United States Patent

Curtis

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[54] LIFE SUPPORT SYSTEM

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[73] Assignee: **Granted to National Aeronautics and Space Administration under the provisions of 42 USC 2457(d)**

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[52] **U.S. Cl.** **128/142.5,** 128/402, 2/2.1

[51] **Int. Cl.** **A62b 7/02**

[58] **Field of Search** 128/142.2, 142.4, 142.5, 142.3, 128/400, 402; 62/259, 223; 2/2, 2.1, 2.5

[56] **References Cited**

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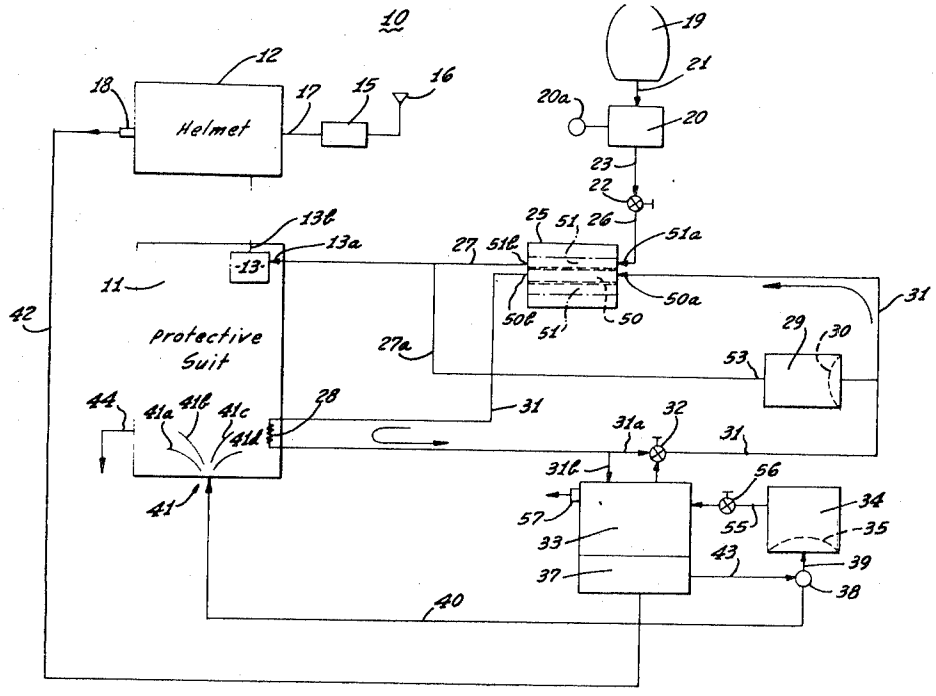
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[57] **ABSTRACT**

A lightweight life support system for extravehicular space activity which may be either mounted in a back-pack or integrated into a protective suit. Two subsystems are provided to maintain the suit inhabitant in his environment. The first subsystem is an open loop, single pass ventilation system, having a high-pressure oxygen and mixed gas storage which is maintained within lightweight, stress-limited pressure vessels. A breathing bag cooperates with the open loop system to meet the peak respiratory demands. The second subsystem comprises a protective suit having a duct network, a liquid pump, and a sublimator-heat exchanger which in combination provide a suitable thermal condition.

