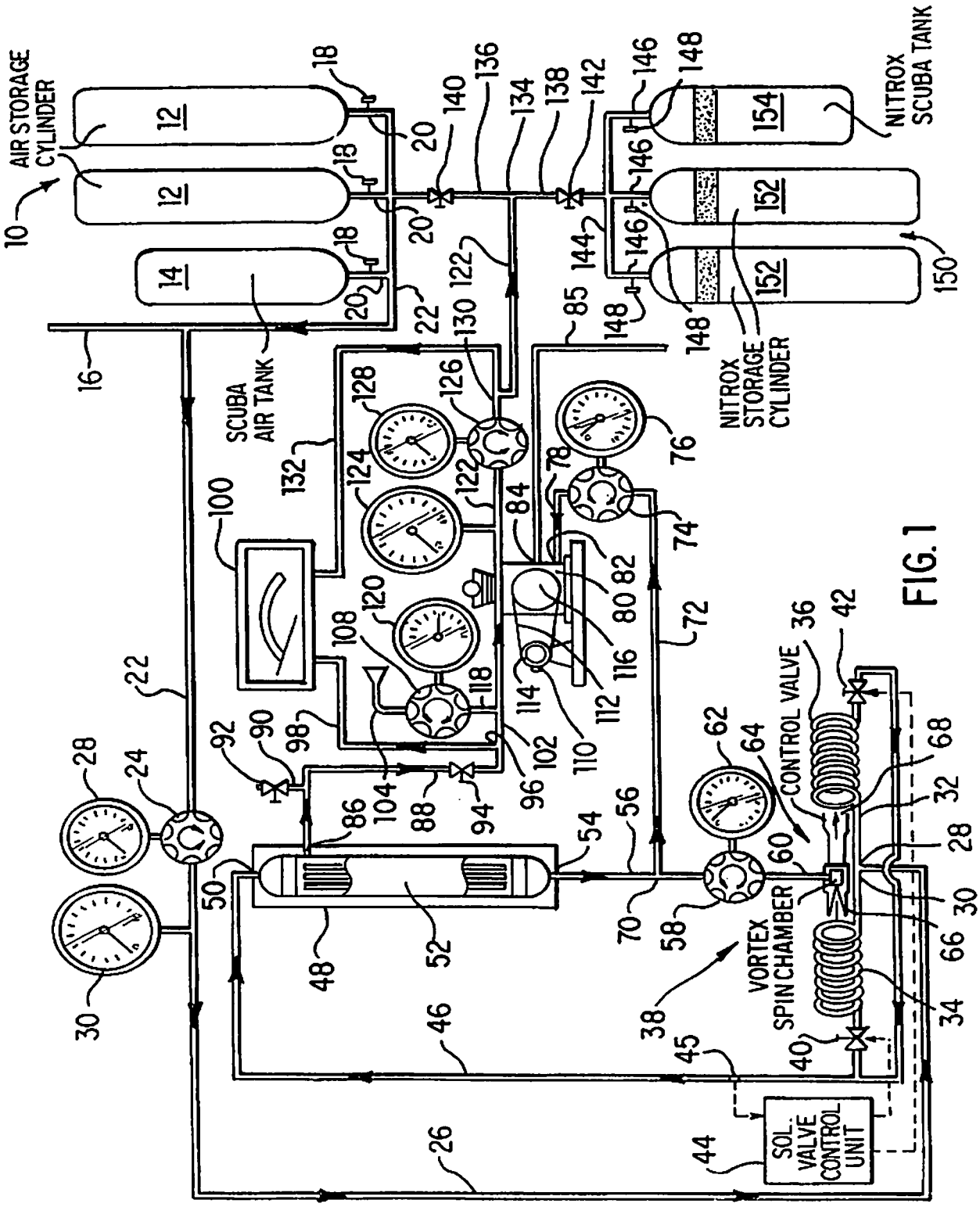

AIR STORAGE CYLINDER
NITROX SCUBA TANK
SCUBA AIR TANK
NITROX STORAGE CYLINDER
CONTROL VALVE
VORTEX SPIN CHAMBER
SOL. VALVE CONTROL UNIT

FIG. 1

OXYGEN ENRICHED AIR GENERATION SYSTEM

This application is a continuation of application Ser. No. 08/822,141, filed Mar. 17, 1997, now U.S. Pat. No. 5,766,308, which is a continuation of application Ser. No. 08/518,020, filed Aug. 22, 1995, now U.S. Pat. No. 5,611,845.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a particular type of oxygen enriched air generation system. A permeable membrane oxygen enriched air and nitrogen gas separation device is utilized. Although the system is particularly suitable for use by dive shops for filling scuba tanks or other types of oxygen enriched air storage vessels, applications in areas such as firefighting, climbing, flight, veterinary, medical and dental treatments, welding, etc., are apparent.

2. Description of Related Art

One known system for producing a mixture of oxygen enriched air and ambient air is disclosed in U.S. Pat. No. 4,860,803 to Wells. In this system, oxygen is injected into a stream of ambient air in order to produce an oxygen enriched air mixture. The mixture is compressed and delivered to storage or scuba cylinders for use in diving or other applications. According to this system, however, a source of oxygen appropriate for injection into the ambient air stream is needed and, therefore, a great deal of caution is required, during generation of the oxygen enriched air mixture, to avoid explosions and other problems typically associated with the use of oxygen.

SUMMARY OF THE INVENTION

It is one object of this invention to provide a suitable alternative system for generating an oxygen enriched air mixture, suitable for breathing purposes, which does not require the use of oxygen supplied from a separate oxygen source.

It is another object of this invention to provide a system which generates a gas stream which may be used by a suitable element, such as a vortex tube, to adjust the oxygen concentration of the oxygen enriched air mixture.

It is a further object of this invention to divert some of the gas stream produced so that the portion of the gas stream diverted may be used for inerting purposes such as, for example, to inert the crankcase of a compressor so that the compressor may be a standard oil-lubricated compressor rather than an oil-free compressor.

According to the present invention, these and other objects are accomplished by the provision of a system for generating oxygen enriched air which includes a compressed air supply for supplying compressed air and a permeable membrane gas separation system for separating a nitrogen gas component and an oxygen enriched air component from the compressed air. An oxygen analyzer is provided to detect an oxygen concentration in the oxygen enriched air component. The nitrogen gas component is divided, by a vortex tube, into a cold gas stream and a hot gas stream, and solenoid valves are actuated to modify a flow path of the compressed air through the cold gas stream and the hot gas stream in order to selectively heat and cool the compressed air. The oxygen enriched air is then selectively distributed for further use. A compressed oxygen enriched air storage assembly, a compressor, a compressor feed line supplying the oxygen enriched air component to a compressor inlet and an outlet line interconnecting a compressor outlet to the compressed oxygen enriched air storage assembly are provided.

The solenoid valves are used to modify the flow path of the compressed air by alternate opening and closing thereof so that the compressed air is selectively heated and cooled by the gas streams to adjust the oxygen concentration of the oxygen enriched air component to a desired oxygen concentration. An ambient air feed line admits ambient air into the compressor feed line so as to mix with the oxygen enriched air component. A regulating valve is used to regulate the amount of ambient air admitted into the compressor feed line and also permits adjustment of the oxygen concentration.

The oxygen analyzer is interconnected with the outlet line to permit monitoring of the oxygen concentration of a mixture of ambient air and the oxygen enriched air component in the outlet line. The system includes an oxygen enriched air supply line and at least one valve provided in the oxygen enriched air supply line to regulate flow of the mixture into appropriate containers for storing the mixture. The oxygen analyzer, or another oxygen analyzer, is also interconnected with an outlet of the permeable membrane gas separation system to permit monitoring of the oxygen concentration of the oxygen enriched air component passing through the outlet. A valve is used to selectively eliminate admission of the oxygen enriched air component into the compressor feed line so that only ambient air passes through the outlet line and the air supply can be recharged. Finally, a branch line for diverting some of the nitrogen gas component to a crankcase of the compressor, in order to reduce any possibility of explosion, is provided.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1, the only drawing figure provided, illustrates the overall structure of an oxygen enriched air generation system according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A compressed air supply is provided by an assembly **10** of one or more storage vessels. Such storage vessels may include one or more conventional, removable, compressed air storage cylinders **12**. Other sources of compressed air, such as a known, oil-free, high pressure compressor (not shown) connected to an alternative compressed air supply branch line **16**, may be provided if desired. If a compressor is not attached to the branch line **16**, then the branch line **16** may be capped.

A flow control valve **18** is provided in each branch line **20** connecting an air storage cylinder **12** to a high pressure feed air line **22**. A self-contained underwater breathing apparatus (scuba) air tank **14** may also be removably connected to the high pressure feed air line **22**, also by a branch line **20** having a flow control valve **18** therein, for reasons which will become apparent. The compressed air is stored in the storage vessels at an initial pressure of anywhere in the range of 3000–6000 p.s.i.g. and, therefore, supplied to the high pressure feed air line **22** at such a pressure. Air flow through the line **22**, and air or gas flow through each of the other lines shown in the drawing figure, occurs in the directions indicated by arrows.

The high pressure air feed line **22** leads from each of the branch lines **16** and **20** to a conventional pressure regulator controlled, by operation of a rotatable knob **24**, so as to reduce the pressure of the air supplied by the feed line **22**.

The pressure regulator is used to reduce the pressure of the compressed air passing into the low pressure feed air line **26** so that it is lower than approximately 600 p.s.i.g. and, typically, in the range of 50–250 p.s.i.g. Air pressure in the low pressure feed air line **26** is monitored by a low pressure side pressure gauge **28** which indicates the air pressure, in p.s.i.g., for example, in the line **26**. A flow meter **30** is used to monitor the rate of air flow in the low pressure feed air line **26** and indicates the air flow rate in standard cubic feet per minute (SCFM), for example.

The low pressure feed air line **26** leads to a junction **28** from which a pair of heat exchanger lines **30** and **32** branch off. A portion of the line **30** defines a first coil **34**, while a portion of the line **32** defines a second coil **36**. As will become clear, the first coil **34** defines a cold coil of a heating and cooling heat exchanger, generally designated **38**, while the second coil **36** defines a hot coil of the heat exchanger **38**.

