# United States Patent [19]

**Rein**

[11] **3,831,594**

[45] **Aug. 27, 1974**


[54] **LIFE SUPPORT SYSTEM**


[75] Inventor: **Charles R. Rein,** Panama City, Fla.

[73] Assignee: **The United States of America as represented by the Secretary of the Navy,** Washington, D.C.



[22] Filed: **Mar. 5, 1973**

[21] Appl. No.: **337,782**

[52] **U.S. Cl.** ..... **128/142,** 62/48, 62/50, 128/203, 165/46

[51] **Int. Cl.** ..... **A62b 7/06**

[58] **Field of Search** ..... 128/142, 142.2, 203; 62/50, 52, 48; 165/46



[56] **References Cited**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 3,366,107 | 1/1968 | Frantom | 128/142.2 |
| 3,370,585 | 2/1968 | O'Neill | 128/142.2 |
| 3,450,127 | 6/1969 | Harwood, Jr. | 165/46 X |
| 3,556,205 | 1/1971 | Harwood, Jr. | 165/46 |
| 3,570,481 | 3/1971 | Woodberry, Jr. | 128/142.2 |
| 3,572,048 | 3/1971 | Murphy | 62/52 |
| 3,707,078 | 12/1972 | Cramer | 62/50 |
| 3,710,553 | 1/1973 | Parker et al. | 128/142.2 X |
| 3,714,942 | 2/1973 | Fischel et al. | 128/203 X |

OTHER PUBLICATIONS

Design News, Vol. 15, July 21, 1969, p. 14.



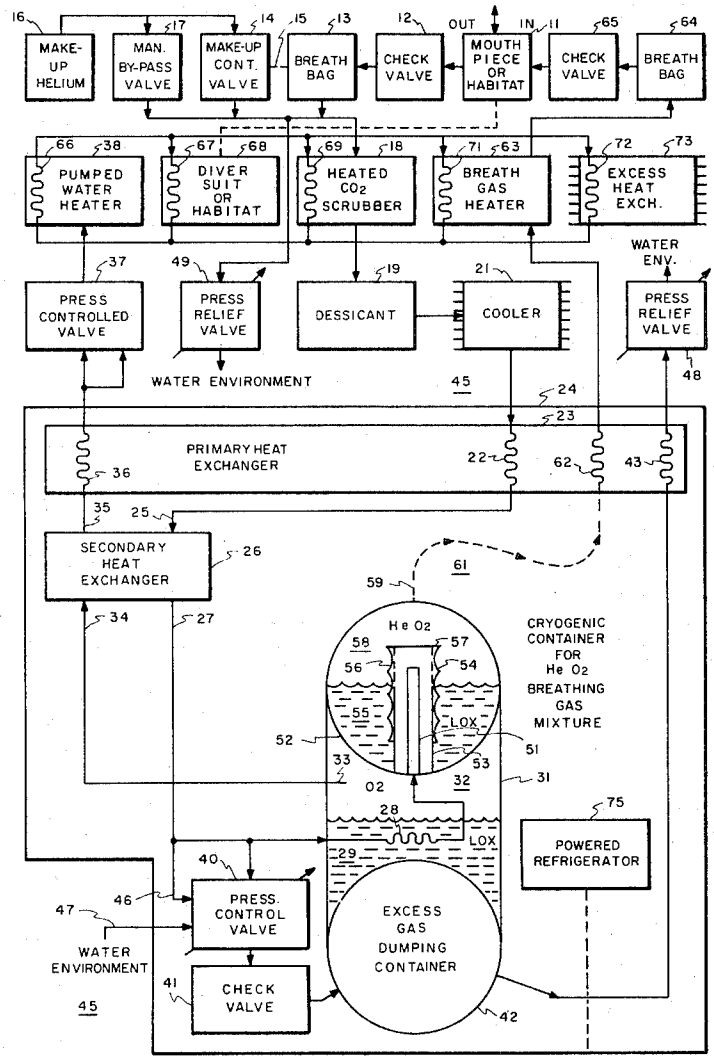
*Primary Examiner*—Kyle L. Howell
*Attorney, Agent, or Firm*—Richard S. Sciascia; Don D. Doty; Harvey A. David