9 Claims, 4 Drawing Figures



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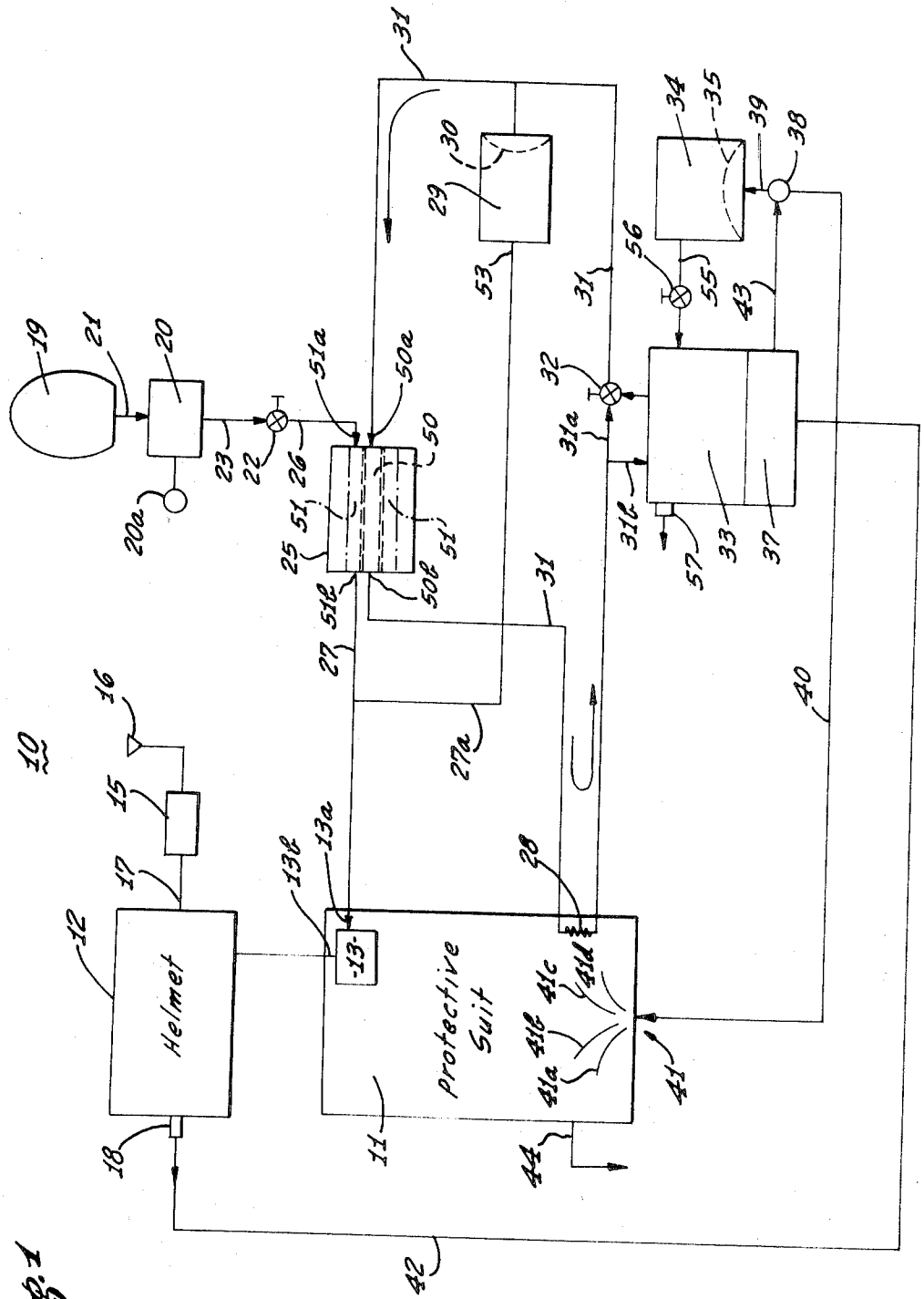