At the outlet of the first coil **34**, a first thermostatically operated ON-OFF solenoid valve **40** is disposed. A second thermostatically operated ON-OFF solenoid valve **42** is similarly disposed at the outlet of the second coil **36**. Each of the solenoid valves **40** and **42** is conventional in construction and is alternatively energized and de-energized by a conventional thermostatically operated control unit **44**. Input may be provided to the control unit **44**, for example, by a temperature sensor **45** or a plurality of such sensors. The control unit, otherwise, could be manually adjusted based on temperature readings obtained from an appropriately located thermometer, if desired. The solenoid valves are controlled by the unit **44** so that when the valve **40** is open to permit compressed air flow through the line **30** and the first coil **34**, the valve **42** is closed to prevent compressed air flow through the line **32** and the second coil **36** and when the valve **42** is open to permit compressed air flow through the line **32** and the second coil **36**, the valve **40** is closed to prevent compressed air flow through the line **30** and the first coil **34**. Alternate opening and closing, i.e. "cycling", of the solenoid valves at variable cycling or oscillation periods is permitted by the control unit **44**. Consequently, if more compressed air is to pass through the first coil **34** than through the second coil **36**, then, for every on-off cycle period, the first solenoid valve **40** is controlled by the unit **44** so that it is open for a longer time than the second solenoid valve **42**. If more compressed air is to pass through the second coil **36** than through the first coil **34**, then, for every on-off cycle period, the second solenoid valve **42** is controlled by the unit **44** so that it is open for a longer time than the first solenoid valve **40**. If the same amount of compressed air is to pass through the coils **34** and **36**, then the solenoid valves **40** and **42** are opened for equal times. Finally, if compressed air is to flow only through the first coil **34**, then only the valve **40** is opened by the control unit, while if compressed air is to flow only through the second coil **36**, then only the valve **42** is opened; no valve cycling or oscillating occurs in these particular situations. The solenoid valves **40** and **42**, therefore, form flow modifying means for modifying a flow path of the compressed air.

Compressed low pressure feed air exits the heat exchanger **38** through a supply line **46**. The supply line **46** passes the compressed low pressure feed air to a compressed air inlet port **50** of a standard, known, commercially available, permeable membrane, oxygen enriched air (NITROX) and nitrogen gas separation system **48**; such a gas separation system **48** is preferably of the type using a membrane cartridge **52** and is readily available from any of a number of companies. U.S. Pat. Nos. 4,894,068 and 5,226,931 describe such separation systems. The knob **24** is used to control the pressure of the air in the low pressure feed air line **26** so that this pressure and the corresponding rate of air flow are appropriate for, and meet the specifications of, the particular gas separation system **48** ultimately selected. Typical pressures are in the 50–250 p.s.i.g. range as mentioned previously.

A nitrogen gas (N_2) component separated from the compressed low pressure feed air supplied through the port **50** passes from the system **48** through an exit port **54** and into a N_2 carrying line **56**. The N_2 carried by the line **56** primarily passes to a conventional pressure regulator controlled, by operation of a rotatable knob **58**, so that the pressure of the N_2 is reduced before entering compressed gas supply line **60** of the heat exchanger **38**. The pressure of the N_2 is monitored by a N_2 supply line pressure gauge **62** and dropped by the regulator so that it is somewhere in the range of approximately 80–100 p.s.i.g. and appropriate for supply to the spin chamber of a known and commercially available vortex tube **64** which forms another part of the heat exchanger **38**. Vortex tubes of this type are available from EXAIR corporation of Cincinnati, Ohio, for example. The vortex tube **64** operates to divide the nitrogen gas component into a cold nitrogen gas stream and a hot nitrogen gas stream. More specifically, cold N_2 leaves the vortex tube **64** through a cold gas exhaust **66**, which is directed towards the first coil **34**, while hot N_2 leaves the vortex tube **64** through a hot gas exhaust **68**, which is directed towards the second coil **36**. In this manner, heat is supplied to the compressed air which is directed through the heat exchanger line **32** and the second coil **36**, while heat is taken away from the compressed air which is directed through the heat exchanger line **30** and the first coil **34**. Appropriate operation of the solenoid valves **40** and **42** by the control unit **44** permits selective heating and cooling, i.e. "temperature conditioning", of the compressed low pressure feed air passing through the heat exchanger **38** and the supply line **46** so that the temperature is appropriate for, and meets the specifications of, the particular separation system **48** selected.

After the N_2 has been used in the heat exchanger **38** for heating or cooling, it may be collected and stored for other uses if desired. Otherwise, the N_2 may be exhausted to the atmosphere as waste gas.

Some of the N_2 carried by the line **56** is diverted, at a junction **70**, through a branch line **72**. The branch line **72** leads to a conventional pressure regulator, controlled by a knob **74**, which reduces the pressure of the N_2 passing into a compressor crankcase supply line **78** to somewhere in the range of approximately 1–3 p.s.i.g. Flow rates of the N_2 through the supply line **78** are about 1–3 liters per minute, which amount to approximately 1%, or less, of the N_2 leaving the exit port **54** of the system **48**. The supply line **78** feeds into a standard crankcase vent **82**, which otherwise would be open to the atmosphere, of a standard, oil-lubricated, high pressure compressor **80**. Operation of the compressor **80** is described later. The N_2 supplied by the line **78** passes through the crankcase and exits through an exhaust port **84**, provided in the crankcase, into a crankcase exhaust line **85** leading to the atmosphere. In this manner, the crankcase of the compressor **80** is inerted by the N_2 supplied in order to reduce any possibility of explosion. This permits the use of the standard, oil-lubricated compressor **80** rather than an oil-free compressor.

A directly breathable, oxygen enriched air (NITROX) component separated from the compressed low pressure feed air supplied through the port **50** passes from the

separation system **48** through an oxygen enriched air exhaust port **86** and into a low pressure oxygen enriched air feed line **88**. The oxygen enriched air passing through the port **86** is a breathable mixture which may be supplied for direct inhalation. Accordingly, an optional branch line **90**, leading from the feed line **88**, may be provided. The oxygen enriched air can be diverted through the line **90** for any of a variety of non-diving applications. Pressure in the feed line **88** is typically quite low, i.e. in the 0.5–5 p.s.i.g. range. A conventional flow control valve **92** may be used to open and close off the optional branch line **90**. A conventional flow control valve **94** is also disposed in the feed line **88** so that the flow of oxygen enriched air through the feed line **88** can be permitted, shut off and regulated.

A small amount of the oxygen enriched air component flowing through the low pressure feed line **88** is diverted, at junction **96**, through a sampling line **98**. The sampling line **98** leads to a conventional oxygen analyzer **100** which detects and provides a reading of the oxygen concentration of the oxygen enriched air passing through the flow control valve **94** and into a compressor feed line **102** leading to the oil-lubricated, high pressure compressor **80**. The analyzer shown can provide oxygen concentration readings anywhere in the range of 0% to 50%. The temperature of the compressed low pressure feed air in the supply line **46** influences the oxygen concentration of the oxygen enriched air passing from the system **48**. Appropriate cycling of the solenoid valves **40** and **42**, therefore, can be used to selectively heat and cool the feed air in the supply line and adjust this oxygen concentration. As is usual, the compressor **80** is operated by an electric or gasoline powered motor **110** interconnected with the compressor **80** by a belt **112** and pulleys **114** and **116**.

An ambient air intake **104** leads to a conventional ambient air flow or pressure regulation valve controlled, by operation of a rotatable knob **108**, so as to modify the flow and pressure of ambient air admitted into the compressor feed line **102** through an ambient air feed line **118**. A pressure gauge **120** can be used to indicate the pressure in the feed line **118** which varies depending on the degree, between 0% and 100%, to which the air flow or pressure regulation valve is opened; as shown, the gauge **120** provides readings which could vary between −15 p.s.i.g. (partial vacuum) and 30 p.s.i.g.

Oxygen enriched air (NITROX) only, ambient air only, or a combination of oxygen enriched air and ambient air may be drawn through the compressor feed line **102** to a compressor inlet when the compressor **80** is operated; typically, a mixture of the oxygen enriched air and the ambient air is drawn into the compressor. Compressed oxygen enriched air, compressed ambient air or a compressed combination of oxygen enriched air and ambient air subsequently passes through a compressor outlet and into a high pressure side outlet line **122**. A conventional flow meter **124** is used to monitor the rate of air flow through the line **122** and indicates such an air flow rate in SCFM. As shown, readings of 0–60 SCFM could be provided by the flow meter **124**. The air pressure in the outlet line **122** is adjusted by a conventional pressure regulator, operated by a rotatable knob **126**, to an appropriate pressure. The air pressure in the outlet line **122** is monitored by a pressure gauge **128** which is conventional in structure. The high pressure side air pressure is typically between 3000 and 6000 p.s.i.g. In the embodiment of the invention illustrated, keeping the high pressure side air pressure below 4000 p.s.i.g. is appropriate because of the capability of the pressure gauge **128**.

At a junction **130**, a high pressure side sampling line **132** diverts a small portion of the compressed oxygen enriched air, the compressed ambient air or the compressed combination thereof from the outlet line **122** to the analyzer **100** (or a completely separate and different oxygen analyzer if desired). A reading of the oxygen concentration of the air passing through the line **122**, be it oxygen enriched, ambient or a combination of oxygen enriched and ambient, is thereby provided.

Air which has been compressed by the compressor **80** passes through the outlet line **122** to a junction **134** at which point the outlet line is divided into a first or ambient air supply line **136** and a second or oxygen enriched air supply line **138**. A conventional flow regulating valve **140** is disposed in the line **136** to regulate the flow of ambient air therethrough, while a conventional flow regulating valve **142** is disposed in the line **138** to regulate the flow of oxygen enriched air therethrough. As is clear from the drawing figure, the air supply line **136** feeds into the high pressure feed air line **22**. As a result, the air supply line **136** is able to supply compressed air to the line **22** and to each of the branch lines **20**. Similarly, the oxygen enriched air supply line **138** feeds into a high pressure feed oxygen enriched air line **144** and any desired number of branch lines **146** associated therewith. Each branch line **146** includes a flow control valve **148**, similar to the valves **18**, to regulate the flow of oxygen enriched air into a compressed oxygen enriched air storage assembly **150** including one or more conventional and appropriately labeled NITROX storage vessels such as removable storage cylinders **152** or a removable NITROX scuba tank **154**. Both assembly **10** and assembly **150** may be located either above water or under water. Applications other than for diving purposes, such as in firefighting, climbing, space or high altitude flight, veterinary, medical and dental treatments, welding, etc., are apparent.

