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Colston

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[54] **BREATHING ASSIST APPARATUS**

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[52] **U.S. Cl.** **128/145.8**
[51] **Int. Cl.** **A61m 16/00**
[58] **Field of Search** .... 128/145.8, 142.3, 142.2, 128/142.4, 145.6, 191, 202, 203, 145.5; 137/100, 63 R

[56] **References Cited**

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[57] **ABSTRACT**

A breathing assist device for deep sea divers and the like including a reversible jet pump powered from a breathing gas supply and controlled by a diaphragm actuated two position poppet valve which operates in response to the pressure differential occurring across the jet pump during a ventilation cycle.

13 Claims, 6 Drawing Figures

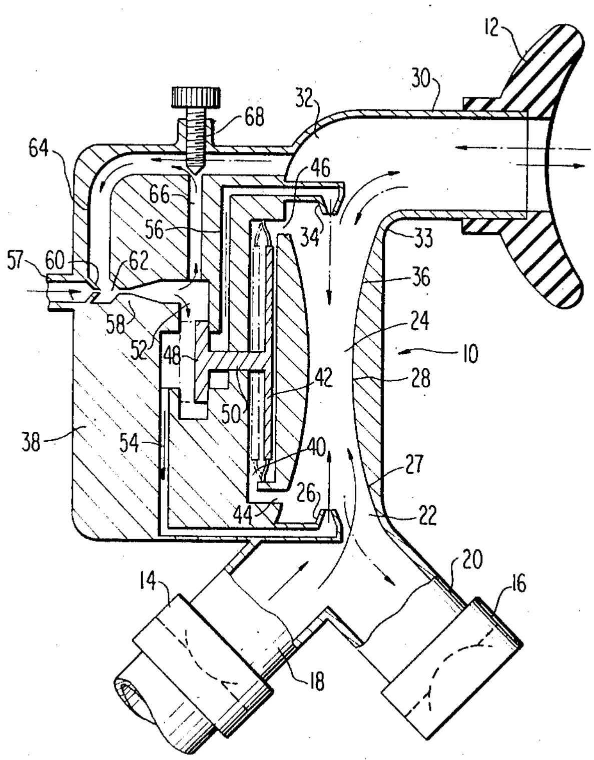


FIG. 3

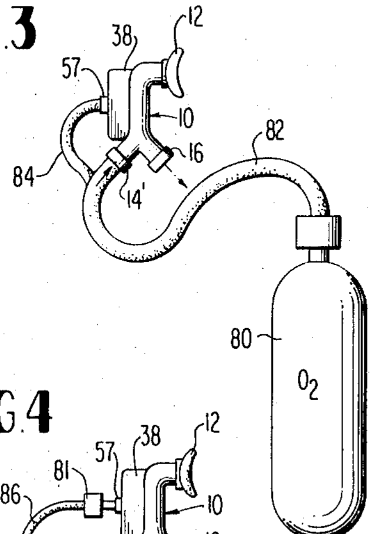


FIG. 1

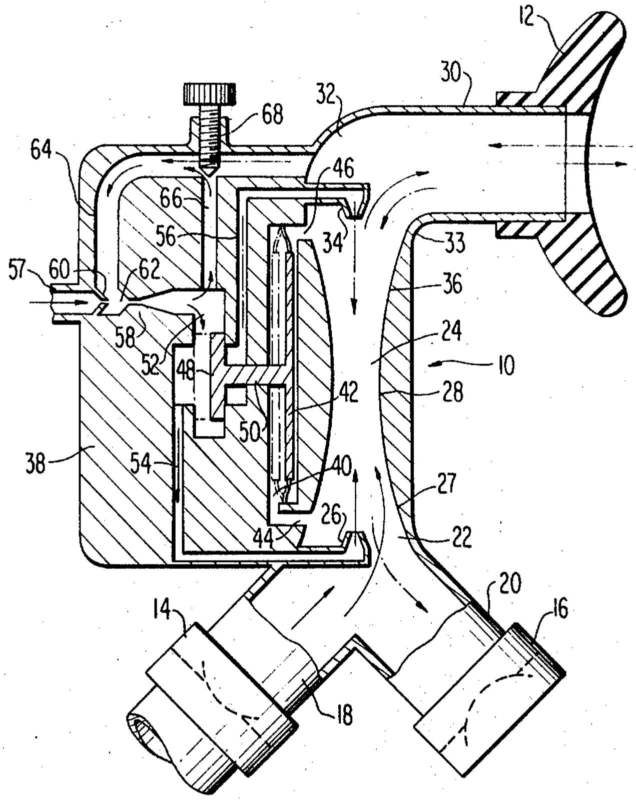


FIG. 4

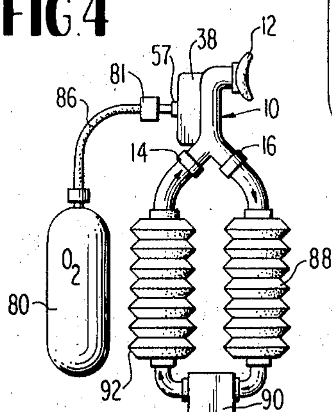