Fig. 1

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Fig. 2

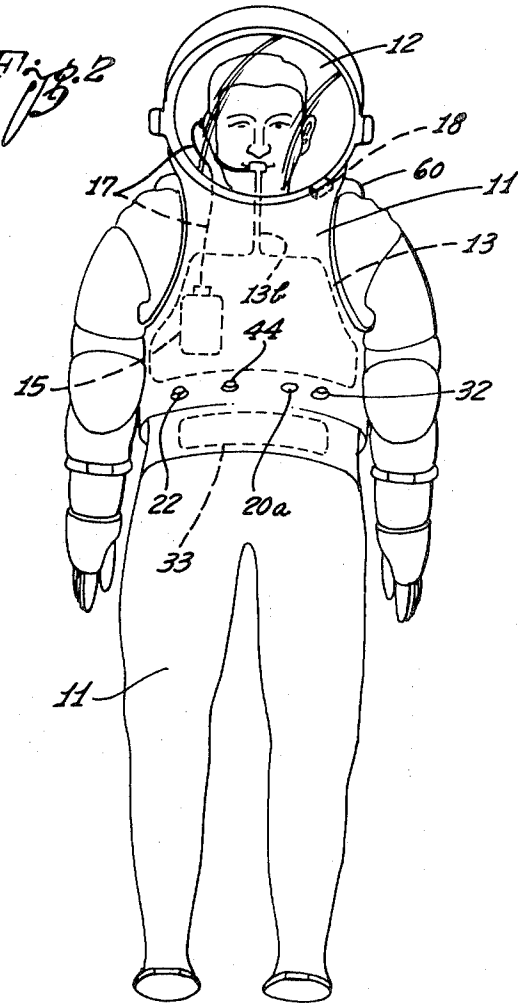


Fig. 3

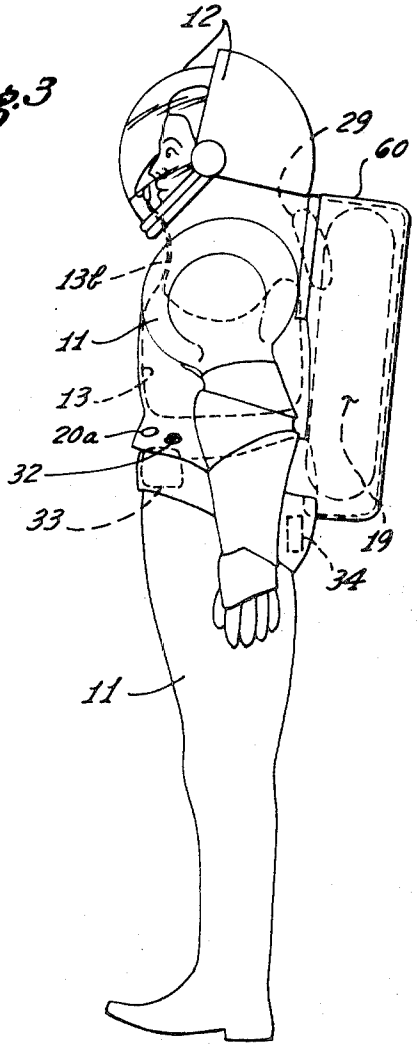
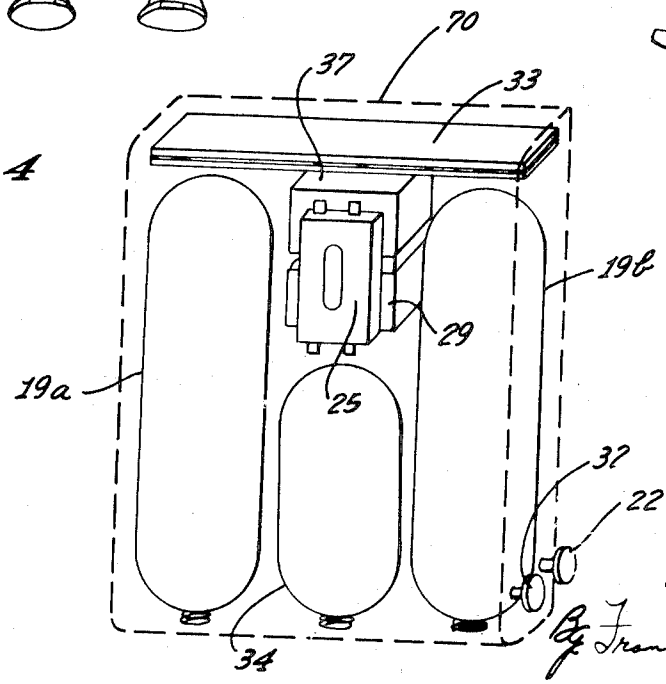


Fig. 4



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LIFE SUPPORT SYSTEM

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; U.S.C. 2457).

FIELD OF THE INVENTION

This invention relates to a life support system and more particularly to a novel open loop life support subsystem which includes a breathing bag as a reservoir.

DESCRIPTION OF THE PRIOR ART

Generally, life support systems may be divided into three categories, namely, closed loop, semiclosed loop and open loop systems. The closed loop system is a highly complex system which leads inevitably to low inherent reliability, thus necessitating high maintainability. Furthermore, a closed loop system requires a rather bulky CO_2 arrangement including a contaminant absorbent, and an electrical circulation fan, which in combination inherently adds additional weight that must be carried by an individual. The semiclosed loop system is also quite complex because of the reprocessing system and the oxygen flow rate is typically four times greater in the semiclosed loop system than in the closed loop system. Thus, roughly four times as much oxygen is required for a mission of the same duration.

On the other hand, the open loop single pass system of the present invention does not require recirculation of the breathing gas and there is no need for a carbon dioxide absorber or a ventilation fan and its associated battery. In addition, the open loop system is more compact and lighter in weight, thus the user may move around with greater dexterity and ease.