A variety of operations can be performed by the system represented in FIG. **1**. To provide an initial charge or a recharge to an air storage cylinder **12**, or a plurality of such cylinders, or to charge a scuba air tank **14**, the appropriate flow control valve or valves **18** is or are opened. The flow regulating valve **140** is opened while the flow regulating valve **142** is closed. The flow control valve **94** is closed to eliminate the admission or flow of oxygen enriched air into the feed line **102**. The knob **108** is rotated to permit free flow of ambient air through the intake **104** and into the compressor feed line **102**. The motor **110** is turned on to drive the compressor **80** and draw ambient air into the feed line **102**. The air is compressed and then passed through the outlet line **122**, the air supply line **136** and the appropriate branch line or lines **20** and into the appropriate air storage cylinder or cylinders **12** and/or scuba air tank or tanks **14**.

To provide an initial charge, or a recharge, to a NITROX storage cylinder **152**, or a plurality of such cylinders, or to charge a NITROX scuba tank **154**, the flow regulating valve **140** is closed, while the flow regulating valve **142** is opened. If it is provided, then the flow control valve **92** is closed. The flow control valve **94** is opened to permit free flow of oxygen enriched air into the feed line **102**. The knob **108** may be rotated to cause the valve associated therewith to set the flow rate of ambient air through the intake **104** and into the feed line **102** to an initial value. The motor **110** is turned on to drive the compressor **80** and draw a mixture of both ambient and oxygen enriched air into the feed line **102**. The air mixture is compressed and then passed through the outlet line **122**, the oxygen enriched air supply line **138** and one or more of the branch lines **146**. At this point, one or more of the branch lines **146** may be left open. The oxygen concentration of the ambient and compressed oxygen enriched air

mixture passing through the outlet line **122** is detected by the oxygen analyzer **100** and, as a result, may be closely monitored during any oxygen concentration adjustment.

It has been found that various parameters influence the concentration of oxygen in the compressed oxygen enriched air passing through the outlet line **122**. These parameters include, for example, the temperature of the feed air in the supply line **46** mentioned previously, the pressure of the air in the low pressure feed air line **26** and, of course, the rate at which ambient air is admitted into the compressor feed line **102** through the ambient air intake **104**. The concentration of oxygen in the compressed oxygen enriched air passing through the high pressure outlet line **122**, therefore, can be modified to any desired concentration by adjustment of these parameters. Such an adjustment may be made by changing the setting of the pressure regulator knob **24**, the setting of the thermostatic control of the unit **44**, the setting of the air pressure regulation valve knob **108** or the settings of two or more of these elements. For diving applications, typically desired oxygen concentrations are 32% oxygen (NOAA NITROX I) and 36% oxygen (NOAA NITROX II). The parameters obviously could be adjusted so that other concentrations of oxygen in the compressed air passing through the outlet line **122** are provided.

Once a suitable oxygen concentration adjustment of the compressed oxygen enriched air and ambient air mixture in the outlet line **122** has been performed, the appropriate NITROX storage cylinders **152** or NITROX scuba tanks **154** may be connected to the branch lines **146**. The flow control valves **148** may then be operated to admit the oxygen enriched air and ambient air mixture into the NITROX storage cylinders **152** and/or the NITROX scuba tanks **154**. Appropriate pressure regulation is provided by the knob **126** and the pressure gauge **128**.

If a diversion of oxygen enriched air through the optional branch line **90** is desired, then the flow control valve **92** is opened. The oxygen enriched air leaving the separation system **48** through the port **86** is then permitted to pass through the optional branch line **90** so that it may be used in any of a variety of non-diving applications. This oxygen enriched-air is directly breathable. As mentioned previously, the pressure in the feed line **88** is usually quite low (in the 0.5 to 5 p.s.i.g. range) and, as a result, the flow of air through the branch line **90** occurs at a fairly low rate. The flow control valve **94** may be left open so that some of the air passing through the port **86** is also permitted to enter the sampling line **98** and, therefore, pass to the oxygen analyzer **100**. In this manner, the oxygen concentration of the oxygen enriched air exiting through the port **86** and flowing through the branch line **90** can be monitored. Thus, the flow control valve **92** and the flow regulating valves **140** and **142**, together with the other elements used to properly route the oxygen enriched air passing through the port **86**, form means for selectively distributing the oxygen enriched air component for further use.

Variations in the embodiment described above and represented in the drawing figure may occur to these skilled in the art. It is intended to protect any such variations which do not depart from the spirit of this invention by the following claims.

What is claimed is:

1. A process of generating oxygen enriched air for subsequent compression and filling of a diving tank used in underwater respiration by a diver in a diver underwater life support system comprising the steps of:

(a) using a permeable membrane oxygen enriched air and nitrogen gas separation system to effect separation of air into a nitrogen gas component and a directly breathable, oxygen enriched air component;

(b) introducing air at a pressure of 50–600 p.s.i.g. and a predetermined temperature at an inlet of said gas separation system;

(c) withdrawing a nitrogen gas component from a first outlet of the separation system;

(d) withdrawing a directly breathable, oxygen enriched air component at a pressure of at least 0.5 p.s.i.g. from a second outlet of said separation system;

(e) detecting oxygen concentration of said directly breathable, oxygen enriched air component; and

(f) regulating the oxygen concentration of said directly breathable, oxygen enriched air component to a value in a range of from about 30% to about 40% oxygen.

2. The process according to claim **1**, wherein said pressure at which said directly breathable, oxygen enriched air component is withdrawn is 0.5–5 p.s.i.g.

3. The process according to claim **1**, wherein said pressure at which said air is introduced into said inlet is 50–250 p.s.i.g.

4. The process according to claim **1**, wherein said oxygen concentration is regulated to 32% oxygen.

5. The process according to claim **1**, wherein said oxygen concentration is regulated to 36% oxygen.

6. The process according to claim **1**, wherein the regulation of oxygen concentration includes controlling the withdrawal of said nitrogen gas component.

7. The process according to claim **1**, and further comprising the step of compressing the directly breathable, oxygen enriched air component to a high pressure.

8. The process of claim **7** including the further step of storing the compressed directly breathable, oxygen enriched air component.

9. The process according to claim **7**, wherein the oxygen enriched air component is compressed to a pressure no greater than 6000 p.s.i.g.

10. The process according to claim **7**, wherein the oxygen enriched air component is compressed to a pressure no greater than 4000 p.s.i.g.

* * * * *

Exhibit 3

Plaintiff's Complaint for Patent Infringement and Breach of Contract Injunctive Relief and Jury Trial Requested

US005865877A

United States Patent [19]

Delp, II

[11] Patent Number: 5,865,877

[45] Date of Patent: *Feb. 2, 1999

[54] **METHOD AND APPARATUS FOR SUPPLYING A PRESSURIZED DIVER'S BREATHING GAS FOR UNDERWATER DIVERS**

[75] Inventor: **William H. Delp, II**, Lake Worth, Fla.

[73] Assignee: **Undersea Breathing Systems, Inc.**, Lake Worth, Fla.

[*] Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

[21] Appl. No.: **822,140**

[22] Filed: **Mar. 17, 1997**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 518,020, Aug. 22, 1995, Pat. No. 5,611,845.

[51] **Int. Cl.**[6] **B01D 53/22**

[52] **U.S. Cl.** **95/12**; 95/17; 95/18; 95/54; 96/4; 96/8

[58] **Field of Search** 95/8, 12, 14, 23, 95/45, 47, 54, 17, 18; 96/4, 7, 8, 10; 55/270, 274

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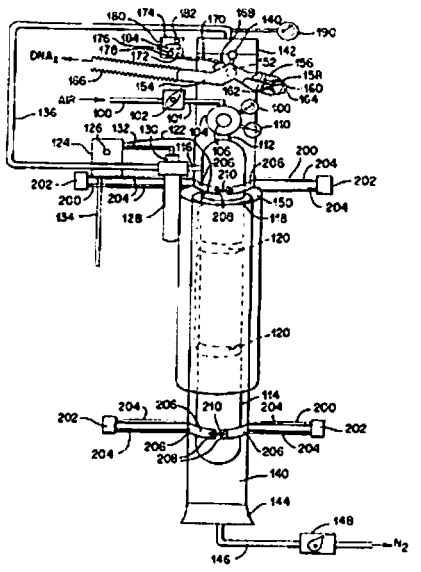
Primary Examiner—Robert Spitzer

Attorney, Agent, or Firm—Evenson, McKeown, Edwards & Lenahan, PLLC

[57] **ABSTRACT**

A system that includes an equipment package for separating nitrogen from air to produce enhanced oxygen air for use by divers. The package is combined with a pressure storage tank for air that is coupled to the package. A pressure storage tank is provided for enhanced oxygen air. A fill station including a high pressure gauge and a high pressure oxygen sensor is provided to fill divers' tanks. A compressor receives the enhanced oxygen air from the package and delivers high or low pressure enhanced oxygen air to the pressure storage tank via a pressure filter. Valving is provided for selectively controlling the flow in the system.