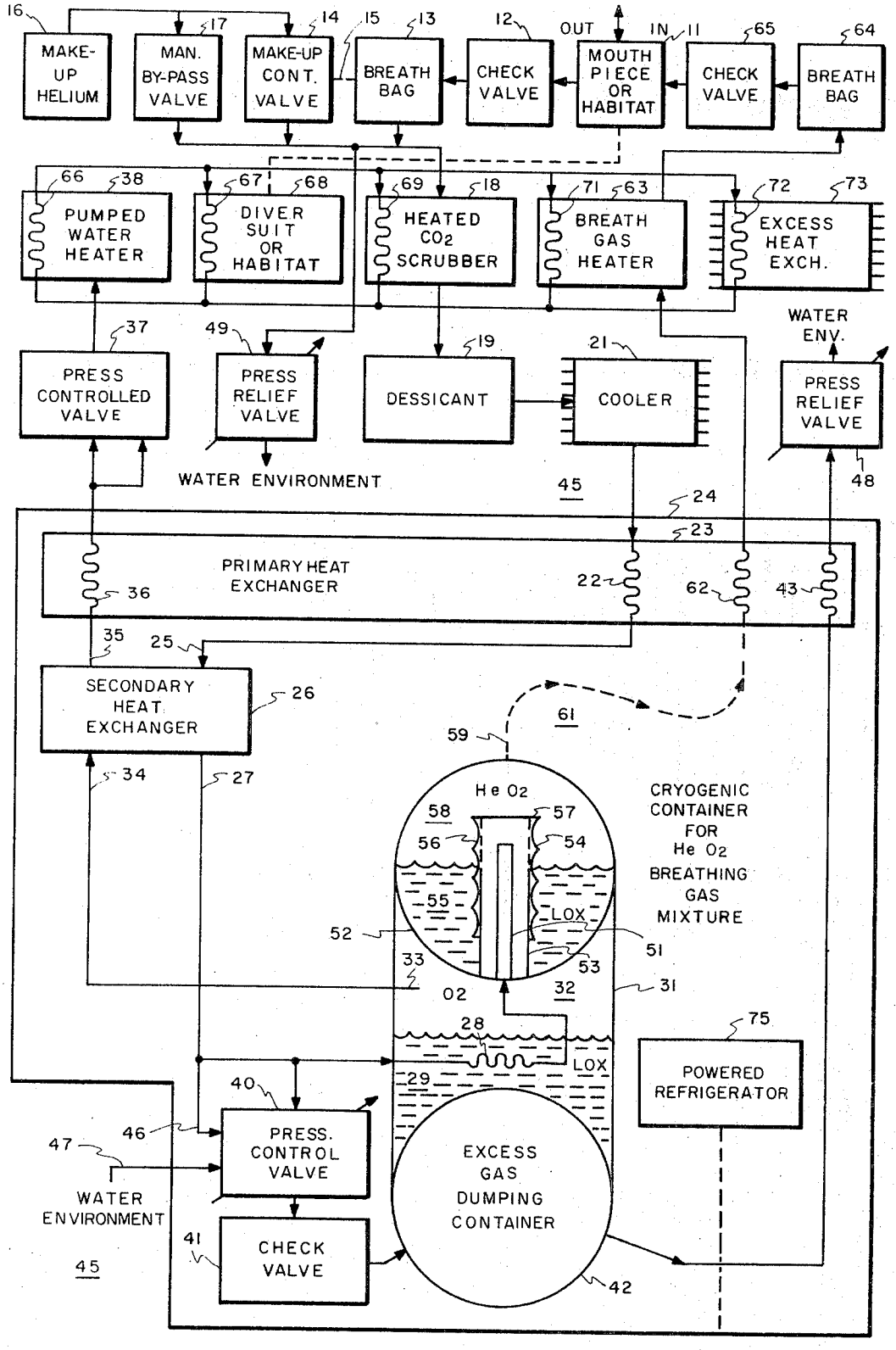


[57] **ABSTRACT**

A closed cycle $HeO_2$ cryogenic underwater life support system is disclosed as including a breathing gas rejuvenation process, wherein helium gas is added thereto to maintain proper breathing gas pressures at various and sundry water depths, carbon dioxide and water are removed therefrom, and life-sustaining oxygen gas is added thereto from liquid oxygen cooled to cryogenic temperatures by means of a cryogenic chamber and refrigeration apparatus. Controlled heating equipment is also disclosed for the purpose of maintaining proper temperatures in said breathing gas rejuvenation process, as well as in a diver's suit. Excess non-rejuvenated gas is stored in a gas dumping container located within the cryogenic chamber, but may be vented to the ambient water environment should said gas dumping chamber become full.


**16 Claims, 1 Drawing Figure**




MAKE-UP HELIUM
MAN. BY-PASS VALVE
MAKE-UP CONT. VALVE
BREATH BAG
CHECK VALVE
MOUTH PIECE OR HABITAT
CHECK VALVE
BREATH BAG
OUT
IN
PUMPED WATER HEATER
DIVER SUIT OR HABITAT
HEATED $CO_2$ SCRUBBER
BREATH GAS HEATER
EXCESS HEAT EXCH.
PRESS CONTROLLED VALVE
PRESS RELIEF VALVE
DESSICANT
COOLER
PRESS RELIEF VALVE
WATER ENV.
WATER ENVIRONMENT
PRIMARY HEAT EXCHANGER
SECONDARY HEAT EXCHANGER
He O2
LOX
CRYOGENIC CONTAINER FOR He O2 BREATHING GAS MIXTURE
O2
POWERED REFRIGERATOR
PRESS. CONTROL VALVE
WATER ENVIRONMENT
CHECK VALVE
EXCESS GAS DUMPING CONTAINER
45
61
16
17
14
15
13
12
11
65
64
66
38
67
68
69
18
71
63
72
73
37
49
19
21
48
24
23
36
22
62
43
35
25
26
34
27
59
58
57
56
54
55
52
51
53
33
32
31
28
29
75
40
46
47
41
42

# LIFE SUPPORT SYSTEM

## STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

1. Field of the Invention

The present invention relates, in general, to life support systems which provide an atmosphere of breathable gas within an environment which would otherwise be too hostile for humans and other air breathing mammals to live and perform useful functions for any reasonable period of time. In particular, it is a closed cycle cryogenic system for producing and supplying a breathable gas mixture to human swimmers and divers operating under water and also to various and sundry compatible under sea habitats.