Accordingly, it is an object of the present invention to provide a life support system having an open loop single pass ventilation flow.

It is a further object of the present invention to provide an improved life support system utilizing an oxygen and mixed gas supply which is circulated in light weight stress-limited pressure vessels.

It is a still further object of the present invention to provide an improved life support system which may be either mounted in a backpack or integrated into a protective suit.

It is another object of the present invention to provide an improved life support system having a pulse pump and a sublimator-heat exchanger to ensure thermal control of a liquid coolant garment.

It is still another object of the present invention to provide an improved life support system wherein a breathing bag serves as a gas reservoir to meet the peak respiratory demands from an average respiratory supply source.

SUMMARY OF THE INVENTION

In accordance with the objects set forth above, the present invention provides a lightweight life support system for extravehicular space activity which may be either mounted in a backpack or integrated into a protective suit. The life support system comprises two subsystems—an open loop ventilation subsystem to meet the ventilation requirements and a thermal control subsystem to maintain suitable thermal conditions. The first subsystem is an open loop, single pass ventilation system, having a high-pressure oxygen and mixed gas storage which is maintained within lightweight, stress-limited pressure vessels. A breathing bag cooperates with the open loop system to meet peak respiratory demands. The second subsystem comprising a protective suit having a duct network, a liquid pump, and a sublimator-heat exchanger in combination provides a suitable thermal condition.

BRIEF DESCRIPTION OF THE DRAWINGS

Additional objects, advantages, and characteristic features of the present invention will become readily apparent from the following detailed description of preferred embodiments of the invention when taken in conjunction with the accompanying drawings in which:

FIG. **1** is a block diagram of a life support system in accordance with the present invention;

FIG. **2** is a front view of an astronaut shown within an integrated life support system in accordance with the present invention;

FIG. **3** is a side view of an astronaut shown within an integrated life support system in accordance with the present invention; and

FIG. **4** is a perspective view of a backpack of a life support system in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. **1**, there is shown one of the embodiments of a life support system **10** in accordance with the principles of this invention. The life support system **10** comprises two subsystems—an open loop ventilation subsystem to meet ventilation requirements and a thermal control subsystem to maintain suitable thermal conditions. Some of the components in the life support system **10** are utilized in both subsystems, for example, a pulse pump **25**. The open loop ventilation subsystem will be discussed first.

Normally, an open loop ventilation subsystem requires that the gas flow to the system inhabitant be controlled by the inhabitant's breathing pattern. This approach, while functional, is considered to be undesirable under certain conditions, for example, where the lungs act as a pump, fatiguing problems are experienced at metabolic rates higher than approximately 1,100 B.t.u./hr. A preferred method of meeting the ventilation requirements of the inhabitant is to provide a gas flow at a continuous rate. The method practices in accordance with the principles of this invention is to provide a continuous bleed of gas from a compressed gas source **19** at approximately 1 c.f.m. However, it must be recognized that while an average flow of 1 c.f.m. matches the average respiratory demand at a metabolic rate of 1,600 B.t.u./hr., the average demand during inhalation is roughly 2 c.f.m. with peak demands as high as 2.5 c.f.m. Thus, a simple gas flow system supplying 1 c.f.m. on a continuous basis is therefore inadequate as it does not provide for the complete cyclical demand of breathing. Therefore, in order to meet the ventilation requirements of the suit inhabitant at all times, a breathing bag **13** is incorporated within the open loop ventilation subsystem to act as a reservoir to meet peak demand periods. While the invention has been described with particular reference to a compressed gas source operating at approximately 1 c.f.m., it should be understood that the practice of this invention is not necessarily limited thereto, but may be practiced to equal advantage utilizing other c.f.m. rates depending upon the requirements of a particular operation.

To meet the necessary respiratory ventilation requirements of the astronaut, the compressed gas source **19** is provided. The use of the term "gas" is understood to include any combination of gases which may serve to provide ventilation to the astronaut. Throughout this disclosure, the system inhabitant will be referred to as an astronaut; however, the life support system **10** may be used in other suitable environments. A regulator **20** is adapted to receive the gas from the gas source **19** via line **21** at approximately 3,500 p.s.i. A gas pressure gauge **20***a* is provided as shown. A pneumatic line **23** connects the output of the regulator **20** to a manual control valve **22**. The manual control value **22** allows the astronaut to adjust the rate of flow of gas out of the regulator **20**. The output of the regulator **20**, at approximately 15 p.s.i., is then fed to a pulse pump **25** via a pneumatic line **26**. The gas is utilized in the pulse pump **25** as a "pumping fluid" to actuate the flow of a liquid

coolant through a liquid coolant garment **28**. The operation of the pulse pump **25** will be explained in more detail in a later discussion of the thermal control subsystem. The gas is routed through the pulse pump **25** and to the breathing bag **13** via a pneumatic line **27** and an input **13***a*.