FIG. 5

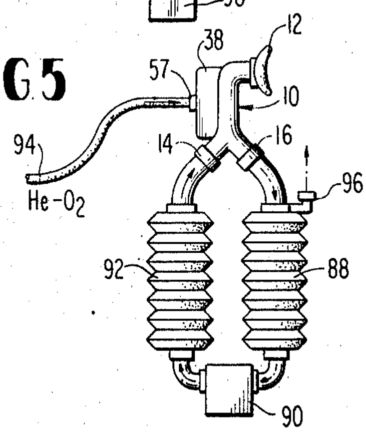
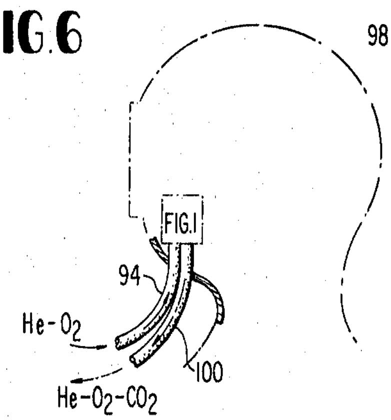


FIG. 6



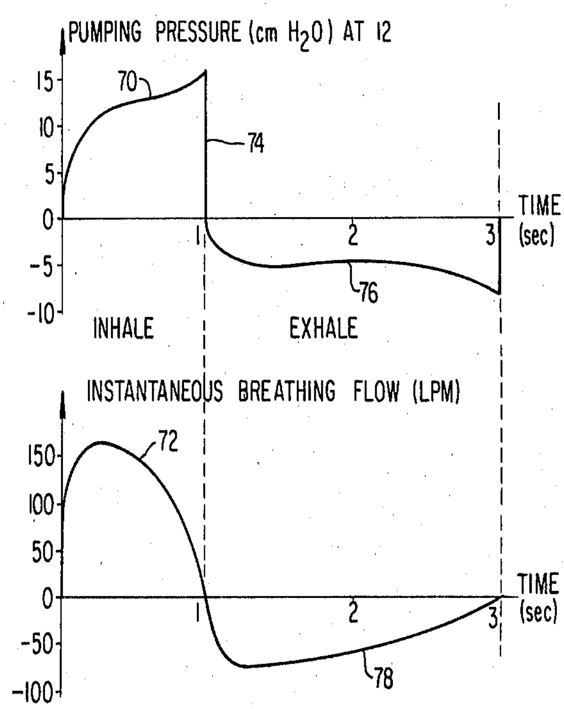


FIG. 2

BREATHING ASSIST APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to ventilation, i.e., breathing apparatus, and more particularly to breathing assist apparatus for supplying breathable gas to a person's lungs, for example a diver working at great depths wherein the high flow resistance pressure drops resulting from the high density of the breathing gas must be overcome in order to receive sufficient quantities of gas in order to function efficiently.

2. Description of the Prior Art

A diver working at relatively great depths encounters increased difficulty in breathing as a function of depth due to the relatively high density of the breathing gas compared to standard air which must be used and the resulting flow restriction pressure drops which occur in the diver's air passages (mouth to lung alveoli).