2. Description of the Prior Art

Heretofore, numerous life support systems have been available to scuba divers and underwater habitats. Ordinarily, pressurized tanks of oxygen and other gases are carried by the diver and selected mixtures thereof are breathed thereby. Although satisfactory for some purposes - usually those associated with water sports - a great deal is to be desired if the diver wishes to keep his presence at some subaqueous location a secret. This is true because most scuba systems release the diver's exhaled breath to the ambient water, thereby causing visible bubbles to betray his presence. Moreover, all known prior art deep diving scuba systems require that part of the gaseous breathing mixtures be vented to the ambient water on momentary ascent - a procedure which also betrays the presence of the diver.

## SUMMARY OF THE INVENTION

The instant invention overcomes many of the disadvantages, either directly or indirectly, associated with the prior art, in that it consists of a plurality of interacting subsystems which not only prevent the betrayal of the location of the diver but also enable him to operate at relatively great water depths with a minimum of discomfort, considerably more of which would otherwise be encountered due to his having to breathe underwater at said depths, and due to his exposure to the low temperatures located thereat. In other words, it is a new and unique life support system which facilitates the diver's working efficiently and safely at considerable water depths in a covert manner.

Therefore, it is an object of this invention to provide an improved life support system for swimmers, divers, underwater habitats, and the like.

Another object of this invention is to provide an improved helium-oxygen gaseous mixture suitable for breathing by humans or other air breathing beings at great water depths for long periods of time.

Still another object of this invention is to provide a new and unique closed cycle, long-lived, cryogenic life support system adapted for being used in hostile ambient environmental mediums, such as, for example, in water, sea water, space, contaminated atmospheres, and the like.

A further object of this invention is to provide a method and means which enables a diver to work safely, efficiently, and comfortably at great water depths without betraying his presence.



Still another object of this invention is to provide an improved method and means for producing and maintaining predetermined breathable mixtures of helium and oxygen at various and sundry environmental locations useful to man and other air breathing mammals.

A further object of this invention is to provide an improved method amd means for producing and maintaining predetermined mixtures of certain inert or other gases with oxygen at useful environmental locations.

Another object of this invention is to extend the time and water depth at which a free diver may operate over those provided by the known prior art, thereby enabling him to work and otherwise perform useful functions for, say, as long as 6 hours and of water depths of approximately 1,000 feet.

Still another object of this invention is to provide a method and means for controlling the partial pressure of oxygen as a result of regulating the temperature of liquid oxygen (LOX).

Another object of this invention is to provide a new and unique apparatus combination for supplying heated, $CO_2$ scrubbed, breathable helium-oxygen gaseous mixtures to heated diver suits, habitats, and the like without electronic controls being required.

Still another object of this invention is to provide an improved closed cycle cryogenic scuba system which permits the breathing gas processing loop thereof to remain at the pressure of the ambient water environment on the momentary ascent of a diver located therein without release of gas thereto.

Other objects and many of the attendant advantages will be readily appreciated as the subject invention becomes better understood by reference to the following detailed description, when considered in conjunction with the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. **1**, the sole FIGURE in this case, illustrates in combined block diagram and mechanical schematic form the closed cycle cryogenic life support system constituting the invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

At the outset, it should perhaps be reiterated for the purposes of clarity and simplicity of disclosure that the preferred embodiment of the invention about to be described is depicted in such manner that the various and sundry conventional components thereof are indicated by blocks with legends, and that the lines respectively drawn therebetween represent pipes which allow the passage of gases or other fluids therethrough.

Referring now to FIG. **1**, the life support system constituting this invention is shown as containing a conduit means or mouth piece **11** of the type used by an underwater swimmer or diver for the purpose of inhaling life-sustaining gas therefrom and exhaling $CO_2$ and $H_2O$ contaminated breath thereto.

Although the instant embodiment of the subject invention is primarily intended for people actually swimming and diving under water, it should be understood at the outset that its use is not limited thereto and, thus, it may be combined with other suitable habitats, chambers, or the like, for the purpose of supplying life-supporting or other gaseous mixtures thereto. Of

course, said mouth piece **11** and many of the components combined therewith would have to be designed for the particular purpose intended and for making it compatible with any other equipment associated therewith, if it is to operate in an optimum manner. However, so doing would be well within the purview of one skilled in the art having the benefit of the teachings presented herewith.

The downstream, exhaled breath output of conduit or mouth piece **11** is connected to the input of a one-way check valve **12,** the output of which is connected to the downstream input of a resilient, flexible exhale breathing bag **13.** A helium or other suitable diluent gas make-up valve **14** is mechanically connected in this particular embodiment in such manner that when bag **13** changes in configuration due to collapsing a lever or other mechanical linkage **15** is adjusted in position, thereby causing control valve **14** to open and allow helium or said other suitable diluent gas to pass therethrough. Of course, said helium gas is supplied to control valve **14** because the output of a pressurized make-up helium container **16** is connected to the input thereof.

A manually operated by-pass valve **17** is connected between the output of make-up helium container **16** and the interconnected outputs of control valve **14** and breathing bag **13.** As a result of such connections, it may readily be seen that the outputs of breathing bag **13,** make-up control valve **14,** and by-pass valve **17** are all connected to the input of a heated carbon dioxide ($CO_2$) scrubber **18.** The gas output of heated $CO_2$ scrubber **18** is connected to the input of a container of dessicant **19** (such as, for instance, silica gel or a molecular sieve), the output of which is connected to the input of a gas cooler **21,** the latter of which is in heat exchange contact with the ambient environmental medium.