A protective suit **11** including a helmet **12** are shown schematically in FIG. **1**. The protective suit **11** may be of any suitable impervious material capable of protecting an individual from atmospheric pressures. Presently, protective suits of either the hard or soft variety are employed depending upon the particular mission. The hard suit type is usually made of aluminum sheet formed into the shape of a human body and having flexible joints where necessary. The soft type is normally made of a fabric that is capable of maintaining a pressurized condition relative to the outside environment. The helmet **12**, which is attached to the protective suit **11**, may be of any suitable type, for example, one having a hemispherical polycarbonate pressure visor, two movable overvisors and a protective visor cover. Normally, the pressure visor would be constructed of sufficient thickness to resist mechanical and micrometeoroid impacts.

The breathing bag **13** is physically located between the protective suit **11** and the chest and back area of the astronaut. The breathing bag **13** has an input **13***a* and an output **13***b*. The output **13***b* of the breathing bag **13** is adapted to allow gas to be fed into the helmet **12**. A communications system **15** including an antenna **16** is shown connected to the helmet **12** via line **17** in order to provide the astronaut with a communications system. A one-way check valve **18** is shown connected to the helmet **12** to provide an outlet for the expired gas of the astronaut.

Since the protective suit **11** provides a rigid torso section in the area of the astronaut's chest and back, the breathing bag will be compressed and inflated in response to the breathing pattern established by the astronaut. During inhalation, the chest of the astronaut will compress the breathing bag **13**, thus allowing additional gas to be available in the oral-nasal region. During exhalation, the breathing bag **13** is allowed to be reinflated by the continuous gas stream into the input **13***a*. Any expired gas routed to the helmet **12** aids in flushing expired gas from the region of the helmet **12**. Thus, the breathing bag **13** serves as an intermediary reservoir allowing peak respiratory demands to be met from an average supply source having a c.f.m. capacity less than half the peak requirements.

The expired gas of the astronaut flows from the helmet **12** via the check valve **18**. This expired gas will be cooled and dehumidified and then routed back into the protective suit **11** where it will assist to maintain the body of the astronaut in a comfortably dry condition. The expired gas first travels to a gas cooler **37** via a pneumatic line **42**. The expired gas is cooled in the gas cooler **37** and then travels to a water separator **38** via a pneumatic line **43**. The water separator **38** may be a standard elbow water trap which will condense the respiratory water vapor from the gas. The condensed water is routed to a water storage unit **34** via a line **39**. The water storage unit **34**, which is primarily part of the thermal control subsystem, provides water to a sublimator-heat exchanger **33** to initiate the sublimation process in addition to storing the aforementioned condensed water. A bladder **35** prevents the condensed water from going to the clean water portion of the water storage unit **34**. The cooled, low-moisture content gas is then allowed to enter an input **41** of the protective suit **11** via a line **40**. This cooled, low-moisture content gas is routed from the input **40** to the body extremities, that is, the arms and legs, of the astronaut via suitable ducts, shown schematically as **41***a*through *d*. The gas then circulates over the body of the astronaut and is expelled from the protective suit **11** at an output **44**. Preferably, the output **44** is located in the chest area of the protective suit **11** to ensure that the cooled, low-moisture content gas maintains substantially the entire body of the astronaut in a comfortably dry position. The continual venting of the expired gas from the output **44** of the protective suit **11** ensures the operation of the open loop ventilation subsystem, thus, there is no need to require a blower to maintain circulation of the ventilation gas.

In addition to the ventilation subsystem described, the life support system **10** includes a thermal control subsystem. The thermal control subsystem comprises the liquid coolant garment **28**, the sublimator-heat exchanger **33**, a pump accumulator **29**, the water storage unit **34**, and associated components. A liquid coolant supply which is stored in the pump accumulator **29** travels in the closed loop **31** in a counterclockwise direction as shown. The thermal control subsystem ensures adequate cooling of the body of the astronaut.