Various systems are known for providing intermittent positive pressure breathing. For example, patients who are able to breathe spontaneously at a self-controlled rate but whose pulmonary function is deficient, make use of many types of ventilating machines. Hospitals and the like employ various types of systems for supplying air, gas or air-gas mixtures to a patient undergoing surgery. An example of the first is disclosed in U.S. Pat. No. 3,586,021 entitled "Fluidic Breathing Assistor" issued to James P. McGuinness, while an example of the second is disclosed in U.S. Pat. No. 3,621,842, entitled "Ventilating Machine" issued to R. E. W. Manley. Additionally, the prior art also discloses emergency breathing gas supply apparatus for use at high altitudes. Such apparatus is disclosed in U.S. Pat. No. 2,929,377 entitled "Emergency Differential Pressure Gas Applying Apparatus," issued to R. D. Cummings. The latter two patents were mentioned because they both disclose venturi type injectors. Finally, U.S. Pat. No. 3,577,988, entitled "Dual Cannister Recirculator," issued to Richard F. Jones is cited because it discloses life support apparatus for an undersea diver having a recirculating type system also including a venturi type injector for enhancing gas flow.

SUMMARY

Briefly, the subject invention is directed to breathing assist apparatus for both the inhalation and exhalation phases of a ventilation cycle and which is particularly useful but not restricted to the life support apparatus worn by undersea divers. The breathing assist apparatus according to the subject invention comprises a reversible jet pump located between a device inserted in the diver's mouth and an input valve and an output check valve, the input valve couples a source of breathing to the jet pump. The output valve acts to conduct the exhaled gas away from the pump. The reversible jet pump includes a unitary converging-diverging throat section with upper and lower supply nozzles respectively located at each end of the throat section. The supply nozzles are alternately supplied from a gas power source during exhalation and inhalation causing a gas pumping action first in one direction and then the other. Control of the nozzles is effected by valving means driven by a diaphragm operable in response to the differential pressure in the region of the supply nozzles. The pressure drop across the jet pump is sensed by the diaphragm which when the pressure drop across the jet pump exceeds a preset value, indicating a decrease in inhalation flow for example, the diaphragm causes the valving means to switch to the opposite position causing the other supply nozzle to become activated, resulting in exhalation flow pumping. This type of breathing device senses the diver's attempt to inhale and exhale and assists his normal breathing and thereby overcome the increase pressure drops due to the relatively high density of the breathing gas at increased depths. If for some reason the diver ceases to breathe on his own power, the present invention will also effect an automatic ventilation of the diver's lungs. Additionally, when desirable, another jet pump may be included between the gas power source which may comprise a replenish supply in a closed or semi-closed system and the valving means as well as a breathing assist pressure adjustment means. The additional jet pump results in quieter operation while the pressure adjustment is advantageous when a diver's work becomes harder and his breathing flow demand increases.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a vertical cross sectional view illustrative of the preferred embodiment of the subject invention;

FIG. **2** is a set of performance curves illustrative of the operation of the subject invention;

FIG. **3** is a side elevational view of the subject invention incorporated in an open circuit or "Scuba" type of underwater life support apparatus;

FIG. **4** is a side elevational view of the subject invention incorporated in a closed circuit life support apparatus;

FIG. **5** is a side elevational view of the subject invention incorporated in a semi-closed life support apparatus fed from an umbilical tube coupled back to an underwater habitat, not shown; and

FIG. **6** is illustrative of the subject invention incorporated in a diving helmet fed a helium-oxygen mixture from a habitat, not shown.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings and more particularly to FIG. **1**, the breathing assist apparatus of the subject invention is shown comprising, inter alia, a reversible jet pump designated generally by reference numeral **10** coupled between a respirator such as a mouthpiece **12** and a pair of valves **14** and **16.** The valve **14** is operable to feed a breathing gas such as air, pure oxygen or helium-oxygen mixture to the mouthpiece **12** for inhalation while the valve **16** is adapted to feed the exhaled gases away from the apparatus either to the outside atmosphere or a breathing bag, not shown. Furthermore, the valve **14** which may be referred to as the input valve is located in an input conduit **18** while the valve **16** which may be referred to as the output check valve is located in an output conduit **20.** The input and output conduits **18** and **20** join together in a region **22** which is common to one diverging end of a unitary converging-diverging throat section **24**, i.e., one having a common constriction or narrow portion between two flared or diverging end portions. A first aspirator type supply nozzle **26** is located in one end portion **27** which also is common to the region **22** and is directed towards the common constriction portion **28.** The supply nozzle **26** and the throat portions **27** and **28** act as the first section of a reversible or bi-directional jet pump for pumping breathing gas from the conduit **18** towards the mouthpiece **12.**