The output of cooler **21** is connected to a "giving-up heat" or cooled passage **22** of a primary heat exchanger **23** located within a cryogenic container **24** but effectively insulated therefrom.

At this time, it might be well to note that any suitable cryogenic container or chamber may be employed as cryogenic container **24.** Moreover, any appropriate conventional means may be employed to cool container **24** to cryogenic temperatures. For example, entire cryogenic chamber **24** may, immediately prior to being used in the subject life support system, be inserted in a suitable chest-type cryogenic refrigerator for cooling purposes. Then, when it has cooled to the proper temperature internally, it is withdrawn from said refrigerator chest and used as intended. On the other hand, if so desired, a cooling coil may be inserted within chamber **24** and supplied with liquid nitrogen or some other cooling fluid from an external source until chamber **24** has cooled to the proper cryogenic temperature. Once such temperature is reached, the external cooling fluid source is manually disconnected from said cooling coil - and, hence, from container **24,** as well - and then cryogenic chamber **24** is used in its normal manner in the subject system.

Obviously, as will be mentioned again subsequently, many well known, conventional refrigeration systems (including those mentioned above) could be readily adapted to this invention for cryogenic cooling purposes by the artisan, so it will not be belabored any further at this time.

The output of cooled passage **22** of primary heat exchanger **23** is connected to a cooled input **25** of a secondary heat exchanger **26,** the cooled output **27** of which is connected to another cooling heat exchanger, such as coil **28,** disposed within a pool of liquid oxygen **29** located within a container **31** in such a manner as to fill it sufficiently to cover said cooling coil **28** but not so full as to prevent a chamber of oxygen gas ($O_2$) **32** from existing above the surface of liquid oxygen **29.** Of course, said oxygen gas **32** occurs as a result of the "boiling" off the surface of the aforesaid liquid oxygen **29** within container **31.**

Extending as a pressure sensing element within the oxygen gas filled portion **32** of chamber **31,** is an open-ended pipe **33,** the other end of which is connected to a warmed input **34** of secondary heat exchanger **26.** The output **35** thereof is connected to the input of a warmed or heated passage **36** located within primary heat exchanger **24,** with the output thereof connected through a water heater pressure controlled valve **37** to the fuel combustion chamber of a powered pump type water heater **38.**

As may readily be seen, pressure controlled valve **37** senses the pressure within the oxygen gas supplied to it and, therefore, it has a pressure sensor connection therewith for such purpose. In addition, pressure controlled valve **37** may optionally be of the type which may be manually adjusted, so that the pressure in supply line **35,** which causes it to open, is proportional to said manual adjustment. As a result of such $O_2$ pressure control procedures being effected by pressure controlled valve **37,** the heat produced by water heater **38** is proportional to the amount of oxygen which is boiled off from LOX supply **29.** This, of course, is proportional to the heat transferred to LOX supply **29.** And the more $O_2$ supplied to the heater, the more heater fuel that is burned and, hence, the more heat that is produced thereby.

In order to prevent the necessity of exhausting gaseous products of combustion from water heater **38** to the ambient water environment, a suitable conventional fuel that prevents the production thereof should be used in heater **38.** For example, such fuels as magnesium and phosphorus may be used for such purpose, since they both form a solid product of combustion when burned with oxygen gas.

Output **27** of secondary heat exchanger **26** is also connected through a pressure controlled valve **40** to the input of a check valve **41.** The output of check valve **41** is connected to an excess gas dumping container **42,** the output of which is connected to the input of another "take-up heat" or heated passage **43** located in primary heat exchanger **23.** Pressure controlled valve **40** is of the automatic control type which can be set for controlling at some given pressure difference between the gas from secondary heat exchanger outlet **27** and the ambient environmental medium - in this case, water **45.** In order to sense such pressure differential, sensors **46** and **47** are connected as shown to pressure controlled valve **40.**

The output of coil **43** is connected to the input of a pressure relief valve **48** which may be set to exhaust to the water environment **45** whenever the pressure in container **42** exceeds its design pressure.

Another pressure relief valve **49** is connected to the output of the aforesaid breathing bag **13** for venting the gas thereat to water environment **45,** in the event its

pressure exceeds that of the ambient water by a predetermined amount. Optionally, pressure relief valve **49** could be put elsewhere in the breathing gas loop.

The output of the aforementioned cooling coil **28** disposed in liquid oxygen **29** in container **31** is connected to the input of a stand pipe **51** extending from the bottom of a container **52.** Surrounding standpipe **51** is another standpipe **53** having a plurality of holes or apertures **54** in the wall thereof at or near the upper end thereof. A predetermined amount of liquid oxygen (LOX) **55** is disposed in container **52** in such a manner as to partially fill it and also partially extend around the lower, non-apertured portion of standpipe **53.** A wick **56** having a closed end **57** is securely hung around the outside of standpipe **53** in such manner as to completely cover apertures **54** and extend down into liquid oxygen **55.** Above the surface of liquid oxygen **55** but within chamber **52** is a volume of helium and oxygen mixture **58** constituting $HeO_2$ breathing gas.