37 Claims, 5 Drawing Sheets



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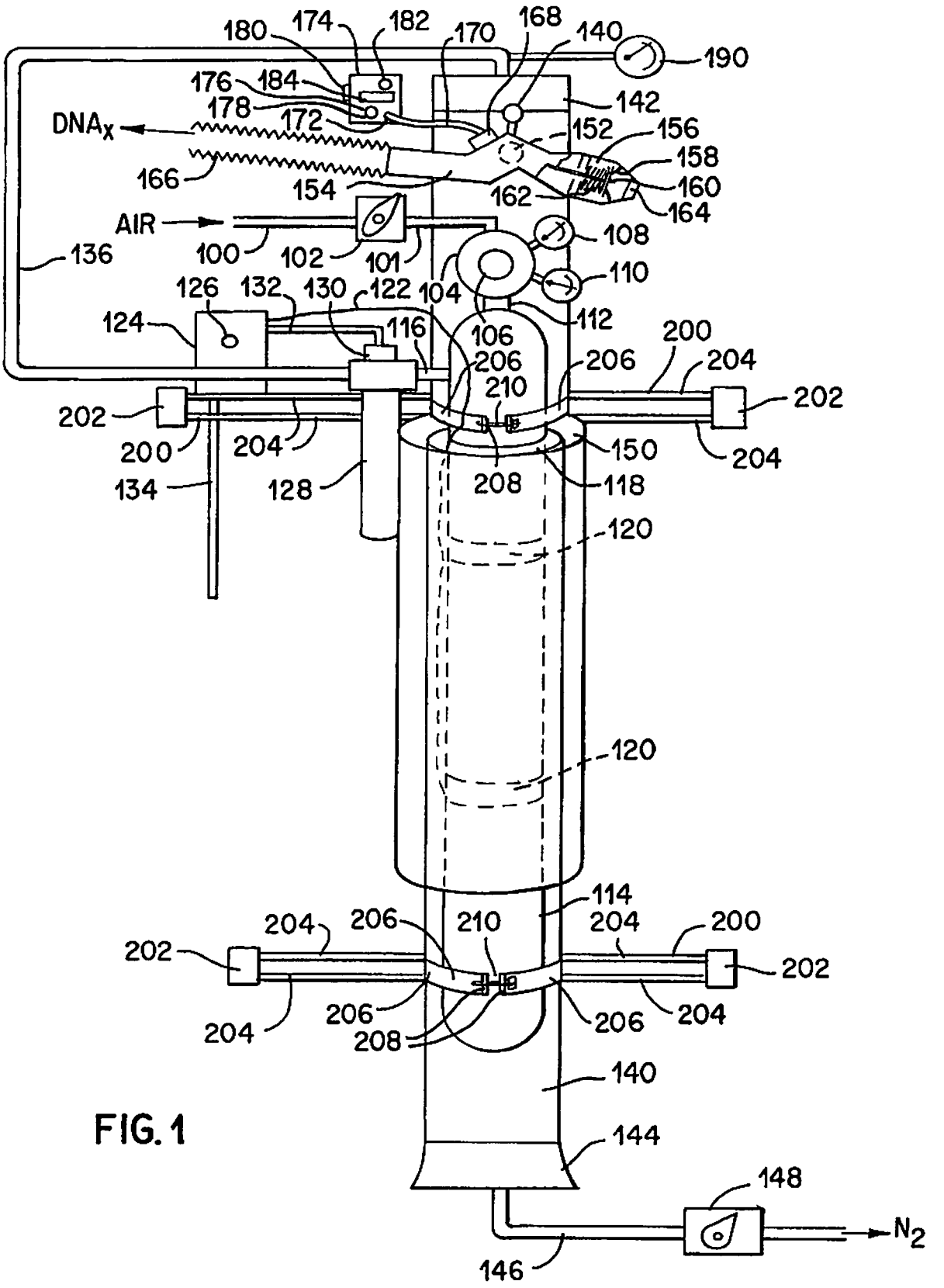

180
174
182
170
168
140
190
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184
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172
DNAx
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152
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158
166
154
162
160
164
AIR
100
102
101
108
136
110
126
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130
122
104
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116
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112
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204
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204
150
134
128
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120
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114
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140
144
148
N2
146

FIG. 1

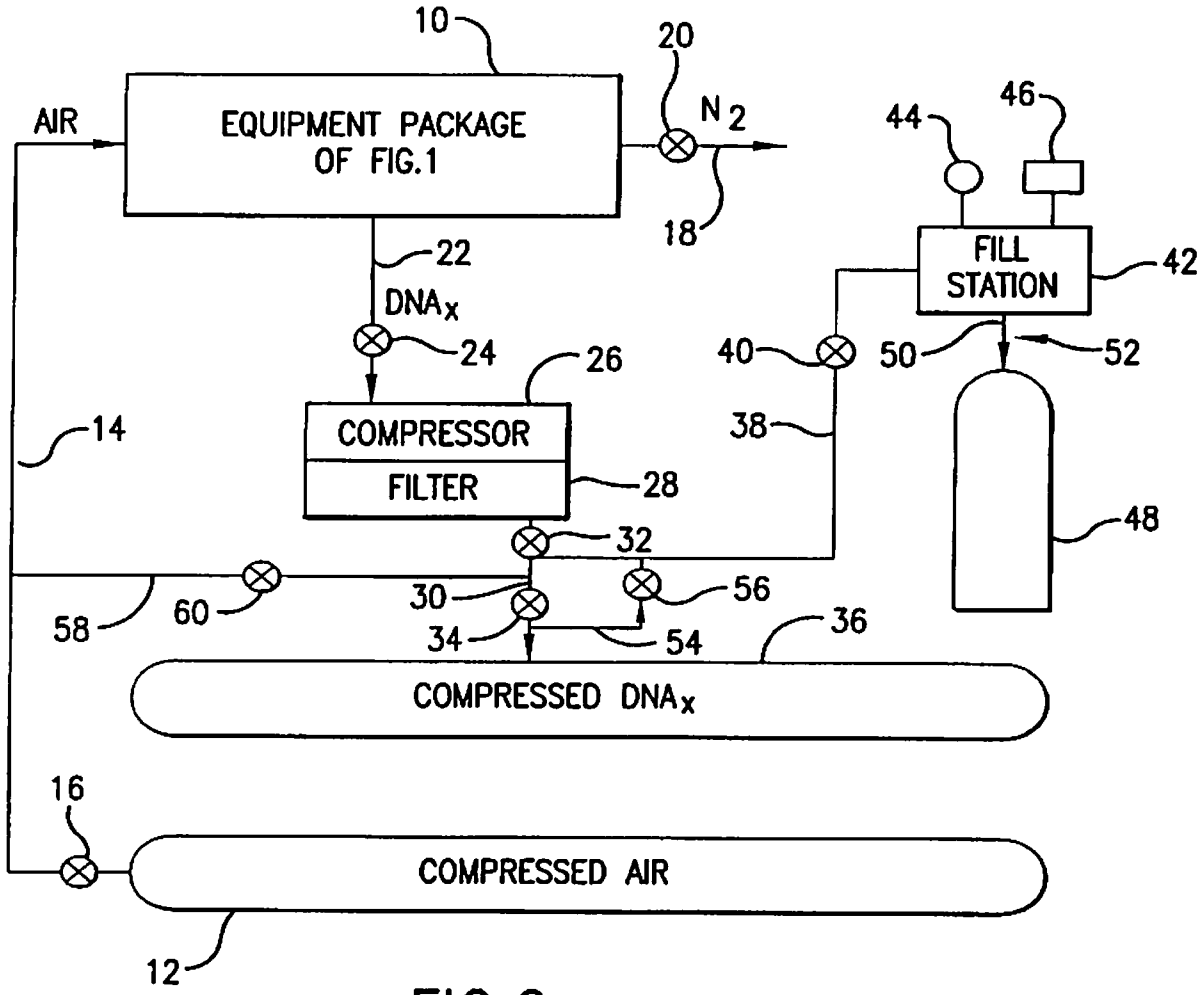

10
20
AIR
EQUIPMENT PACKAGE OF FIG.1
N 2
44
46
18
22
FILL STATION
42
DNAx
24
26
40
50
52
14
COMPRESSOR
38
FILTER
28
48
32
58
60
30
56
34
54
36
COMPRESSED DNAx
16
COMPRESSED AIR
12

FIG.2

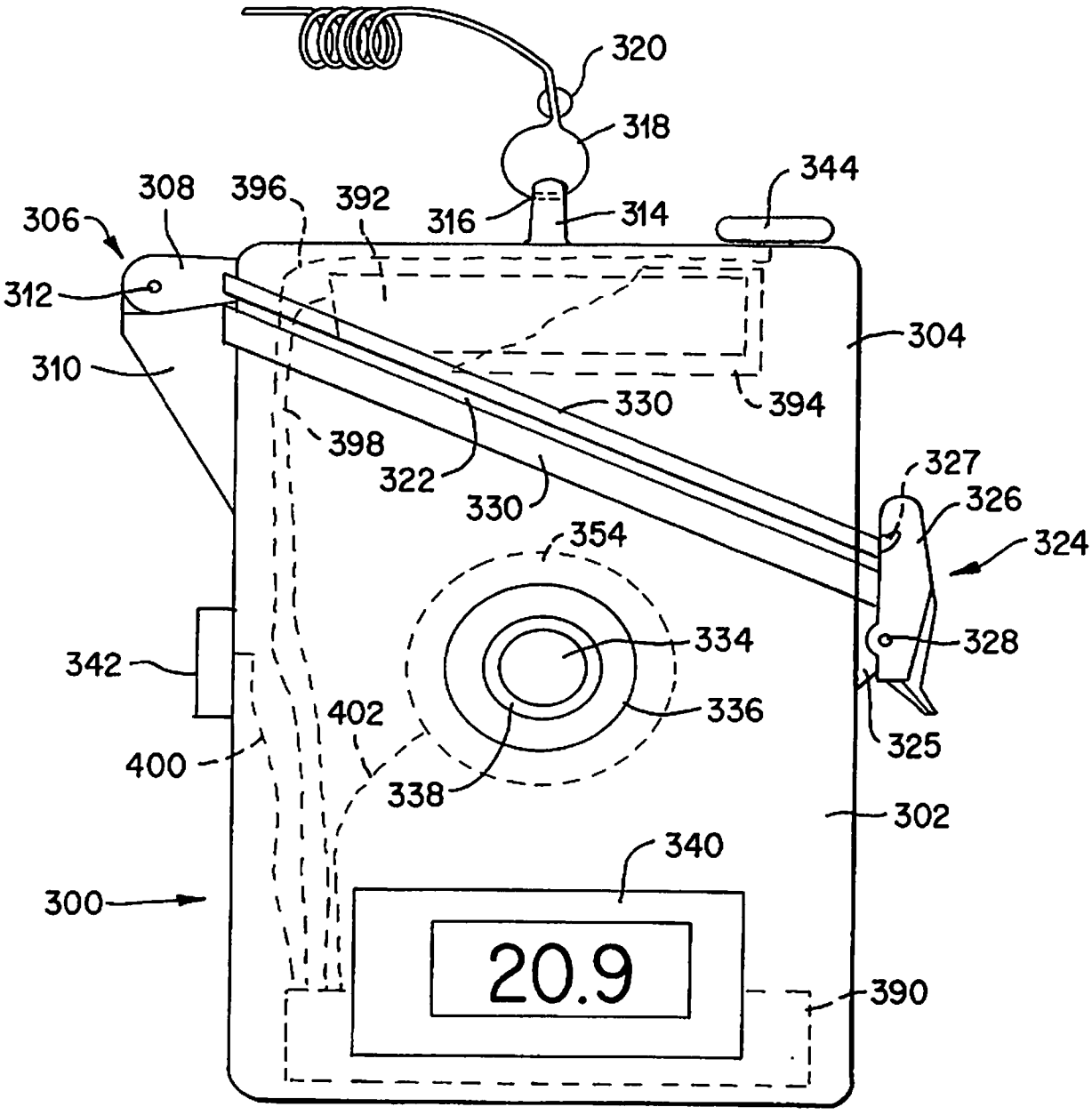

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308
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398
322
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354
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328
342
336
402
325
400
338
302
340
300
20.9
390