The mouthpiece **12** is attached to a relatively short length of conduit **30** which terminates in a bend at a region **32** which is common to the other diverging end of portion **33** of the converging-diverging throat section **24.** A second aspirator type supply nozzle **34** is located in the end portion **33** and is directed toward the common constriction portion **28** and is adapted to pump the exhaled gas to the conduit **20** from the mouthpiece **12** and the conduit **30.** Thus the supply nozzles **26** and **34** in combination with the respective end portions **27** and **33** and the common constriction portion **28** provides a double acting jet pump for pumping breathing gas in a first direction and then pumping the exhaled gas in the opposite direction through the throat configuration **24.**

The bi-directional jet pump **10** is contained in a body **38** which additionally includes a chamber **40** located adjacent the converging-diverging throat section **24** in which is located a diaphragm **42** which separates the chamber into two parts. One part of the chamber **40** is coupled to the region **22** by means of a channel **44** while the other part of the chamber **40** is coupled to the region **32** at the opposite end of the nozzle **34** by means of the channel **46.** Thus the pressure on one side of the diaphragm **42** is at the pressure in the vicinity of the region **22** while the pressure on the other side of the diaphragm is at the pressure in the vicinity of the region **32.** The reason for this configuration will become evident when a description of the operation of the subject invention is set forth below.

The diaphragm **42** is connected to a double acting poppet valve **48** by means of a stem **50.** The valve **48** is located in a valve chamber **52,** having an input orifice in one side thereof. In a first position of the valve **48,** the chamber **52** is coupled to the supply nozzle **26** by means of a fluid passage **54** while in the second position of the valve **48,** the chamber **52** is coupled to the supply nozzle **34** by means of the fluid passage **56.** The valve chamber **52** is fed a breathable gas for powering the jet pump **10** from a conduit **57** coupled to a suitable source, not shown, which may be for example a replenish supply in a closed or semi-closed system. The gas applied to the conduit **57** is adapted to supply the pumping power alternately to the supply nozzles **26** and **34** during inhalation and exhalation respectively, and is fed to the valve chamber **52** by means of a first stage uni-directional jet pump **58** including a supply nozzle **60** and a throat portion **62.** The incoming gas supplied by means of conduit **57** is adapted to provide a pumping action of gas coupled thereto from the region **32** by means of the passage **64.** At the output of the first stage jet pump **58** is a by-pass air passage **66** which couples back to the air passage **64.** The amount of by-pass or bleed flow is controlled by means of a manually operated screw **68** mounted in the outer wall of the body portion **38.**

The breathing assist apparatus shown in FIG. **1** constitutes a bi-stable device which senses the attempt to inhale and exhale by reason of the pressure differentials between the regions **22** and **32** to trigger the necessary pumping action to assist normal breathing. The apparatus shown in FIG. **1** operates in the following manner. Assume for purposes of illustration that exhalation has ceased and inhalation starts. At that moment the pressure in the region **32** begins to drop with respect to the pressure in region **22.** The pressure differential in the passages **46** and **44** causes the diaphragm **42** to move to the position shown in FIG. **1,** shutting off passage **56** from the chamber **52** while opening passage **54.** The incoming gas applied to the first stage jet pump **58** by means of the conduit **57** is coupled to the passage **54** and to the supply nozzle **26,** causing a pumping action from the check valve **14** and the conduit **18** by means of the venturi effect. A positive feedback action occurs via the gas flow in passage **64** causing still further pumping action due to the venturi effect and pumping action of the first stage jet pump **58.** Toward the end of the inhalation stage wherein the lungs become fully charged with the breathing gas, the pressure in region **32** increases, due to the back pressure provided by the gas in the lungs. This phase of a ventilation cycle is shown for example by reference to curve **70** shown in FIG. **2** which depicts the pumping pressure existing at the mouthpiece **12** shown in FIG. **1.** When the pressure in region **32** becomes greater than the pressure in region **22,** the diaphragm **42** will move to the left, forcing the valve **48** to shut off passage **54** and open passage **56.** The valve **48** will be held in the second position by the differential pressure across the valve in a positive manner due to the pressure differential existing between passages **56** and **54.** Whereas breathing flow increased very rapidly at the beginning of the inhalation stage as shown by curve **72** shown in FIG. **2,** at the end of the breath, the flow drops to zero and the pressure at the mouthpiece immediately drops as evidenced by the portion of the curve shown by reference numeral **74.** The flow of the input gas to the first jet pump **58** now flows through the passage **56** and out of the supply nozzle **34,** causing a low pressure high reverse flow from the mouthpiece **12** initiating and/or aiding exhalation of the gases from the lungs toward the output conduit **20** and check valve **16.** The pressure at the mouthpiece **12** now exhibits a characteristic as shown by the curve **76** in FIG. **2** while the flow out of the lungs appears as shown by the curve **78** shown in FIG. **2,** until, where for example at the end of the three second period exhalation flow ceases and the inhalation action again is triggered.