The output of the compartment of chamber **52** containing said $HeO_2$ gas is open by means of a predetermined vent pipe **59** to the entire inner chamber **61** of cryogenic container **24,** and said inner chamber **61** is also in communication with the input of the "taking-up heat" or breathing gas heat exchanger passage **62** located in the aforesaid primary heat exchanger **24.**

At this time, it would perhaps be noteworthy that excess gas dumping container **42** and chamber **52** are separated by but connected to chamber **31.** Also, it should be noted that all three thereof are very cold for several reasons: (**1**) chambers **31** and **52** contain liquid oxygen, a very cold substance; (**2**) all three, being connected together in a heat conductive manner, tend to act as heat sinks, respectively, and thus reach a temperature equilibrium near the temperature of liquid oxygen; and (**3**) all three are located within cryogenic container **24,** itself a very cold chamber. Because excess gas dumping container **42** is very cold, it will hold considerably more excess gas than it would if it were at ambient water temperature. This will prevent the necessity of venting excess breathing gas to the ambient water every time the diver ascends for some reason or another until the pressure in container **42** equals the ambient water pressure. This, in turn, allows the diver to operate covertly under water, if he so desires.

The output of coil heat exchanger passage **62** is connected to the input of a breathing gas heater **63,** the breathing gas output of which is connected to the input of a resilient, inflatable inhaling breathing bag **64.** The output of breathing bag **64** is connected through check valve **65** to the upstream input of the aforesaid mouth piece **11** for supplying breathable $HeO_2$ thereto and via the out-in portion thereof to the diver (not shown).

As may readily be seen, the portion of the subject invention discussed so far constitutes the closed breathing gas loop and several pressure and temperature controls therefor. In addition, there is an equipment heating loop, of which the aforesaid water heater **38** is a part. This heating loop is, of course, a closed loop of several components of the invention, some of which are directly connected thereto and some of which are indirectly associated therewith.

Water heater **38** contains a heated water passage **86** (including, for example, a battery powered pump for pumping heated water therethrough and to other heated units of the invention) which is connected in parallel by passage **67** of diver suit (or habitat) **68,** passage **69** of $CO_2$ scrubber **18,** passage **71** of breathing gas heater **63,** and passage **72** of an excess heat exchanger **73,** the latter of which is disposed for transferring excess heat to ambient water environment **45,** like the aforesaid cooler **21.**

Of course, as previously suggested, depending on the circumstances involved and the nature of the environmental medium concerned, any other appropriate container, housing, unit, device, habitat, or the like, may be substituted for diver unit **68** for any given operational purposes or added on to the hot water loop.

In the event a habitat is substituted for mouth piece **11,** it may, if desired, be substituted for diver suit **68,** too, and thus be heated by the hot water from pumped water heater **38.** To show such habitat in its proper relationship with its associated components, a dashed line is shown interconnecting elements **11** and **68.**

Numerous possible alternate arrangements may be made in the instantly disclosed invention by the informed artisan without violating the spirit or scope thereof. For instance, any or all fluids enroute to the cryogenic section may be put in thermal contact with any or all fluids being removed from the cryogenic section. The primary and secondary heat exchangers may be combined into one heat exchanger. Sometimes, depending on operational conditions, the breathing gas cooler can be eliminated or combined with or placed upstream of the dessicant canister. Furthermore, the evaporation rate of the heater LOX may be held above a set minimum value by installing an additional controlled heat leak to the cryogenic section. The heat applied to the $CO_2$ scrubber could be recovered from the breathing gas flowing out of it by gas flowing to the breathing gas heater or to the mouth piece. Although the system of the disclosed preferred embodiment assumes that $CO_2$ and water are to be removed by conventional heated or unheated scrubbers, said $CO_2$ and water could be solidified in a heat exchanger or somewhere in the cryogenic section. Although the use of pumps in one or both of the fluid circulation loops is probably desirable, with the power therefor being electrical, pumping could be effected manually or by a simple heat engine operated by the excess heat or by other means. A breathing gas regenerator could be substituted for the breathing gas heater, if so desired. Control of the volume of the breathing gas could be effected by the motion of a bellows or other pumping device in the breathing gas loop, as well as by the pressure difference between the breathing gas and the water. And, moreover, in operations where heat is not required, the cryogenic coolant could be a substance which evaporates or melts to take up heat. The heating apparatus would then be eliminated from the subject system, but bubbleless performance would still be possible.

Obviously, one skilled in the art having the benefit of the teachings presented herewith could make the aforementioned system and perhaps other design choices and changes which would result in any other preferred embodiment of the invention warranted by operational and environmental circumstances.

Because container **24** is a cryogenic container for the $HeO_2$ breathing gas mixture and the other apparatus shown in FIG. **1,** it becomes necessary to cool it to and maintain it at cryogenic temperatures. Several conventional procedures and devices, as previously suggested, may be used for such purpose. For example, cryogenic container **24** may be put into a refrigerated chest and

cooled to the desired temperature just before it is to be used by a diver. Of course, under any circumstances, the walls of container **24** must be exceedingly good insulators, in order to prevent an inordinant amount of deleterious heat transfer from occurring between the outside ambient environmental medium and the inside thereof. For some practical applications, a Dewar might be used as container **24**; on the other hand, for many other practical applications, it would be preferable for container **24** to have its own refrigerator equipment, so that it would be self-contained, so to speak. Accordingly, by way of example and without any limitation intended, a powered refrigerator **75** - the power supply of which may be either internal or external - is depicted as being mounted within cryogenic container **24** for the purpose of cooling it to and essentially maintaining it at cryogenic temperatures.

If so desired, pressure, temperature, and other parameters may be monitored at various and sundry locations within the subject system. For such purpose, test points may be optionally incorporated anywhere therein by the artisan. In addition, appropriately disposed fill lines may be included as necessary to replace all of the fluids in the system.