The liquid coolant garment **28** may be of any suitable type, for example, the type described in the Alan S. Penfold U.S. Pat. application, Ser. No. 376,745, assigned to the same assignee of this invention. The liquid coolant garment **28** is designed to cover the body areas extending from the knees to the elbow, including the back of the neck and skull. Normally, elastic material is employed in the arm and leg areas to maintain proper pressure contact of the garment with the skin. The pump accumulator **29**, including a diaphragm **30**, ensures that an adequate liquid coolant supply is available to flow through the liquid coolant garment **28**.

As discussed earlier, pulse pump **25** is utilized to provide a smooth flow of liquid coolant through the liquid coolant garment **28**. The pulse pump **25** may be of the type shown in the Daniel L. Curtis U.S. Pat. application, Ser. No. 488,367, assigned to the same assignee of this invention. The pulse pump **25** is shown schematically with the proper inlets and outlets. Basically, the pulse pump **25** comprises a pump casing **51** having an inlet port **51***a* and an outlet port **51***b*, through which the gas from the compressed gas source **19** may flow, and a flexible wall chamber **50**, which may be a tubular membrane, positioned within the pump casing **51** having an inlet port **51***a* and an outlet port **51***b*. The liquid coolant from the pump accumulator **29** is fed to the inlet port **50***a*, through the flexible wall chamber **50**, and then out of the outlet port **50***b* to the liquid coolant garment **28**.

In the operation of the pump **25**, when the liquid coolant fills the flexible wall chamber **50**, the chamber becomes fully distended and covers the outlet port **50***b* thereby inhibiting the flow of the gas through the pump casing **51** so that the pressure of the gas within the casing will increase. The flexible wall chamber **50** is thereby inflated to its maximum dimension, as limited by the internal wall of the pump casing **51**. Thus, an effective gas seal is formed by the flexible wall chamber **50** against the inner wall of the pump casing **51** and gas flow into the pump from the constant pressure source is trapped causing the gas pressure in the pump **25** to increase. As the gas pressure increases it becomes greater than the pressure of the liquid coolant, so as to cause the flexible wall chamber **50** to collapse and pump the liquid coolant contained therein in a smooth motion from one end of the pump casing **51** to the other. The gas seal is broken upon the collapse of the flexible wall chamber **50**, allowing the gas to exit the pump through the outlet port **51***b*. The sudden drop in gas pressure within the pump, as the gas escapes through the outlet port **51***b*, results in the pressure of the liquid coolant being greater than the gas pressure and allows the liquid coolant to enter the flexible wall chamber, forcing it to reexpand. Thus, the pumping cycle is initiated again.

A pneumatic line **27***a* is connected between the pneumatic line **27** and the inlet port **53** of the pump accumulator **29** in order to provide a pressure head on the liquid coolant in the pump accumulator **29**. The pressure head is maintained by the diaphragm **30**, which separates the gas from the liquid coolant.

Also included within the closed loop **31** is a diverter valve **32**. A portion of the liquid coolant from the liquid coolant garment **28** flows directly to the diverter valve **32** via line **31***a*, while another portion is diverted via line **31***b* through the sublimator-heat exchanger **33**. The liquid coolant diverted through the sublimator-heat exchanger **33** will be cooled. Thus, the temperature of the liquid coolant out of the diverter

valve 32 that is ultimately fed to the liquid coolant garment 28, may be regulated. The diverter valve 32 allows the astronaut to adjust the flow of liquid coolant through the heat exchanger portion of the sublimator-heat exchanger 33. If the body surface temperature of the astronaut is too warm, the diverter valve 32 may be adjusted to allow additional liquid coolant to flow through the sublimator-heat exchanger 33. On the other hand, if his body surface temperature is too cool, the astronaut may adjust the diverter 32 to allow less liquid coolant to flow through the sublimator-heat exchanger 33.