The apparatus as shown in FIG. **1** is particularly adapted to overcome the pressure drop increase with depth experienced with relatively high density breathing gases (helium-oxygen) utilized in underwater life support apparatus. The configuration as disclosed in FIG. **1** is operable to sense a diver's attempt to inhale and exhale and assist his normal breathing of these relatively high density breathing gases. If for some reason the diver ceases to breathe on his own power, the present invention will cause automatic ventilation of the diver's lungs. In this sense it also becomes a life sensing device.

The first stage jet pump **58** shown in FIG. **1** acts to convert high pressure low flow gas in the conduit **57** into a medium pressure medium flow output into the valve chamber **52** and the by-pass or bleed passage **66.** The first stage jet pump results in a quieter operating device. Adjustment of the screw **68** adjusts the pressure occurring at the output of the supply nozzles **26** and **34,** which is advantageous, for example, when a diver increases his work output requiring a greater breath flow demand.

Since jet pumps are momentum conserving devices, much of the energy in the gas energy applied to the first stage jet pump **58** from the conduit **57** is dissipated in the form of turbulence and noise. A second reason for the desirability of the first stage jet pump **58** is to reduce the length of the converging-diverging nozzle **24** of the reversible jet pump **10.** The first stage jet pump results in larger areas and lower velocities in the supply nozzles **26** and **34.** This in turn results in a shorter distance for the velocity to become reasonably uniform in the throat section **24** of the reversible jet pump **10.**

It has been pointed out above that the apparatus shown in FIG. **1** has particular utility for diving life support systems. FIGS. **3** through **6**, inclusively, disclose various combinations of life support systems which the subject invention can be used in conjunction therewith. FIG. **3,** for example, is illustrative of an open circuit system which might, for example, comprise a "Scuba" diving rig wherein a tank **80** containing oxygen or air is coupled to an input demand valve **14'** by means of a flexible hose **82** and to the conduit **57** by means of another hose **84** branching off of the hose **82.** The gas supplied through the hose **84** acts simply as a power source for operating the apparatus. On inhalation, gas is drawn from the bottle **80** through the demand valve **14'** and out of the mouthpiece **12.** During the exhalation phase, the exhaled gases including carbon dioxide CO_2 is fed back through the mouthpiece **12** where it is pumped out of the output check valve **16** to the surrounding water environment.

FIG. **4,** on the other hand, discloses a closed circuit breathing apparatus whereupon the oxygen bottle **80** is coupled by means of a flow regulating valve **81** to the conduit **57** by means of a flexible tube **86** to act as a make up or replenish source and power the supply nozzles **26** and **34.** In this instance the exhaled gases are fed from the output check valve **16** into a first breathing bag **88** which feeds into a canister **90,** which removes the carbon dioxide from the exhaled air. The output of the canister **90** comprises CO_2-free breathing gas which is fed to a second breathing bag **92** where it can then be fed back to the input valve **14** so that the breathing gas is recirculated. Oxygen consumed by breathing is replenished by gas from the oxygen bottle **80.**

The configuration shown in FIG. **5** constitutes a semi-closed system which is adapted to replenish and power the breathing assist mechanism shown in FIG. **1** and is particularly useful in connection with deep diving apparatus where a helium-oxygen mixture is coupled to the apparatus shown in FIG. **1** from a habitat not shown, by means of an umbilical line **94.** Such a system using a $He-O_2$ mixture normally requires a relief valve such as shown by reference numeral **96** at the input to the exhalation breathing bag **88.** Such a relief valve feeds to the surrounding atmosphere and acts to relieve the pressure build up in the exhalation breathing bag **88.**

FIG. **6** is intended to illustrate, for example, the apparatus as depicted in FIG. **1,** incorporated in a diving helmet shown in phantom section by reference numeral **98.** Also instead of a single umbilical line **94** feeding the breathing assist apparatus, a second umbilical line **100** is utilized to feed the exhaust gases, including helium, oxygen and carbon dioxide back to an underwater habitat, not shown.