## MODE OF OPERATION

The operation of the invention will now be discussed briefly in conjunction with the sole FIGURE of the drawing.

As previously indicated, the invention is primarily intended for supporting life within deep water and to do it in such manner that gas does not have to be vented to the ambient water, even during momentary ascension, and provides, as an additional benefit, thermal protection for divers in cold waters.

Referring now to FIG. **1**, it may be seen that the subject system comprises several interactive, either directly or indirectly, gas flow piping loops or circuits. Beginning with mouth piece **11** of the first loop or subsystem which, of course, is partially inserted in the mouth of a diver (not shown), an in-out member is symbolically disclosed in connection therewith as means for receiving the diver's exhaled breath and supplying the diver's inhaled breath, respectively. When, for example, the diver has exhaled into mouth piece **11**, it passes through one-way check valve **12** into breathing bag **13**, thereby expanding it. Of course, the diver's exhaled breath does not travel to breathing bag **64** because it is stopped by one-way check valve **65**. With each exhaled breath, bag **13** expands somewhat, and with each inhaled breath bag **13** collapses somewhat. Normal breathing should keep bag **13** filled some minimum amount at all times; however, if due to descent of the diver or for some other reason the inflation of bag **13** is not maintained at said minimum level, the physical position thereof becomes such that lever **15** is moved, thereby opening up make-up valve **14** sufficiently to allow some helium from pressurized make-up helium container **16** to pass therethrough and into the exhaled gas exit line of breathing bag **13**.

At this time, it may be noteworthy that, in the event make-up valve **14** does not work properly, the diver could manually open by-pass valve **17** and produce the same result, namely, supply more helium to the output line of bag **13**.

The exhaled breath of a diver, of course, contains an excess quantity of carbon dioxide ($CO_2$) gas as well as water vapor ($H_2O$) and a reduced amount of oxygen ($O_2$) gas, for further life support purposes. Hence, the exhaled breathing gas is scrubbed to remove said $CO_2$ in heated scrubber **18**, after which it is passed through dessicant canister **19** to remove the moisture therefrom. After removal of the moisture therefrom, the exhaled gas is cooled to the temperature of the ambient water by natural convection cooler **21**; however, if desired, in some cases, the exhaled gas may be cooled before it is dried in the dessicant. Next, the exhaled gas is cooled to cryogenic temperatures by passing successively through primary heat exchanger **24**, secondary heat exchanger **26**, and cooling coil **28** located in liquid oxygen (LOX) **29**. After being so cooled, the exhaled gas passes up through standpipe **51**, through standpipe holes **54**, and through oxygen saturated wick **56**, where it, too, becomes saturated with oxygen in $HeO_2$ chamber **58** above the surface of LOX **55**.

At wick **56**, the exhaled gas again attains the proper partial pressure of $O_2$ for life support at a diver, so from here on, it will be known as the inhalable gas, although several other operations are still to be performed on it.

From chamber **58**, the inhalable gas passes through cryogenic container **24**, through heater coil **62** of primary heat exchanger **23**, gas heater **63**, expandable breathing bag **64**, and check valve **65** before being returned to mouth piece **11**. Of course, breathing bag **64**, like downstream breathing bag **13**, is desirable at the disclosed position upstream of mouth piece **11**.

As suggested in brief above, a gas flow subsystem is employed for supplying helium gas to the downstream exhaled gas whenever bag **13** is too collapsed, as a result of loss of gas volume in the aforementioned first loop. In spite of variations in pressure, the actual volume of the breathing gas must be held approximately constant, so when, for example, the diver descends to a greater water depth, helium from make-up helium container **16** flows into loop one, the breathing gas loop, to maintain the actual breathing gas volume, thereby allowing the diver to fill his lungs with each breath. It would appear to be especially noteworthy at this time, that the helium is injected into the downstream or exhale region of the breathing gas, so that helium make-up occurs without significant change in the partial pressure of oxygen in the inhaled gas.

The third subsystem performs the gas volume regulation during the ascent of the diver, thereby preventing venting of gas to the water. On ascent, the breathing gas is vented to excess gas dumping container **42** where it is stored at the same temperature as LOX **29**. Storage of said gas at such temperature, as previously implied, permits storage of gas in approximately one third the volume that otherwise would be necessary if the gas were stored at ambient temperature.

Actual regulation of the aforesaid excess brathing gas during ascent is effected by pressure controlled valve **41**. If the gas pressure of effluent **27** of secondary heat exchanger **26** becomes significantly greater than that of ambient water environment **45**, sensors **46** and **47** sense the pressure difference therebetween and open valve **41**, thereby venting some of the exhaled breathing gas into container **42**, rather than sending it on through cooling coil **28** in container **31**. As a general rule, to facilitate such gas dumping, excess gas dumping container **42** should be evacuated at the beginning of the dive.

When the breathing gaseous mixture is vented to the excess gas dumping container, there is no corresponding counter flow through the primary and secondary heat exchangers, and, thus, an increase in the boil-off rate of water heater temperature control LOX **29** must occur. The evaporated oxygen gas is not released to the water, however, but, instead, flows through the fourth flow subsystem to water heater **38,** where it reacts with the heater fuel. Since said heater fuel is magnesium, phosphorus, or other appropriate fuel which does not produce gaseous products of combustion when combined with oxygen, no material discharge from water heater **38** to ambient water environment **45** is necessary. Of course, as a result of no discharge occurring from heater **38,** the excess heat produced thereby must be transferred to water **45** by excess heat exchanger **73.** The net result of such procedure, then, is that the diver's ascent causes heat to be given off to water **45** instead of gas bubbles. Of course, this is a welcome trade for any diver who desires to avoid detection.