The sublimator-heat exchanger 33 is typical of the class of heat dissipation devices that are used in a vacuum for the purpose of rejecting system heat to the vacuum such as the type disclosed in the copending Daniel L. Curtis U.S. Pat. application, Ser. No. 825,812, filed May 19, 1969 and assigned to the same assignee of this invention. Other sublimator-heat exchangers have been previously disclosed in U.S. Pat. Nos. 2,990,696; 3,170,303 and 3,197,973 among others. The sublimator-heat exchanger 33 may be a typical sublimator consisting of a porous material, usually metal, with an adjacent surface of the porous material exposed to a vacuum. The vacuum in the case of utilization of the system by an astronaut would be outerspace. In the operation of a sublimator-heat exchanger 33, a liquid, usually water, is allowed to make contact with the porous material, in the present case, water from the water storage unit 34. This water is fed to the sublimator portion of the sublimator-heat exchanger 33 via line 55 and valve 56. The valve 56 may be closed during the time the astronaut is in the spacecraft to prevent water leakage. The water in the porous material evaporates to a point that sufficient heat is lost and the water freezes. The water in a frozen state sublimates directly to a gas. The gas may be vented overboard via port 57. Since the liquid is water, then the porous material surface of the sublimator maintains itself at an average temperature of 32° F., independent of the heat load, by its self-controlling sublimation of the water. The device is self-regulating because as the heat input to the sublimator-heat exchanger 33 rises, the vapor pressure in the sublimator-heat exchanger 33 rises and the sublimation process speeds up. Thus, heat from the liquid coolant in the closed loop 31 may be transferred to the sublimator-heat exchanger 33. Therefore, the suit inhabitant may control the temperature of the liquid coolant by adjusting the diverter valve 32 which controls the amount of liquid coolant flowing through the sublimator-heat exchanger 33, which in turn, determines the amount of heat released from the liquid coolant.

Referring now to FIGS. 2 and 3, a front view and a side view, respectively, of an astronaut within an integrated life support system are shown. The protective suit 11 is shown with the accompanying helmet 12. The breathing bag 13 is located between the protective suit 11 and the chest and back area of the astronaut. The output 13*b* of the breathing bag 13 allows gas to be fed to the helmet 12. The liquid coolant garment 28 which covers nearly all of the body of the astronaut is not shown. Also shown is the communications set 15 including the connection 17 to the astronaut. The check valve 18 is shown connected to the helmet which provides an outlet for the expired gas of the astronaut along with the output 44 which allows the cooled low-moisture gas to be vented into space after being circulated over the body of the astronaut. The manual control valve 22 and the diverter valve 32 are shown on the torso section of the protective suit 11, for controlling the gas flow and water flow, respectively. Additional items shown are the sublimator-heat exchanger 33, the compressed gas source 19, the pump accumulator 29, the water storage unit 34, the gas pressure gauge 20*a*, and a compartment 60 for holding the various components, for example, the compressed gas source 19 and the pump accumulator 29. Other components are shown which are numbered in accordance with the block diagram of FIG. 1.

Referring now to FIG. 4, there is shown a perspective view of a backpack 70 of a life support system. The backpack 70 as illustrated would utilize two compressed gas sources 19*a* and 19*b*, for supplying primary and emergency ventilation requirements, respectively. Also shown are various other components, illustrated without connections, such as the sublimator-heat exchanger 33, the gas cooler 37, the pump accumulator 29, the pulse pump 25, the water storage unit 34, the manual control 22, and the manual water control, for controlling the gas flow and water flow, respectively.

Depending upon the requirements of the vehicle, the environment, or the mission, the integrated life support system of FIGS. 2 and 3 or the backpack arrangement of FIG. 4 may be utilized by the astronaut in a particular operation.

Thus, although the present invention has been shown and described with reference to particular embodiments, nevertheless, various changes and modifications obvious to a person skilled in the art to which the invention pertains are deemed to lie within the spirit, scope, and contemplation of the invention as set forth in the appended claims.

What is claimed is:

1. A life support system for an individual comprising:
   a. an atmosphere-impervious suit enclosing said individual;
   b. closed loop means secured to said suit for regulating the thermal condition of said individual's said closed loop means including:
      i. a liquid coolant garment in pressure contact with the body of said individual, said liquid coolant garment having an input port and an output port;
      ii. a pump accumulator having a liquid coolant therein, said pump accumulator having an input port and an output port;
      iii. a pulse pump having a first and second port connected to said output port of said pump accumulator and said input port of said liquid coolant garment, respectively;
      iv. a sublimator-heat exchanger having a first and second port connected to said output port of said liquid coolant garment and said input port of said pump accumulator, respectively, said sublimator-heat exchanger including a water storage unit; and
   c. open loop means secured to said suit for providing the ventilation requirements of said individual, said open loop means cooperating with said closed loop means to insure proper regulation of the terminal condition of said individual.

