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[54] **OMINPOSITIONAL CRYOGENIC UNDERWATER BREATHIND APPARATUS**
19 Claims, 2 Drawing Figs.

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[51] **Int. Cl.** **F17c 7/02**
[50] **Field of Search** .... 62/52, 53, 203; 431/(Inquired); 122/(Inquired); 137/38, 45; 220/(Inquired); 244/135; 128/142.2; 222/376

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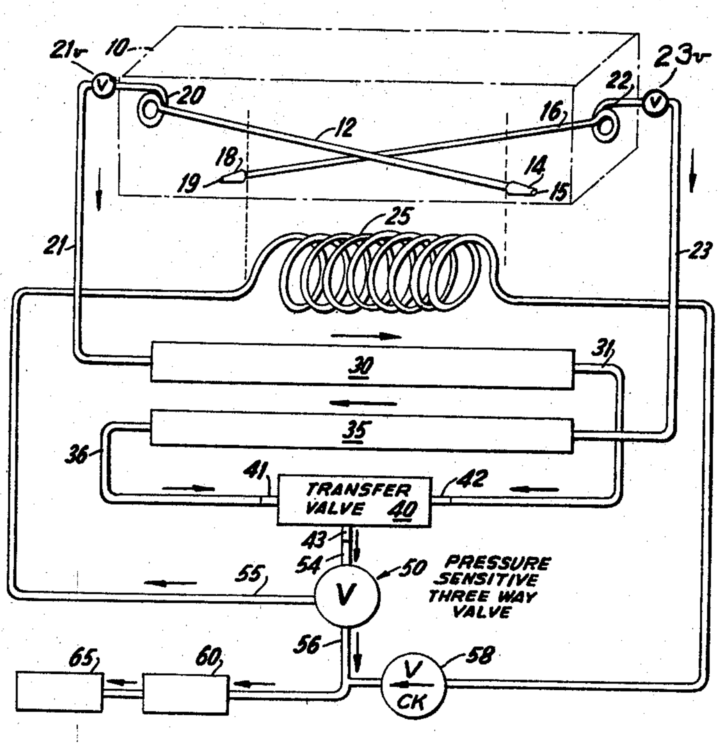
ABSTRACT: Cryogenic underwater breathing apparatus comprises a liquified air storing tank having mounted therein freely pivoted pickup tubes for extracting the stored fluid. An orientation responsive transfer valve automatically connects at least one of the pickup tubes, having a weighted receiving orifice disposed within the liquid phase air mass under the action of gravity, to an output demand regulator for consumption via air vaporizing apparatus, with structure being provided to maintain the system in a proper pressurized relationship relative to the ambient environment.