FIG. 3

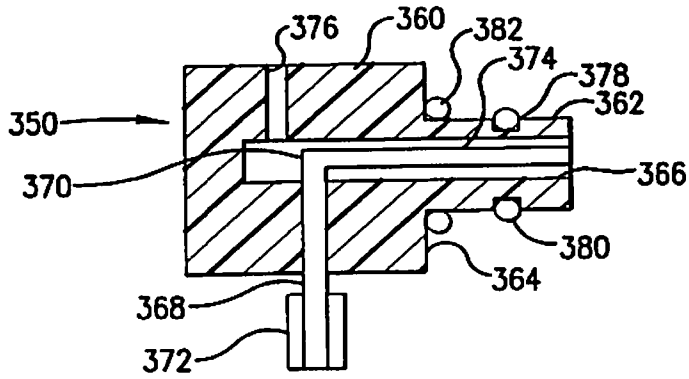

376
360
382
374
378
362
350
370
366
380
364
368
372

FIG.4

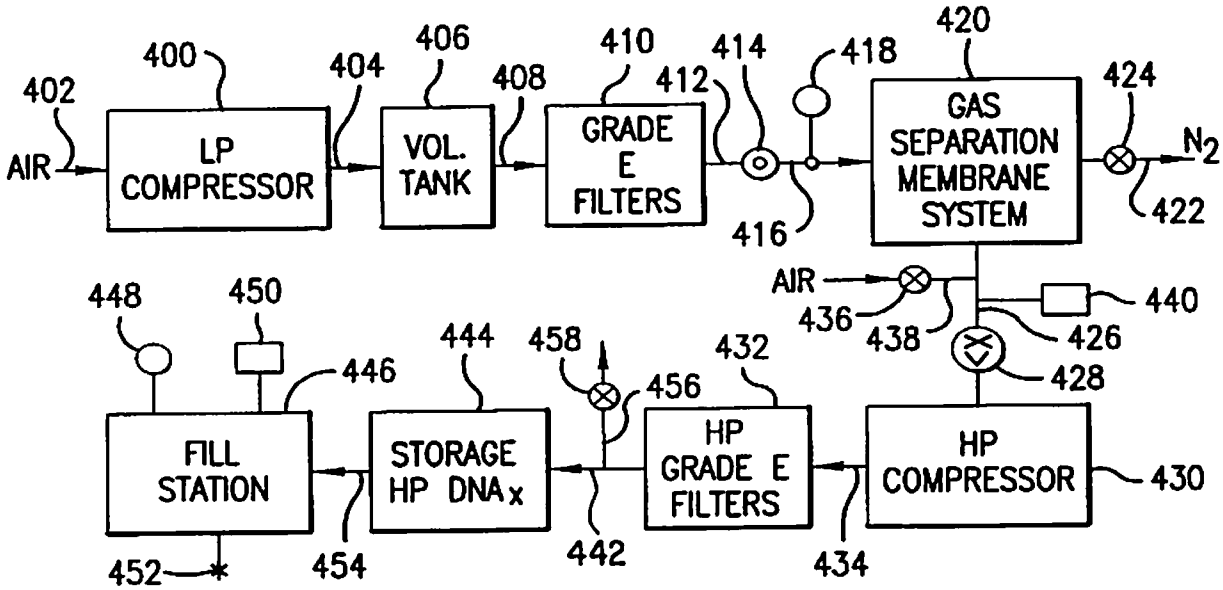

400
402
AIR
LP COMPRESSOR
404
406
VOL. TANK
408
410
GRADE E FILTERS
412
414
416
418
420
GAS SEPARATION MEMBRANE SYSTEM
424
N2
422
AIR
436
438
440
426
428
448
450
446
444
458
456
432
FILL STATION
STORAGE HP DNAx
HP GRADE E FILTERS
HP COMPRESSOR
430
452
454
442
434

FIG.5

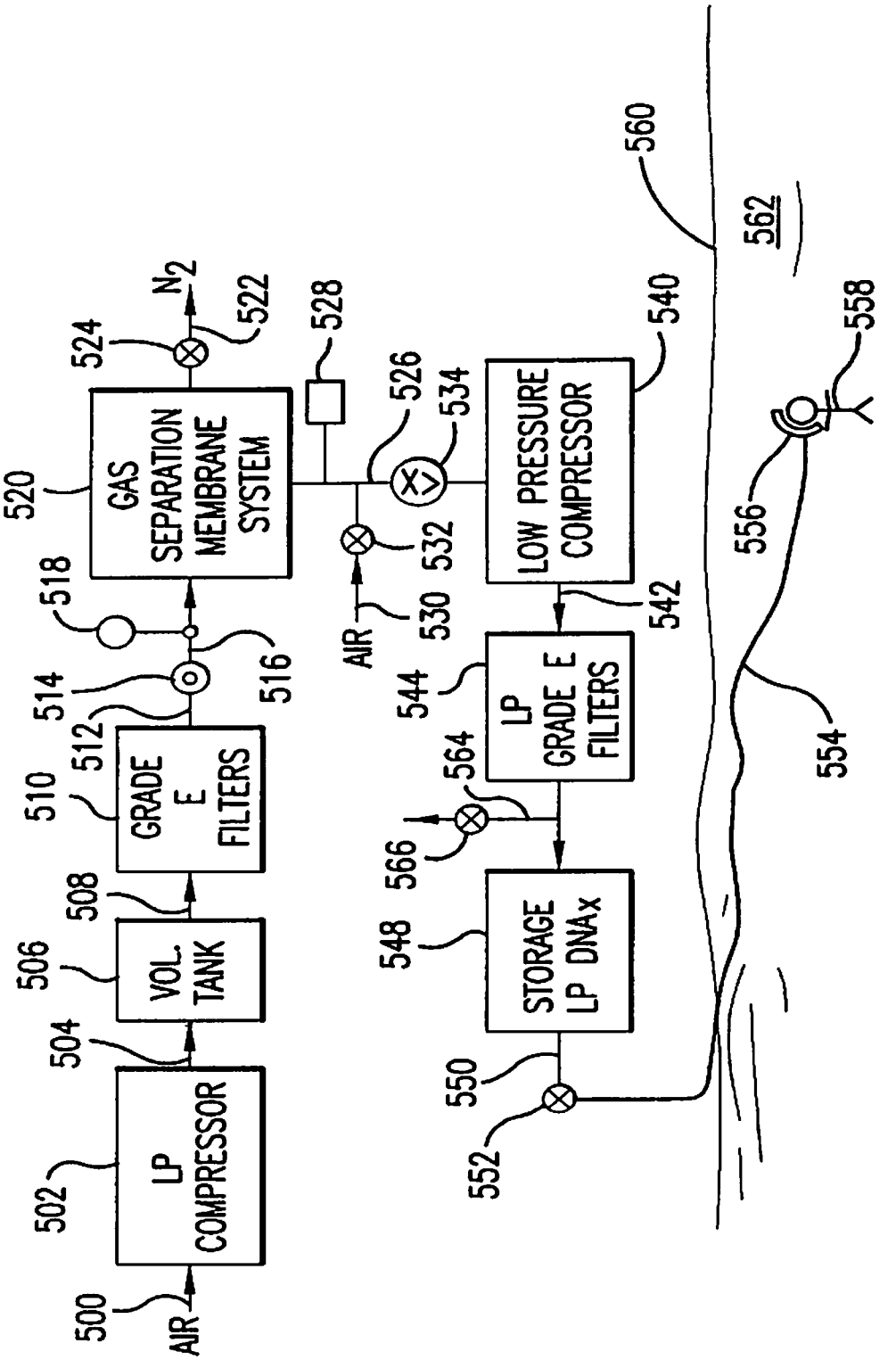

500
AIR
502
LP COMPRESSOR
504
506
VOL. TANK
508
510
GRADE E FILTERS
512
514
516
518
520
GAS SEPARATION MEMBRANE SYSTEM
522
N_2
524
526
528
530
AIR
532
534
540
LOW PRESSURE COMPRESSOR
542
544
LP GRADE E FILTERS
548
STORAGE LP DNAx
550
552
554
556
558
560
562
564
566

FIG.6

METHOD AND APPARATUS FOR SUPPLYING A PRESSURIZED DIVER'S BREATHING GAS FOR UNDERWATER DIVERS

This application is a continuation-in-part of U.S. patent application Ser. No. 08/518,020, filed Aug. 22, 1995, now U.S. Pat. No. 5,611,845.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a novel method and apparatus for life support systems for supplying a pressurized diver's breathing gas for underwater divers and, more particularly, to a subassembly equipment package useable by dive shops, remote sites, diver boats, live aboards and the like for incorporation into the novel apparatus of the present invention whereby an advantageous life support system for supplying diver's breathing gas can be readily produced.

2. Description of Related Art

Techniques for producing a mixture of oxygen enriched air, known in the art as EAN_x (enriched air nitrox), have been known for many years, as well as the advantages of using such enriched air as a diver's breathing gas. However, the life support systems for producing same have utilized the concept of enriching air by adding pure oxygen to it. Such a system is disclosed by U.S. Pat. No. 4,860,803 to Wells, which shows oxygen injected into a stream of ambient air in order to produce an oxygen enriched air mixture. The mixture is compressed and delivered to storage or scuba cylinders for use in diving or other applications. A source of oxygen appropriate for injection into the ambient air stream is needed in this known system and, consequently, not only is a great deal of caution required during generation of the oxygen enriched air mixture to avoid explosions and other problems typically associated with the use of oxygen, but, even more important, such systems require oxygen cleaning which is a drawback.

SUMMARY OF THE INVENTION

Accordingly, it is a principal object of the present invention to provide a method and apparatus for life support systems for supplying or producing a diver's breathing gas, DNA_x, that avoids the problems and drawbacks of the prior art and functions in a more efficacious and versatile manner.

It is a further object of this invention to provide an improved life support system for enhancing the oxygen content of air to generate a pressurized enhanced oxygen air mixture suitable for a diver's breathing purposes, which does not require the use of oxygen supplied from a separate oxygen source. The DNA_x (Denitrogenated Air Nitrox) is produced by an enhancement technique as opposed to an enrichment technique.