The curves shown in FIG. **2** and the values associated therewith are based on calculations provided in an analysis for a diver at the depth of 1,000 feet of sea water, breathing 4% O_2-96%He gas mixture with the breathing assist pressure adjusted to a maximum value of 15cm H_2O for no flow. The peak instantaneous breathing flow is assumed to be 2.5 meters per second. The value of 15cm H_2O is shown as the maximum pumping pressure because values greater than this could result in air being forced into a diver's stomach.

Thus what has been shown is an improved means of overcoming the pressure drop increase as a function of depth utilizing a reversible jet pump operated in a bi-stable mode in response to differential pressure changes occurring during a breathing cycle. Such apparatus acts to overcome the restrictive pressure drops of relatively high density breathing gases encountered at depths wherein unassisted breathing becomes increasingly difficult.

Having shown and described what is at present considered to be the preferred embodiment of the subject invention,

I claim:

1. Breathing assist apparatus in a system having a breathing input/output device coupling the respiratory system to a source of breathing gas, comprising in combination:

a reversible jet pump, having a pair of opposed aspirators each including a supply nozzle, said supply nozzles being directed toward one another and respectively located at either end of a converging-diverging throat section including a common relatively narrow intermediate portion, and flared end portions;

means coupling one end portion of said jet pump to said input/output device;

input means coupling said source of breathing gas to the other end portion of said jet pump;

output means also coupled to said other end portion of said jet pump for removing exhaled gases therefrom;

a gas power source;

valve means having bi-stable operating states being operable to alternately couple each of said supply nozzles to said gas power source whereby in a first operating state the supply nozzle located at said other end of said jet pump operates to pump breathing gas toward said input/output device through said thraot section and in a second operating state said supply nozzle located at said one end of said jet pump operates to pump exhaled gas to said output means through said throat section;

means responsive to the pressure differential between each end portion of said jet pump in the region of said supply nozzles for actuating said valve means and comprising a pressure chamber including a diaphragm, in parallel relationship to said reversible jet pump, dividing said pressure chamber into two parts and additionally including a first channel coupling the region at said one end of said jet pump to one part of said chamber and a second channel coupling the region of the other end of said jet pump to said second part of said chamber; and

means coupling said diaphragm to said valve means.

2. The apparatus as defined by claim **1** and additionally including another jet pump coupling said gas power source to said valve means.

3. The apparatus as defined by claim 2 wherein said another jet pump comprises a uni-directional device including a nozzle and a throat section, and

additionally including a gas conduit coupling said one end portion of said reversible jet pump to the region of said another jet pump including the nozzle.

4. The apparatus as defined by claim 3 and additionally including an adjustable variable flow conduit between the last recited conduit and the output of the throat section of said another jet pump for controlling the output pressure from said supply nozzles.

5. The apparatus as defined by claim 1 wherein said source of breathing gas and said gas power source comprise a single breathable gas supply including first and second coupling means respectively coupling said supply to said input means and said valve means.

6. The invention as defined by claim 5 and additionally including a jet pump coupled between said second coupling means and said valve means.

7. The apparatus as defined by claim 1 wherein said system additionally includes a first breathing bag coupled to said output means for receiving exhaled gases, exhaled gas reconditioning means coupled to said first breathing bag, and a second breathing bag coupled between said gas reconditioning means and said input means, and

wherein said gas power source comprises a replenish breathing gas supply coupled to said valve means.

8. The apparatus as defined by claim 7 and additionally including a uni-directional jet pump coupled between said replenish gas supply and said valve means.

9. The apparatus as defined by claim 7 and additionally including pressure relief valve means coupled to said first breathing bag, and

wherein said gas power source is comprised of a remote supply and additionally including an umbilical line coupling said remote supply to said valve means.

10. The apparatus as defined by claim 9 wherein said remote gas supply is adapted to supply a helium-oxygen mixture to said breathing assist apparatus.

11. The apparatus as defined by claim 10 and additionally including a second jet pump coupled between said umbilical line and said valve means.

12. The apparatus as defined by claim 1 wherein said source of breathing gas and said gas power source comprise a common breathing gas supply situated at a remote location and additionally including a first umbilical line means coupling said common supply to said input means and said valve means, and a second umbilical line coupling said output means to said remote location for returning exhaled gases.

13. The apparatus as defined by claim 12 wherein said remote location comprises a habitat.

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