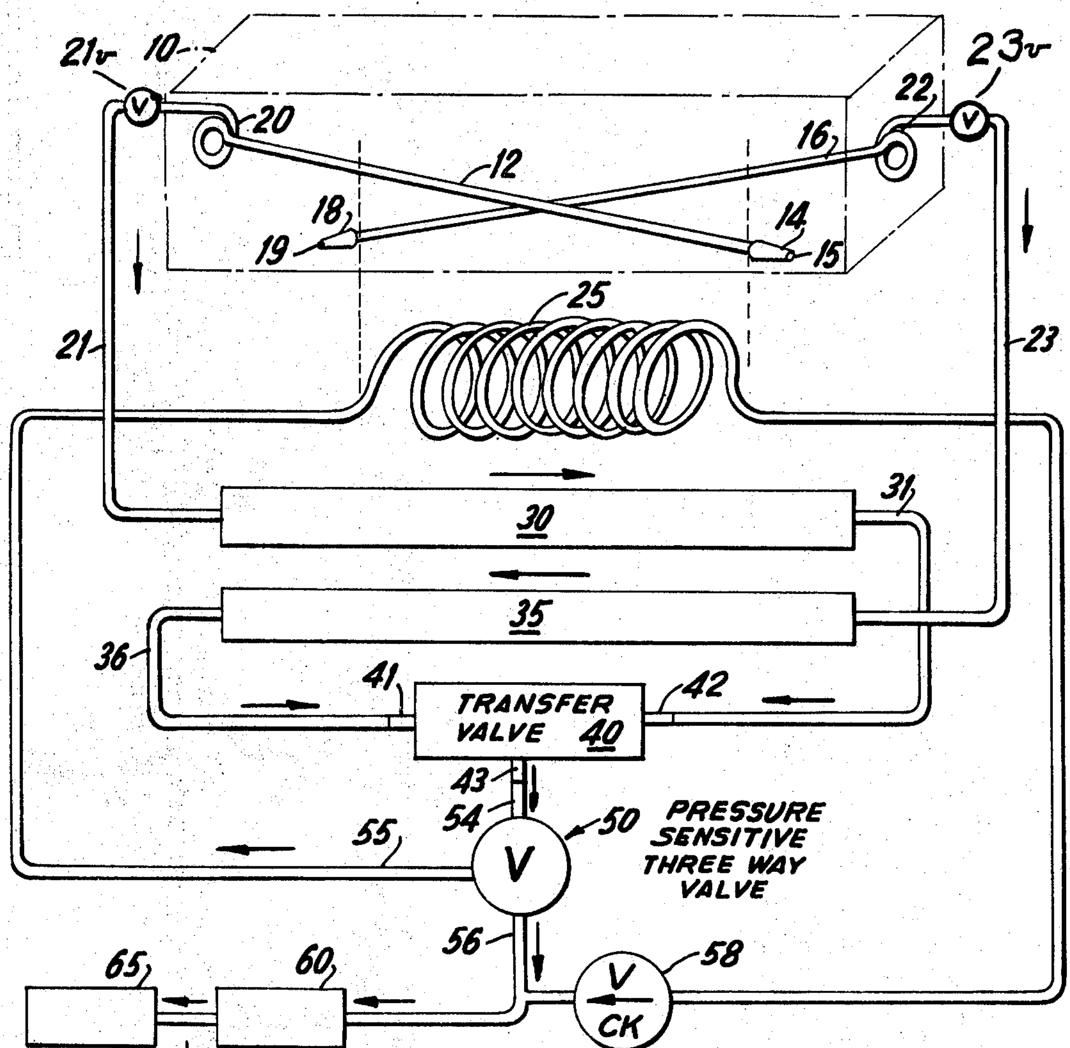


FIG. 1

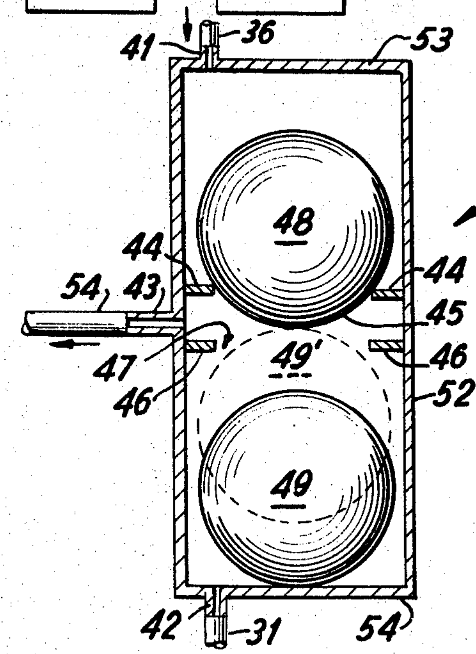


FIG. 2

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OMINPOSITIONAL CRYOGENIC UNDERWATER BREATHIND APPARATUS

This invention relates to underwater life support systems and, more specifically, to an underwater air supplying arrangement employing cryogenic, liquid state air storage.

Air has typically been carried by personnel engaged in underwater activities, such as military demolition and hazard fabrication, treasure hunting and salvage, scuba explorations, or the like in pressurized metallic air cylinders. However, the maximum permissible underwater stay for a user employing such pressurized cylinders is limited both by the restricted air capacity thereof for the range of permissible pressures, and by weight and bulk limitations which determine the maximum size and number of cylinders which may be transported.

To obviate this air capacity difficulty, cryogenic air supplies, i.e., very cold, liquid state air sources have been suggested. However, a cryogenic supply which is pressure rather than gravity actuated, and which ensures that the air supplied to a user is in all instances developed from a liquid and not a gas phase source thereof, and therefore contains the air constituents in a proper proportionate relationship, has heretofore been unavailable.