It is another object of this invention to provide such a life support system in a convenient equipment package which is easily transportable and can be installed together with other on-site equipment to create the apparatus and method of the present invention in a dive shop, diver's boat, remote site and other such locations.

According to the present invention, these and other objects are accomplished by the provision of a unique equipment package that includes a special permeable membrane gas separation system, such as the one supplied by PERMEA, INC. of St. Louis, Mo. and sold under the trade name PRISM Membrane System. The PERMEA, INC.

PRISM Alpha Membrane System uses thousands of membrane fibers each having an axially through lumen that are bundled into and appropriately sealed in a cylinder. Air is introduced axially into one end of the cylinder and oxygen and a portion of the nitrogen permeate through the fibers and are drawn off through a radial outlet that communicates with the annular space surrounding the fibers. Nitrogen passes axially through the fibers and is discharged axially at the other end of the cylinder. This membrane system is disclosed in U.S. Pat. No. 4,894,068 which is incorporated herein by reference. Other similar membrane systems using bundles of hollow fibers are shown, e.g., in U.S. Pat. No. 5,226,931.

The package also includes an entry conduit for higher pressure air provided with an on-off valve that leads to a thermostatically controlled heat exchanger via a pressure regulator that expands the air with cooling to a lower pressure, i.e., a corresponding drop in temperature and pressure. The discharge of the lower pressure, temperature controlled air of the heat exchanger is passed through a carbon filter, and into one end of the membrane gas separation system cylinder. As noted, nitrogen is discharged from the other end of the cylinder and the discharge is controlled by a manually or automatically controllable needle valve.

The enhanced oxygen air (DNA_x), sometimes referred to herein simply as Nitrox, is discharged radially from the cylinder through a low pressure conduit and monitored by a low pressure oxygen analyzer. This equipment package is connected at the utilization site with a high pressure compressor driven by a suitable prime mover via an overpressure valve set at a predetermined value above the design pressure in the low pressure conduit. The high pressure Nitrox (DNA_x) is filtered in a known CGA Grade E filtration system. The output of the filtration system is distributed by appropriate valving to either a high pressure compressed DNA_x storage cylinder or to a fill station provided with a pressure gauge and a high pressure oxygen analyzer. Also, a high pressure compressed air storage cylinder serving as a supply to the equipment package is, by appropriate valving, also available to the fill station.

As noted, the package includes a pressure regulator for reducing a feed air pressure of from 175–6000 p.s.i.g. to a pressure in a range of 50–400 p.s.i.g. Depending upon the characteristics of the gas separation membrane system, the heat exchanger will adjust the feed air temperature to the design temperature of the membrane by either heating or cooling the feed air after reduction of the high pressure feed air to a low pressure. This pressure reduction selectively produces a cooling effect. The oxygen content of the DNA_x discharged from the package is controllable by adjusting the reduced pressure or temperature of the feed air into the gas separation membrane system. The preferred way, however, is to adjust the rate of discharge of the nitrogen from the membrane system, and, to this end, an adjustable valve, preferably a needle valve, is placed in the nitrogen discharge line. Manipulation of the needle valve controls the nitrogen discharge flow rate, which, in turn, controls the oxygen concentration of the enhanced oxygen air, (DNA_x), passing from the package. The nitrogen flow rate is directly proportional to the oxygen content, i.e., a greater flow rate produces a greater oxygen content at the DNA_x outlet.

In other systems according to the invention, the feed air to the pressure regulator can be obtained from a low pressure compressor, optionally via a volume tank. In this case, the output of the low pressure compressor is feed air at 50–175 p.s.i.g. Also, the DNA_x discharging from the gas membrane separation system can be fed, via a suitable overpressure (relief) valve to a low pressure compressor and then to a

DNA_x storage or volume tank via filters. The output from the DNA_x volume tank can be used directly by an underwater working diver with a full face mask connected by a breathing tube and flow control valve to the DNA_x volume tank.

Other and further objects and advantages of the present invention will become more apparent and evident from the following description of a preferred embodiment and best mode when taken in conjunction with the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view in side elevation showing the novel subassembly equipment package of the invention.

FIG. 2 is a block diagram of a novel embodiment of the method and apparatus according to the present invention.

FIG. 3 is a view in side elevation showing a novel oxygen sensor as used in the equipment package of FIG. 1.

FIG. 4 is a view in axial section of a fitting used with the oxygen sensor of FIG. 3.

FIG. 5 is a block diagram showing another novel embodiment of the method and apparatus according to the present invention.

FIG. 6 is a block diagram showing still another novel embodiment of the method and apparatus according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring initially to FIG. 2, a novel embodiment of the apparatus and method according to the present invention is shown and consists of an equipment package **10** (a subassembly) that receives high pressure, compressed air from compressed air tank **12** via line **14** and valve **16**. Nitrogen is discharged or exhausted from package **10** via line **18** and valve **20**. Nitrox, enhanced oxygen air (DNA_x) is discharged or exhausted from package **10** via line **22** and overpressure valve **24**, and is connected to the inlet of a high pressure compressor **26** driven by a suitable prime mover (not shown). The high pressure compressed DNA_x passes through filter **28** and exhausts through line **30** via valves **32** and **34** to a high pressure compressed DNA_x storage cylinder **36**. Branch line **38** connects line **30** to a DNA_x fill station **42** via valve **40**. Fill station **42** is provided with a high pressure gauge **44** and a high pressure oxygen analyzer **46**. Scuba tanks **48** (only one shown) are filled at the fill station **42** via line **50** and control valve **52**. High pressure DNA_x from storage cylinder **36** can pass to the fill station via line **30**, branch line **54** and valve **56** coupled to branch line **38**. Compressed air from cylinder **12** can pass to the fill station **42** via branch line **58** and valve **60**, if it is desired to fill tanks with compressed air.

Reverting now to FIG. 1, line **14** from tank **12** couples to package **10** via line **100**, which may be simply a continuation of line **14**. An on-off valve **102** is coupled to line **100** to control the flow rate.

The high pressure feed air from tank **12** supplied through the air inlet line **100** is at a pressure of from 175–6000 p.s.i.g. but preferably from 1000 to 4500 p.s.i.g. Line **101** connects valve **102** to a pressure regulator **104** controlled, by operation of a rotatable knob **106**, to adjust or reduce the pressure of the high pressure feed air supplied through the inlet line **100** to a low pressure of from about 50 to about 400 p.s.i.g., but preferably from 100–300 p.s.i.g. which is the preferred range. A first gauge **108** provides a high pressure inlet reading, in p.s.i.g., and a second gauge **110** provides a reduced pressure reading for the low pressure feed air exiting the pressure regulator. The reduction in pressure through valve **104** selectively produces a cooling of the low pressure feed air depending upon the selected pressure drop.

Low pressure cooled feed air exits the pressure regulator **104** and is introduced via tube **112** axially into an elongated copper tube **114** about 2–2½ inches in diameter serving as a heat exchanger. The low pressure air passes axially down the tube **114** which is appropriately baffled to first lead the air down and then up to a radial discharge port near the top of tube **114**, which port is connected with line **116**. Tube **114** is jacketed with insulation **118** throughout most of its length (about 95%) and is provided with resistance heating bands **120** axially spaced on tube **114**. A pair of wires **122** carry electricity to bands **120** from a manually controllable thermostat **124**, controlled by knob **126**. An electric power cord **134** supplies power via thermostat **124** to the resistance heating bands **120**. Alternatively, the heating of the air can be effected by a resistance coil positioned axially in tube **114** with wires **122** connected through the wall of tube **114** in an insulated and gas tight manner. The air is heated to from about 80° F. to about 150° F. and preferably in the range of from about 90° F. to about 125°.

Low pressure air is discharged from tube **114** through line **116** which connects into a carbon filter **128** designed to remove hydrocarbons. A thermocouple **130** is mounted on filter **128** and is exposed to the air passing therethrough. The output of thermocouple **130**, which senses the air temperature, is connected to the thermostat **124**, via leads **132**. The heated low pressure air exhausting or discharging from filter **128** is led by line **136** to the top of a gas separation membrane system in the form of an elongated plastic (PVC) tube **140** having aluminum end caps **142**, **144** at its ends.

The gas separation membrane system shown in FIG. 1 consists of a bundle of hollow fibers contained in the tube **140** and this system is sold by Permea, Inc. under the trade name PRISM Alpha Membrane Separator. The fibers are sealed together at their ends and sealed in the tube **140** spaced slightly from caps **142**, **144**. Entry into the tube **140** of low pressure heated air is axially at one end with discharge of nitrogen being axially at the other end. Since oxygen migrates through the walls of the hollow fibers faster than nitrogen, the oxygen and some nitrogen is collected in the annular space surrounding the hollow fibers. The nitrogen that traverses the hollow fibers collects at the other end. Nitrogen, containing less than about four percent oxygen, passes out of tube **140** through line **146** having a manually or automatically adjustable needle valve **148** interposed therein to control the flow rate. The nitrogen exhausting from line **146** is a waste gas and couples with line **18** of FIG. **2** to lead the nitrogen to a location where it can be dispersed in the ambient without danger to life due to suffocation or oxygen deprivation.

Tube **140** is jacketed with insulation **150** extending coextensive with jacket **118** of tube **114**. A temperature gauge **190** is tapped into line **136** where it connects into the center of cap **142** to provide a visual reading of the temperature of the low pressure heated air as it enters the gas separation membrane system.

The DNA_x that collects in the annular space in tube **140** is withdrawn through radial port **152** defined or formed in the wall of tube **140** and passes into a plastic tube **154**, one end of which contains an enlarged cross section **156** within which is mounted a one-way check valve consisting of valve seat **158**, stemmed valve element **160** and a spring **162**

biasing the element **160** against seat **158** with a force of about 1–3 p.s.i, but preferably 0.5 p.s.i. The end of tube **154** is closed by a porous resilient filter **164**, such as plastic foam, to filter ambient air entering tube **154** against the force of the one-way check valve. The other end of the tube **154** is connected to corrugated tube **166** which couples to or is simply a continuation of line **22** of FIG. **2**. A nipple or projection **168** containing a monitoring orifice is mounted on the tube **154** adjacent to radial port **152**, on its downstream side, that is, toward tube **166**. The orifice is exposed to the interior of tube **154** and, therefore, a small quantity of DNA_x will flow through the orifice. A tube **170** friction fits into projection **168** and couples the downstream side of the orifice and projection **168** to the inlet **172** of a low pressure, temperature compensated, oxygen sensor **174**. Sensor **174** consists of a housing into which a fitting **176** is received in a gas tight fashion which is coupled to tube **170** and provides an exhaust port **178**. Also, mounted on the housing of sensor **174** is an on-off contact switch **180**, a digital display **184**, a calibration knob **182** to "zero" or set the digital display **184** to ambient O_2 conditions, and, within the sensor **174**, an oxygen sensor, a battery, appropriate electronics, as known, and leads connecting all components.