The fifth loop or subsystem is a liquid loop that carries the heat produced by water heater **38** to diver suit **68** and breathing gas heater **63.** Also, as indicated, $CO_2$ scrubber **18** may be heated in such manner that it will provide optimum scrubbing operations. Excess heat exchanger **73** is, of course, necessary in order to transfer excess heat to ambient water **45** whenever heater LOX **29** boil-off rate causes heater **38** to produce more heat than the other heated components require. If so desired, said components which require heat may also incorporate their own individual internal thermostats. The pressure of heater LOX **29** is effectively regulated at the entrance side of heater **38** by pressure controller **37.** If the pressure in water heater LOX chamber **31** is so controlled, the temperature of LOX **29** and the rest of the cryogenic section will also be properly controlled, Thus, the partial pressure of $O_2$ in the breathing gas is properly controlled, thereby effecting an optimum $HeO_2$ gaseous mixture for diver breathing purposes, regardless of the water depth at which he is working.

From the foregoing, it may readily be seen that exceedingly worthwhile results are produced by the new and unique life support system constituting this invention, and that the above mentioned objectives thereof are fully met thereby.

Obviously, other embodiments and modifications of the subject invention will readily come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing description and the drawing. It is, therefore, to be understood that this invention is not to be limited thereto and that said modifications and embodiments are intended to be included within the scope of the appended claims.

What is claimed is:

**1.** A system for supporting life in a predetermined environment, comprising in combination:

respiratory means having a unitary input-output for receiving the exhaled breath of and for supplying a predetermined breathable, life-sustaining, gaseous mixture to an ordinarily air-breathing being, a downstream exhaled breath output, and an upstream inhalable gas input;

a first check valve, adapted for free downstream flow, connected to the downstream exhaled breath output of said respiratory means;

a first resilient, inflatable breathing bag having an input and an output, with the input thereof connected to the output of said first check valve;

means connected to the output of said first resilient, inflatable breathing bag for removing carbon dioxide gas from the exhaled gaseous breath passing therethrough;

means connected to the output of said carbon dioxide gas removing means for removing the moisture from the exhaled gaseous breath passing therethrough;

means connected to the output of said moisture removing means for cooling the exhaled gaseous breath passing therethrough to the temperature of said predetermined environment;

means effectively connected to the output of said carbon dioxide gas removing means for adding a predetermined quantity of gaseous oxygen to the exhaled gaseous breath passing therethrough at a predetermined partial pressure from a reservoir of liquid oxygen disposed within a cryogenic container;

means connected to the output of said gaseous oxygen adding means for warming the gaseous breath to which said gaseous oxygen was added to a temperature which facilitates the breathing thereof by said ordinarily air-breathing being;

a second resilient, inflatable, breathing bag having an input and an output, with the input thereof connected to the output of said oxygen-added gaseous breath warming means;

a second check valve, adapted for allowing free downstream flow, connected between the output of said second resilient, inflatable bag and the upstream inhalable gas input of said respiratory means;

a container of pressurized predetermined make-up breathable gas;

a make-up control valve, adapted for being opened in proportional response to predetermined inflation conditions of said first breathing bag, connected between the output of said predetermined make-up breathable gas container and the input of the aforesaid carbon dioxide gas removing means; and

a manually operable by-pass valve connected in parallel with said make-up control valve.

**2.** The system of claim **1,** wherein said respiratory means comprises a diver's mouthpiece.

**3.** The system of claim **1,** wherein said respiratory means comprises a habitat for air-breathing beings disposed within said predetermined environment.

**4.** The invention of claim **1,** further characterized by:

a controllable water heater having a pump incorporated therein in such manner as to pump heated water out the output thereof;

a diver suit connected to and downstream of said controllable water heater in such manner as to be heated a predetermined amount by the pumped heated water therefrom;

means connected to and downstream of said water heater for heating said carbon dioxide removing means a predetermined amount by the pumped heated water therefrom;

means connected to and downstream of said water heater and pump for supplying a predetermined

amount of heated water to said gaseous oxygen-added breath warming means for effecting the proper warming thereof; and

an excess heat exchanger connected to and downstream of said water heater and pump for transferring excess heat in the pumped heated water to said predetermined environment.

**5.** The invention of claim **1**, further characterized by:

a controllable water heater having a pump incorporated therein in such manner as to pump heated water and the output thereof;

habitat means which enables human beings and other air-breathing mammals to live and perform useful functions in an otherwise unlivable environment connected to and downstream of said controllable water heater in such manner as to be heated a predetermined amount by the pumped heated water therefrom;

means connected to and downstream of said water heater and pump for heating said carbon dioxide removing means a predetermined amount by the pumped heated water therefrom;

means connected to and downstream of said water heater and pump for supplying a predetermined amount of heated water to said gaseous oxygen-added breath warming means for effecting the proper warming thereof; and

an excess heat exchanger connected to and downstream of said water heater and pump for transferring excess heat in the pumped heated water to said predetermined environment.