It is therefore an object of the present invention to provide an improved underwater air source.

More specifically, an object of the present invention is the provision of a cryogenic air source which supplies only transformed liquid state air to a user, and which ensures air availability by positive pressure actuation for any orientation of the equipment.

These and other objects of the present invention are realized in a specific, illustrative embodiment thereof wherein a tank containing a liquid state air mixture includes two fluid pickup tubes flexibly mounted to the tank end walls by coiled tube sections. The tubes traverse through the tank, include weighted input orifices disposed at the free ends thereof, and are each connected by an evaporating tube member, exposed to the underwater medium, to an input of a transfer valve.

The transfer valve selectively connects one or both of the air supplying conduit paths to a common demand-type regulator from which the user can draw air as required. Depending upon the physical orientation of the composite system, one or both of the two pickup tube orifices will reside within the liquid phase air pool, with liquid air being removed from the tank through the tube(s), under action of the internal tank pressure, vaporized into a gaseous state, and passed to the user.

To ensure delivery of air, the system is maintained in a sufficiently pressurized state by selectively passing the vaporized, relatively heated air through a coil located in the liquid tank to supply pressure increasing thermal energy thereto. Also, to keep the system pressure below dangerous proportions and in a range of regulation, a pressure lowering mechanism comprising a pressure reducing valve is connected at each input tube orifice to vaporize liquid within the tank, thereby extracting thermal energy from the contents thereof and lowering the tank pressure.

A complete understanding of the present invention, and of the above and other features and advantages thereof may be gained from the following detailed description of an illustrative embodiment thereof presented hereinbelow in conjunction with the accompanying drawing in which:

FIG. 1 is a schematic diagram, partly in exploded view form, depicting the cryogenic breathing arrangement which embodies the principles of the present invention; and

FIG. 2 is a cross-sectional view of a transfer valve shown in FIG. 1.

Referring now to FIG. 1, there is shown a cryogenic underwater breathing arrangement which includes a tank 10 of any geometry which stores air in liquified form. The tank 10 is mounted by insulation standoffs in an outer, durable tank jacket with an insulating medium being disposed between the reservoir 10 and the jacket. For purposes of clarity, the insulating standoffs and the tank jacket are not shown in the drawing.

Two liquid air pickup tubes 12 and 16 traverse through the length of the tank 10 and respectively include, at one end, a weight 14 or 18 and a liquid air input orifice 15 or 19. The tubes 12 and 16 are respectively connected to coiled tube sections 20 and 22 which have springlike properties, and which permit the weighted ends of the tubes bearing the input orifices 15 and 19 to freely move about the cross section of the reservoir 10 under the action of gravity operating upon the weights 14 and 18. Thus, as long as some liquid air remains in the reservoir 10, at least one of the two orifices 15 or 19 will be positioned within the liquid pool for extraction thereof independent of the orientation of the composite breathing arrangement.

Liquid air will selectively flow through the tube members 12 and 20 under pressure actuation, more particularly described hereinafter, next passing through a conduit 21 and into a heat exchanging evaporator tube 30 which may comprise a hollow straight or coiled tube which is exposed to the ambient underwater environment. Since the water temperature (typically from above freezing to around 90° F.) is very much higher than that of the liquid air (a temperature measured in hundreds of degrees below zero degrees Fahrenheit), the liquid air will boil and vaporize as it absorbs heat while passing through the tube 30. The gas phase air leaving the tube 30 flows through a conduit 31 and into an input port 42 of a transfer valve 40. Similarly, liquid air selectively flows through the tube members 16, 22 and 23 into a heat exchanging evaporator tube 35 where it is converted to gaseous form, and thence flows via a conduit 36 into an input port 41 of the valve 40.

The transfer valve 40, an illustration embodiment which is shown in detail in FIG. 2, is physically attached to the reservoir tank 10, with the long axes thereof being parallel. Accordingly, the valve 40 changes its orientation as the attitude of the tank 10 changes. The transfer valve 40 includes an outer housing 52 of cylindrical or other suitable shape, having end plates 53 and 54, and two centrally located, spaced annular discs or O-ring members 44 and 46 which extend transversely across the housing in its midsection and respectively include central apertures 45 and 47. The valve inlet ports 41 and 42 are eccentrically mounted on the end plates 53 and 54 or the valve housing 52 between these end plates and the corresponding discs 44 and 46, and the outlet port 43 is disposed intermediate the plates 44 and 46.