A pair of rails **200** are provided for mounting the components of the package. Rails **200** are U shaped channel sections of extruded aluminum having plastic end caps **202**. The open mouth of the rails **200** faces horizontally and is slightly closed or narrowed by inwardly directed flanges **204**. Clamps, in the form of bent bars **206** of aluminum, are notched to be received in rails **200** and engaged with flanges **204** and extend around tubes **140** and **114**, defining bent flanges **208** that are coupled by nut and bolt assemblies **210**. Thermostat **124** is attached to the top of top rail **200** as viewed in FIG. **1** by a conventional attachment. Tube **146** can be brought to either rail with needle valve **148** being clamped to the rail by a conventional clamping means. Tube **170** is received in projection **168** in a friction fit that provides a substantially gas tight coupling while being removable from projection **168** simply by pulling out. Tube **170** can be reinserted into projection **168** simply by pushing in. The reason for this is that the oxygen sensor **174** is delicate and needs to be handled separately from the remainder of the package when it is being moved about, such as when installed. In the manner described, sensor **174** and tube **170** can be readily decoupled.

The high pressure compressed air in tank **12** is at a pressure of from about 175–1000 as a minimum to about 6000 p.s.i.g. and preferably from about 1000 to about 4500 p.s.i.g. Regulator valve **104** regulates the feed air from high pressure of tank **12** by expanding the high pressure compressed air and dropping the pressure into the low pressure range of from about 50 to about 400 p.s.i.g., and, preferably, from about 100 to about 300 p.s.i.g. When the high pressure is dropped to the low pressure, considerable cooling is effected. Heater **114** adjusts the temperature of the low pressure air to from about 90° F. to about 125° F. This combination of pressure and temperature optimizes the efficiency of the Permea Gas Separation Membrane System, which is the preferred membrane system. The pressure of the DNA_x exiting the port **152** is from about 0.5 to 5 p.s.i.g., the preferred range is from about 1 to about 2.5 p.s.i.g., and the best operating condition is from 1 to 2 p.s.i.g. The monitoring orifice in projection **168** meters the DNA_x at the rate of from about 0.25 liters per minute to about 0.5 liters per minute when the pressure at the exit port **152** is from about 1 to about 2 p.s.i.g. and, to insure control, a pressure gauge **240** is tapped into tube **154** in the immediate vicinity of port **152**. The pressure, temperature and other operating conditions including flow rate of the package are adjustably controlled to achieve the exit pressure at port **152** of from about 1 to about 2 p.s.i.g.

The one-way check valve in tube **154** serves as a safety for the compressor **26** when the package is connected into the system of FIG. **2**. The valve element **160** is biased by spring **162** to open at 0.5 p.s.i.g. to admit ambient air when a negative pressure is in tube **154**. Filter **164** is a porous resilient plastic foam mass and serves to keep out dust, dirt and other foreign matter. When compressor **26** is started and insufficient DNA_x is exhausting through port **152**, and when the pressure in tube **154** is less than ambient by 0.5 p.s.i.g. or more, the one-way check valve will open and admit ambient air to insure a proper compressor loading. The one-way check valve will close when the DNA_x pressure in tube **154** is equal to or greater than ambient pressure (atmospheric).

The output pressure of the compressor **26** is from about 600 p.s.i.g. to about 4500 p.s.i.g. but could be higher depending on the rating of the tank **36** and scuba tank **48**. Also, overpressure valve **24** is set at 0.5–4 p.s.i. above the pressure of the DNA_x in line **22** which is the same as exiting port **152**. The heat setting for valve **24** is 2.8 p.s.i. The enhanced oxygen content of the DNA_x exiting through port **152** is adjustably controlled by changing the operating conditions of the package, i.e., by controlling pressure, temperature and flow rate. The best mode contemplated for controlling oxygen content of the DNA_x is to manually adjust the exhaust flow rate of the nitrogen in line **146** by manually and selectively adjusting the position of needle valve **148** while visually monitoring the digital display of oxygen sensor **174**. There is a slight time delay in the procedure, so adjustment of the needle valve **148** needs to be effected stepwise with small delays to allow the system to equilibrate, i.e., come to equilibrium. The preferred oxygen concentrations in the DNA_x are 32%, 36% and 40% although others may be selected.

Referring now to FIGS. **3** and **4**, a novel low pressure, temperature compensated, oxygen sensor **300** is shown. This sensor is used for sensor **174** in the equipment package of FIG. **1**. As shown, sensor **300** is a box-like structure or housing consisting of a bottom part **302** and a top part **304** joined together by hinge member **306** consisting of a pair of spaced ears **308** attached to top part **304**, a projection **310** attached to the bottom part **302** which fits between the ears **308** and a hinge pin **312** holding the ears **308** and projection **310** together in a relatively rotatable relationship. The joint **322** between the bottom and top parts is on an oblique line extending downwardly from the hinge member **306**. A projection **314** in the form of an ear is attached to the top surface of top part **304** and an endless cord **318** is looped through hole **316** formed in projection **314**. Bead **320** is slidably carried by the cord **318** to adjust the loop in contact with ear **314**.

A clamp member **324**, consisting of mutually engaging hook elements, the outer one **326** of which is pivoted to a support plate **325** mounted on bottom part **302** by a pivot pin **328**, and the inner one being a hook **327** formed on top part **304**, serves to effect closure of top part **304** to bottom part **302**. The joint between the top and bottom parts **304**, **302** is flanged or thickened as indicated by reference numeral **330** and one flange is provided with an endless groove or depression for receiving a gasket or sealing ring. When the parts are pivotally brought together and clamped by clamp member **324**, the gasket is compressed and a substantially liquid tight seal is effected.

A bore 334 is formed through the front wall of bottom part 302 with an annular plug 336 fitted and sealed into bore 334 and having a slightly elevated inner annular rim 338 immediately surrounding the bore 334. A digital display 340, e.g., an LED, is located on the front wall or face of the bottom part 302 below plug 336. A contact on-off switch 342 slightly projects from the side wall of bottom part 302 opposite clamp member 324. A rotatably mounted calibration knob 344 is mounted on the top wall of top part 304.

A feed plug 350 is shown in axial section in FIG. 4, which is received in the bore 334. The function of feed plug 350 is to connect with line 170 of FIG. 1 and to bring the metered DNA_x into the bore 334 where it is contacted with the oxygen sensor 354 mounted in bottom part 302 on the inside of the wall surrounding the bore 334 in a gas tight manner. Plug 350 consists of an outer cylinder 360 of plastic and an integral inner cylinder 362 of plastic having a reduced section so that the cylinders define between them a shoulder 364. An axial bore 366 extends from the free end of cylinder 362 back into cylinder 360 and terminates spaced from the free end of cylinder 360. A metal tube 368 is radially received in cylinder 360 and extends into bore 366 where it is bent 90° at 370 to then be directed axially through the bore to terminate at the free end of cylinder 362. A plastic sleeve 372 is fitted over the radially projecting end of tube 368 to facilitate coupling to tube 170. An annular space 374 is defined between the axial extension of tube 368 and the wall of bore 366. A radial bore 376 in cylinder 360 communicates space 374 with the ambient. The outer peripheral surface of cylinder 362 substantially midway between shoulder 364 and the free end of cylinder 362 defines a peripheral groove 378 extending in a plane normal to the axis of cylinder 362. An O-ring seal 380 is received in groove 378. A second O-ring seal 382, of smaller diameter, is received on the periphery of cylinder 362 and sits at the junction of shoulder 364.

The plug 350 is received in the bore 334 with cylinder 362 projecting into bore 334 and with the free end of cylinder 362 lying in close proximity with oxygen sensor 354. DNA_x metered into tube 170 passes into metal tube 368 and is exhausted from the other end of tube 368 at the free end of cylinder 362 in close proximity to oxygen sensor 354. DNA_x leaving tube 368 eventually passes back through annular space 374 and bore 376 to be exhausted to the ambient. Cylinder 362 force fits into bore 334 and O-ring 380 bears against the wall of annular plug 336 defining bore 334 to effect a gas tight seal. O-ring 382 bears against raised rim 338 to reinforce the gas tight seal.

The electronics of the oxygen sensor are contained on a board 390 mounted in the lower region of the inside wall of the bottom part 302. A power supply in the form of a battery 392 is wedged on opposite sides by foam plastic pieces 394 into the inside of the top part 304. Electric leads 396, 398, 400 and 402 connect calibration knob 344, battery 392, on-off contact switch 342 and temperature compensated oxygen sensor 354, respectively, to the circuit board 390. The electronics of the circuit board 390 are known in the art.

The life support embodiment shown in FIG. 5 consists of a low pressure compressor 400 receiving ambient air as an inlet via line 402. The output from compressor 400 (from about 50–about 175 p.s.i.g.) is directed by line 404 to volume tank 406, line 408 to grade E filters 410 and by line 412 to pressure regulator valve 414 which reduces the pressure to >50 to <175 p.s.i.g. with some cooling. The cooled expanded feed air passes by line 416 to gas separation membrane system 420 as previously described. A temperature gauge 418 monitors and displays the temperature. The nitrogen discharge from system 420 passes via line 422 in which manually or automatically controllable needle valve 424 is interposed.

The DNA_x discharged from membrane system 420 passes by line 426 through an overpressure valve 428 to a high pressure compressor 430. The output of compressor 430, compressed air at from about 600–4500 or greater p.s.i.g. passes to high pressure, grade E filters 432 via line 434. A low pressure oxygen sensor 440 monitors line 426. Ambient air can be drawn into line 426 through a check valve 436 via line 438 as previously described. The output of filters 432 is fed by line 442 to storage tank 444 for storing high pressure DNA_x. A fill station 446 provided with a temperature gauge 448, a high pressure oxygen sensor 450 and a fill valve 452 is connected to tank 444 by line 454. Branch line 456 with on-off valve 458 provides a bypass to tank 444, e.g., if it is desired to go directly to fill station 446 or provide other utilization of the high pressure DNA_x.