**6.** The system of claim **1**, wherein said means connected to the output of said carbon dioxide removing means for removing the moisture from the exhaled gaseous breath passing therethrough comprises a canister of dessicant.

**7.** The system of claim **6** wherein the dessicant of said canister of dessicant comprises silica gel.

**8.** The system of claim **1**, wherein said means effectively connected to the downstream exhaled breath output of said respiratory means for removing carbon dioxide gas from the exhaled gaseous breath passing therethrough comprises a heatable carbon dioxide gas scrubber.

**9.** The invention of claim **8**, further characterized by means connected to said carbon dioxide gas scrubber for the heating thereof to a predetermined temperature.

**10.** The system of claim **1**, wherein said means effectively connected to the output of said carbon dioxide removing means for adding a predetermined quantity of gaseous oxygen to the exhaled gaseous breath passing therethrough at a predetermined partial pressure from a reservoir of liquid oxygen disposed within a cryogenic container comprises:

a primary heat exchanger having a plurality of heating passages and a cooling passage;

a secondary heat exchanger having a heating passage and a cooling passage, with the input of the cooling passage thereof connected to the output of the cooling passage of said primary heat exchanger;

an elongated container having a first self-contained container section at one end thereof with a predetermined vent in the wall thereof, a second self-contained container section at the other end thereof, and a third self-contained container section located between said first and second self-contained container sections, said first, second, and third self-contained container sections being in heat sink configurations with each other, respectively;

a first open-ended standpipe located within said first self-contained container section and extending a predetermined distance from the wall thereof that is opposite the vent thereof;

a second standpipe located within said first self-contained container section, disposed around said first standpipe, and extending a greater distance from said wall than said first standpipe, said second standpipe having one end thereof closed by said wall and a plurality of apertures through the wall thereof in proximity with the other end thereof;

a first quantity of liquid oxygen partially filling said first self-contained container section in such manner that it surrounds a predetermined length of said second standpipe without passing through a plurality of apertures through the wall thereof;

a wick mounted on said second standpipe and dipsosed therearound in such manner as to be partially submersed in said first quantity of liquid oxygen;

a second quantity of liquid oxygen partially filling said third self-contained container section;

a cooling passage, having an input and an output, disposed within said second quantity of liquid oxygen, with the input thereof connected to the output of the cooling passage of the aforesaid secondary heat exchanger, and with the output thereof connected to the open end of said first standpipe that is adjacent to the wall from which it extends; and

a cryogenic containe for housing the aforesaid primary and secondary heat exchangers and the first, second, and third self-contained container sections of said elongated container, with the internal chamber thereof connected for communication with that portion of the internal chamber of said vented first self-contained container section not occupied by said first and second standpipes, said wick, and said first liquid oxygen and for communication with the input of one of the heating passages of the aforesaid prim ary heat exchanger.

**11.** The container of claim **10**, further characterized by: primary

a water heater having a pump included therein for pumping heated water therethrough and therefrom, said water heater effecting the heating of said pumped water as a result of the oxidation of a fuel that leaves only solid products of combustion and requires no discharge of materials to said predetermined environment;

first open-ended pipe means communicating between that portion of said third self-contained container section not occupied by said second quantity of liquid oxygen and the cooling passage disposed therein and the input of the heating passage of said secondary heat exchanger;

second open-ended pipe means connected between the output of the heating passage of said secondary heat exchanger and the input of still another heating passage of said primary heat exchangers; and

a pressure controlled valve connected between the output of said another heating passage of said primary heat exchanger and the input of the combustion chamber of said water heater adapted for

being opened in accordance with a preset pressure upstream of said pressure controlled valve.

**12.** The invention of claim **10,** further characterized by:

first open-ended pipe connected between that portion of said third self-contained container section not occupied by said second quantity of liquid oxygen and the cooling passage disposed therein and the input of the cooling passage of said secondary heat exchanger;

means connected between the cooling passage output of said secondary heat exchanger, said predetermined environment, and the input of said second self-contained container section for dumping the exhaled gas from said secondary heat exchanger cooling passage thereto whenever the pressure difference between said cooled exhaled gas and said predetermined environment exceeds a given amount;

second open-ended pipe means connected between the output of said second self-contained container and the input of another heating passage of the aforesaid primary heat exchanger;

third open-ended pipe means connected between the heating passage output of said secondary heat exchanger and the input of another heating coil of said primary heat exchanger; and

a pressure relief valve located outside said cryogenic container and connected to the output of said another heating passage of the aforesaid primary heat exchanger for discharge of the non-rejuvenated gas stored in said second self-contained container section whenever the pressure thereof exceeds a predetermined pressure.

**13.** The invention of claim **10,** further characterized by another pressure relief valve effectively connected between the output of the aforesaid conduit means and said predetermined environment for venting the exhaled gaseous breath from said conduit means thereto whenever the pressure thereof therein exceeds a predetermined amount.

**14.** The system of claim **10,** further characterized by means effectively connected to said cryogenic container for effecting the refrigeration thereof to a cryogenic temperature.

**15.** The system of claim **1,** wherein said pressurized predetermined make-up breathable gas comprises helium, and wherein said predetermined breathable, life-sustaining, gaseous mixture includes $HeO_2$.

**16.** The system of claim **1,** further characterized by a habitat, adapted for housing ordinarily air-breathing beings within a predetermined environmental medium, connected to the input-output of said respiratory means for effecting the life support of said ordinarily air-breathing beings housed therein.

* * * * *