A metallic spherical ball 48 is included in the valve 40 in the chamber between the plates 44 and 53, with the ball being free to roll between these members under gravity actuation. Similarly, a ball 49 is adapted for rolling translation and is included in the valve 40 in the chamber between the plates 46 and 54.

When the valve 40 is oriented as shown in FIG. 2, such that the end plate 53 is vertically upward, the ball 48 rests on the plate 44, thus sealing the aperture 45 and isolating the valve ports 41 and 43. Further, the ball 49 rests on the end plate 54. The air must be free to pass from the eccentrically mounted input port 42 around the ball 49. Therefore, the cross section of the housing 52, if round, must be larger than the diameter of the balls 48 and 49. If the cross section of the housing is irregular the balls will not completely seal the inner periphery of the housing. Air then passes through the aperture 47 in the disc-shaped plate 46 and out through the output port 43. Thus, for this particular valve attitude illustrated, the ports 42 and 43 are connected and the port 41 is blocked.

When the valve 40 is inverted with the end plate 54 up, the sphere 49 covers the aperture 47 in the plate 46 thereby isolating the ports 42 and 43, with the ball 48 resting on the end members 53 thus permitting passage of air from the input port 41 to the output port 43.

The discs 44 and 46 are spaced close enough together such that the balls 48 and 49 cannot simultaneously block the apertures 45 and 47. Examining FIG. 2, note that with the ball 49 touching the seated ball 48 as shown for the dashed position 49′ (a possible condition when the valve 40 is horizontal), the aperture 47 is unblocked, and the ports 42 and 43 are connected. This relationship accrues when the diameters of the balls 48 and 49; the diameters of the disc apertures 45 and 47; and the spacing of the plates 44 and 46 are adjusted such that the balls will interfere and prevent the apertures 45 and 47 from being simultaneously blocked under any condition. Accordingly, the output port 43 is always connected to one of the input ports 41 and 42 and sometimes connected to both.

Referring again to FIG. 1, the output 43 of the valve 40 is connected by a tube 54 to a pressure sensitive three-way valve 50. The valve 50 passes air from the tube 54 to an output conduit 56 when the air pressure in the tube 54 exceeds the ambient pressure by a predetermined amount. If the pressure is less than this threshold level, the valve 50 diverts the air flow in the tube 54 to a conduit 55. Specific embodiments for the valve 50 will be readily apparent to those skilled in the art. More specifically, when the pressure in the air supplying system does not exceed the ambient parameter by at least the desired minimal amount, the gaseous airstream is diverted to the tube 55 by the three-way valve 50 and thence flows through a coiled tube 25 physically included within the insulated tank 10 and preferably surrounding the tubes 12 and 16. The relatively warm air in the tube 25 gives up thermal energy at it flows through the tube 25 thus heating the contents of the tank 10, thereby in accord with known laws of physics, increasing the pressure thereof since the volume of gas plus liquid remains substantially unchanged.

After exiting from the coil 25, the air vapor reenters the conduit 56 through a check valve 58. It is warmed by passage through a heat exchanging tube 60 (similar in construction to 30 and 35) exposed to the ambient temperature after its travel through the tank 10 to be warmed to a more satisfactory temperature to the air system user, and then flows for end use to a demand regulator 65 of any well-known construction where it is available for withdrawal by the user at ambient pressure.

To illustrate a typical sequence of operation for the underwater breathing apparatus of FIGS. 1 and 2, assume that the arrangement is attached to a user, as by a back-mounting pack or the like. The tank 10 exhibits a temperature-dependent internal pressure generated by vaporization of a portion of the liquid air in a fixed volume. When the user is vertically oriented, one end of the tank 10, e.g., that supporting the tube coil 20, and the corresponding end of the valve 40, i.e., that defined by the end plate 53 are disposed vertically upward. As long as this condition obtains, the internal pressure in the tank 10 forces liquid state air into the orifice 15 of the tube 12, with the force of gravity acting on the weight 14 and the liquid air pool to place the orifice 15 near the bottom of the liquid mass in the lowermost region of the tank. The air is driven by the internal system pressure through the members 12, 20 and 21 into the heat exchanger 30 where it vaporizes upon exposure to the relatively warm ambient temperature, and next flows into the port 42 of the transfer valve 40. Since the valve spheres 48 and 49 respectively reside against the valve members 44 and 54, the air passes through the valve 40 to the outlet port 43 and to the tube 54. Assuming the internal system pressure to be sufficiently large, the air passes through the valve 50 to the tube 60 where it is further warmed for user comfort and finally moves to the demand regulator 65 for consumption.