The life support embodiment of FIG. 6 consists of an ambient air line 500 input to low pressure compressor 502 which outputs via line 504 to volume tank 506, line 508, grade E filters 510 and line 512 to pressure regulator 514. Line 516 with temperature gauge 518 leads to membrane system 520. Nitrogen discharge is via line 522 and needle valve 524. DNA_x discharge is via line 526 which is monitored by low pressure oxygen sensor 528 and into which line 530 connects to allow ambient air to be drawn in via check valve 532. An overpressure valve 534 is interposed in line 526. To this point the components and parameters are the same as described in FIG. 5.

A low pressure compressor 540 receives the output of line 526 and outputs a compressed DNA_x having a pressure from about 50–about 175 p.s.i.g. which passes via line 542 to low pressure grade E filters 544 and line 546 and then to storage tank 548 for low pressure DNA_x. Line 550 connects tank 548 through a flow regulator 552 with a flexible breathing tube 554 leading to a full face mask 556 on a diver 558 working or swimming under the surface 560 of a body of water 562. Bypass branch line 564 connects to line 546 and has a control valve 566 interposed therein.

Although the foregoing description has been with reference to a vertical orientation for the equipment package illustrated in FIG. 1, the orientation can be horizontal or at any angle. Also, the gas separation membrane systems of the type used by the method and apparatus of the invention, namely, a bundle of hollow fibers, operate within the temperature ranges stated in the foregoing except in one case. In this case, the operating temperature ranges from about 35° F. to about 50° F. When this membrane system is used in the invention, the heat exchanger of the equipment package will cool or heat as necessary to adjust the low pressure feed air to the appropriate operating temperature for the membrane system.

Although the invention has been described herein by reference to a preferred embodiment, nevertheless, changes and modifications are possible as will be evident to those skilled in this art. Such changes and modifications which do not depart from the spirit, scope and teachings are deemed to fall within the purview of the appended claims.

I claim:

1. A process for supplying enhanced oxygen air for use by divers as a life support system comprising the steps of:

(a) providing a supply of pressurized feed air;

(b) reducing the pressure of said pressurized feed air, with cooling, to 50–400 p.s.i.g.;

(c) modifying the temperature of the reduced pressure feed air to a preselected value resulting in temperature modified, reduced pressure feed air;

(d) separating nitrogen from said temperature modified, reduced pressure feed air by a permeable membrane gas separation system using a bundle of hollow fibers resulting in enhanced oxygen air;

(e) discharging the nitrogen from the separation system;

(f) discharging the enhanced oxygen air from the separation system;

(g) controlling the oxygen content of the discharged enhanced oxygen air by varying the flow rate of the nitrogen discharge;

(h) compressing the discharged enhanced oxygen air to a preselected pressure; and

(i) storing the compressed enhanced oxygen air as breathable air useable underwater.

2. A process as defined by claim 1, wherein said preselected temperature value is in one of a range of from about 35° F. to about 50° F. and a range of from about 80° F. to about 150° F.

3. A process as defined by claim 1, further comprising the step of adjusting the rate at which the nitrogen is discharged in order to modify the oxygen content of said enhanced oxygen air to a preselected value.

4. A process as defined by claim 1, further comprising the step of removing hydrocarbon impurities from said feed air before separating nitrogen from said feed air.

5. A process for supplying enhanced oxygen air for use by divers as a life support system comprising the steps of:

(a) providing a supply of high pressure feed air having a pressure in the range of from about 175 to about 6000 p.s.i.g.;

(b) reducing the pressure of said high pressure feed air, with cooling, to 50–400 p.s.i.g.;

(c) modifying the temperature of the reduced pressure feed air to a preselected value resulting in temperature modified, reduced pressure feed air;

(d) separating nitrogen from said temperature modified, reduced pressure feed air by a permeable membrane gas separation system using a bundle of hollow fibers resulting in enhanced oxygen air;

(e) discharging the nitrogen at a controllable flow rate;

(f) discharging the enhanced oxygen air from the separation system;

(g) compressing the discharged enhanced oxygen air to a high pressure of from about 600 p.s.i.g. to above 4500 p.s.i.g.; and

(h) storing the compressed enhanced oxygen air as breathable air useable underwater.

6. A process as defined by claim 5, wherein said preselected temperature value is in a range of from about 80° F. to about 150° F.

7. A process as defined by claim 5, further comprising the step of adjusting the rate at which the nitrogen is discharged in order to modify the oxygen concentration of said enhanced oxygen air to a preselected value.

8. A process as defined in claim 5 further comprising the step of removing hydrocarbon impurities from said feed air before the nitrogen separation.

9. A process for supplying enhanced oxygen air for use by divers as a life support system comprising the steps of:

(a) providing a supply of pressurized feed air at a pressure of from about 50–175 p.s.i.g.;

(b) reducing the pressure of said pressurized feed air, with cooling, to 50–less than 175 p.s.i.g.;

(c) monitoring the temperature of the reduced pressure feed air;

(d) separating nitrogen from said reduced pressure feed air by a permeable membrane gas separation system using a bundle of hollow fibers resulting in enhanced oxygen air;

(e) discharging the nitrogen at a controllable flow rate;

(f) discharging the enhanced oxygen air from the separation system;

(g) compressing the discharged enhanced oxygen air to a pressure of from about 50 to greater than 4500 p.s.i.g.; and

(h) storing the compressed enhanced oxygen air as breathable air useable underwater.

10. A process as defined by claim 9, wherein step (g) compresses said enhanced oxygen air in a range of from about 50 p.s.i.g. to about 175 p.s.i.g.

11. A process as defined by claim 9, wherein step (g) compresses the enhanced oxygen air from about 600 to about 4500 p.s.i.g.

12. A process as defined by claim 9, further comprising the step of adjusting the rate at which the nitrogen is discharged in order to modify the oxygen concentration of said enhanced oxygen air to a preselected value.

13. A process as defined in claim 9, wherein the feed air is filtered before and after step (g).

14. A process for supplying enhanced oxygen air for use by divers as a life support system comprising the steps of:

(a) providing a supply of pressurized feed air;

(b) reducing the pressure of the feed air, with cooling, to 50–400 p.s.i.g.;

(c) monitoring the temperature of the reduced pressure feed air;

(d) separating nitrogen from said temperature modified, reduced pressure feed air by a permeable membrane gas separation system using a bundle of hollow fibers resulting in enhanced oxygen air;

(e) discharging the nitrogen at a controllable flow rate;

(f) discharging the enhanced oxygen air from the separation system;

(g) compressing the discharged enhanced oxygen air to a pressure of from about 50 to about 175 p.s.i.g.; and

(h) feeding the compressed enhanced oxygen air as an underwater breathable air life support system to a diver located underwater via a conduit, flow control valve and face mask.

15. A process as defined by claim 14, wherein said feed air is filtered before and after step (g).

16. A process as defined by claim 14, further comprising the step of adjusting the rate at which the nitrogen is discharged in order to modify the oxygen concentration of said enhanced oxygen air to a preselected value.

17. A subassembly package for use in generating enhanced oxygen air, particularly, for underwater use by divers as a life support system comprising:

a pressure regulator for reducing with cooling a pressurized feed air to a lower predetermined value;

a heat exchanger for modifying the cooled reduced pressure feed air to a predetermined temperature;

a hollow fiber permeable membrane gas separation system for separating nitrogen from the modified feed air to thereby enhance the oxygen content of the feed air;

an adjustable valve which varies the discharge rate of the separated nitrogen from the package to vary in response the oxygen content of the enhanced oxygen air;

a discharge member for receiving the discharge of the enhanced oxygen air from the separation system; and

a low pressure oxygen sensor for monitoring the oxygen content of the enhanced oxygen air in the discharge member.

18. A package as defined by claim 17, wherein the heat exchanger is electrically heated to heat the feed air temperature to the predetermined temperature.

19. A package as defined by claim 17, wherein the heat exchanger cools the feed air.

20. A package as defined by claim 17, further comprising a one-way check valve connected to said discharge member for introducing ambient air.

21. A package as defined by claim 17, further comprising a thermostat for monitoring the feed air temperature and controlling the heat exchanger.

22. A package as defined by claim 21, wherein the thermostat is manually adjustable for monitoring and adjusting said feed air temperature.

23. A package as defined by claim 17, wherein the oxygen sensor includes a digital display.

24. A package as defined by claim 17, wherein a metering device is provided to meter a portion of the separated enhanced oxygen air to the oxygen sensor.

25. A package as defined by claim 24, wherein said metering device is constructed to meter enhanced oxygen air at a rate of from about 0.25 liters/min. to about 0.5 liters/min.

26. A package as defined by claim 17, wherein the heat exchanger and membrane gas separation system are comounted on a pair of spaced rails.

27. A package as defined by claim 17, wherein the temperature of said feed air is modified to a temperature in one of a range of from about 35° F. to about 50° F. and a range of from about 80° F. to about 150° F.

28. A package as defined in claim 27, wherein said feed air is heated to a temperature of from about 90° F. to about 125° F.

29. A package as defined by claim 17, wherein the separated and discharged enhanced oxygen air is maintained at a pressure of from about 0.5 p.s.i.g. to about 5 p.s.i.g.

30. A package as defined by claim 29, wherein the discharged enhanced oxygen air is maintained at a pressure of from about 1 to about 2 p.s.i.g.

31. A life support system for a diver while underwater comprising the package according to claim 17, combined with a pressure storage tank for compressed air coupled to said package, a pressure storage tank for enhanced oxygen air, a fill station including a high pressure gauge and a high pressure oxygen sensor, a pressure filter, a compressor for receiving enhanced oxygen air from said package and delivering pressurized enhanced oxygen air to the pressure storage tank for enhanced oxygen air via said pressure filter, and valving for selectively controlling the flow in the system.

32. A system as defined in claim 31, wherein a low pressure compressor supplies air to the pressure storage tank for compressed air.

33. A system as defined in claim 31, wherein the compressor is a high pressure compressor having an output from about 600 to above 4500 p.s.i.g.

34. A system as defined in claim 31, wherein the compressor is a low pressure compressor having an output from about 50 to about 175 p.s.i.g.

35. A system as defined in claim 31, wherein a second pressure filter is interposed between the pressure storage tank and said package.

36. A system as defined in claim 31, wherein a fill station including a high pressure gauge and a high pressure oxygen sensor is coupled to the pressure storage tank for enhanced oxygen air.

37. A system as defined in claim 31, wherein a conduit is coupled at one end to the pressure storage tank for enhanced oxygen air, a diver's face mask is coupled to the other end of the conduit, and a flow control is interposed in the conduit.

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