2. A life support system as recited in claim 1 wherein said atmosphere-impervious suit comprises:
   a rigid torso section;
   four sections covering the extremities of said individual, said four sections connected to said rigid torso section, said four sections having flexible joints relative to respective natural joints of said individual; and
   a helmet connected to the upper part of said rigid torso section so as to enclose the head of said individual, said helmet having an input port and an output port.

3. A life support system as recited in claim 2 wherein said open loop means comprises:
   compressed gas means; and
   a breathing bag having an input port and an output port, said output port connected to said input port of said helmet, said input port of said breathing bag adapted to receive gas from said compressed gas means, said breathing bag constructed in the shape of a vest covering the chest and back area of said individual, said breathing bag adapted to be retained between said rigid torso section and said chest and back area of said individual so as to be compressed and inflated in accordance with the breathing pattern of said individual.

4. A life support system as recited in claim 3 wherein said compressed gas means cooperates with said pulse pump of said closed means for ensuring a flow of said liquid coolant through said liquid coolant garment.

5. A life support system as recited in claim 4 comprising:
   drying means for drying the skin surface of said individual, said drying means having an input port and an output port, and

dehumidifying means coupled between output port of said helmet of said suit and said input port of said drying means for cooling and dehumidifying the expired gas of said individual.

6. A life support system as recited in claim 5 wherein said dehumidifying means comprises:

a gas cooler having an input port and an output port, said input port being coupled to said output port of said helmet;

a water separator having an input port and first and second output ports, said input port being connected to said output port of said gas cooler, said first output port being connected to said water storage unit and said second output port being connected to said first input port of said drying means.

7. A life support system as recited in claim 6 wherein said drying means comprises a network of four ducts coupled from said input port of said drying means to the responsive outer extremities of said individual, said ducts being capable of carrying the cooled, low-moisture content gas from said water separator, and said output port of said drying means is located in said rigid torso section of said suit.

8. A life support system for an individual comprising:

an atmosphere-impervious suit enclosing said individual, said suit including a rigid torso section, four sections connected to said rigid torso section and covering the respective extremities of said individual, said four sections having flexible joints relative to respective natural joints of said individual, and a helmet connected to the upper part of said rigid torso section, said helmet enclosing the head of said individual and having an input port and an output port;

a liquid coolant garment in pressure contact with the body of said individual, said liquid coolant garment having an input port and an output port;

a pump accumulator having a liquid coolant therein, said pump accumulator having an input port and an output port;

a pulse pump having a first input port and first output port connected to said output port of said pump accumulator and said input port of said liquid coolant garment, respectively, said pulse pump further having a second input port and a second output port;

a sublimator-heat exchanger having a first input port and first output port connected to said output port of said liquid coolant garment and said input port of said pump accumulator, respectively, said sublimator-heat exchanger including a diverter means for bypassing part of said liquid coolant from entering said sublimator-heat exchanger, said sublimator-heat exchanger further having a second input port and second output port;

a water storage unit having a bladder interposed therein for providing a first and second compartment, said first compartment having an input port and said second compartment having an output port, said output port of said first compartment being connected to said second input port of said sublimator-heat exchanger;

at least one regulated compressed gas source connected to said second input port of said pulse pump;

a breathing bag having an input port and an output port connected to said second output port of said pulse pump and said input port of said helmet, respectively, said breathing bag constructed in the shape of a vest covering the chest and back area of said individual, said breathing bag adapted to be retained between said rigid torso section and said chest and back area of said individual so as to be compressed and inflated in accordance with the breathing pattern of said individual;

a gas cooler having an input port and an output port, said input port being coupled to said output port of said helmet;

a water separator having an input port and first and second output ports, said input port being connected to said output port of said gas cooler, said first output port being connected to said input port of said water storage unit; and

drying means including a network of four input ducts and an output valve, said network of four input ducts coupled between said second output port of said water separator and said respective outer extremities of said individual, said ducts adapted to carry cool, low-moisture content gas from said water separator, and said output valve being located in said rigid torso section of said suit.

9. A life support system for an individual as recited in claim 8 wherein said regulated compressed gas source, said sublimator-heat exchanger, said gas cooler, said pump accumulator, said pulse pump, and said water storage unit are mounted in a backpack means for providing the capability of detaching the substantial bulky items of said life support system when said individual is not required to utilize said life support system during a particular mission.

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