Should the internal tank and system pressure drop below the threshold level for any reason, or should the external ambient pressure greatly increase, as by the user moving to a lower water depth, the pressure sensitive three-way valve 50 operates to divert the incoming warmed vaporized air in the tube 54 to the tube coil 25. The relatively warm air in the coil 25 transfers heat to the contents of the tank 10, thus increasing its temperature and thereby also the internal pressure thereof. The air, cooled by the above heat exchanging process then flows out of the tube 25, and through the check valve 58 to the tube 60 where it is rewarmed and finally delivered to the regulator 65. This mode of operation continues until the system pressure is increased sufficiently whereupon the pressure valve 50 reconnects the tube sections 54 and 56 for direct passage of air.

Further for the above-assumed orientation for the composite breathing apparatus, gas phase air is driven under pressure from the upper portion of the tank through the orifice 19, the tube members 16, 22 and 23, and the heat exchanging tube 35 to the valve port 41. However, it is blocked by the ball 48 from reaching the valve output port 43 and hence is not supplied to the user. This vapor state source of air at the top of the tank 10 tends to be abnormally rich in nitrogen because of the difference in vaporization properties of oxygen and nitrogen. Should vapor state air be permitted to pass to the user for appreciable periods for any attitude of the system, the user would be supplied with nitrogen enriched air during such periods with the remaining liquid state air becoming oxygen rich. Thus, the user would alternately consume air with excess nitrogen (when the gaseous source thereof is used) and oxygen (when the liquid state material is drawn upon), a dangerous and potentially fatal condition. However, for the arrangement of FIGS. 1 and 2, the selected tube 12 or 16 (or both) draw only from liquid state source material, thus maintaining a proper constituent proportionate relationship in the end air product.

When the user inverts his attitude as by descending head first, liquified air is driven through the orifice 19 and the tube members 16, 22 and 23 to the tube 35 where it vaporizes, and then passes between the valve 40 ports 41 and 43 for passage to the warming heat exchanger 60 and the regulator 65. The air may or may not pass through the coiled tube section 25 under control of the three-way valve 50 depending upon the internal and external pressure conditions then obtaining.

For a horizontal orientation of the tank 10 and the valve 40 typically both of the tube apertures 15 and 19 will lie within the liquid air pool at the lowermost portion of the reservoir 10. At least one of the ports 41 and 42 of the valve 40 will be connected to the output port 43 and thus air taken by both of the tubes 12 and 16 can reach the regulator 65 for delivery to the user.

Thus, the arrangement of FIGS. 1 and 2 has been shown by the above to reliably convert liquid-state air to a gaseous phase for delivery to a user as demanded, under pressurized actuation, for all orientations of the apparatus.

"On-off" valves 21*v* and 23*v* will usually be included in the tubes 21 and 23 near or at their junction with the tank jacket, and maintained in the "off" condition until the arrangement is ready for use. This constrains the liquid air to the insulated tank 10 where it may be temporarily stored. Normally, however, the tank 10 will be charged with liquid air just before use. Similarly, vent and fill valves will be included within the lines 21 and 23 for cryogenic air refilling purposes, and a pressure-relief valve is connected to the tank 10 for safety, over pressure-relief purposes.

Then also, the weights 14 and 18 may advantageously comprise, or be supplemented with pressure reducing valves mounted at the ends of the pickup tubes 12 and 16. These valves produce a pressure drop as the liquid air is driven therethrough and, accordingly, a portion of the flowing liquid vaporizes within the tubes 12 and 16 by typical throttling action. Such evaporation occurring within the confines of the tank 10 substracts the heat required for its vaporization from the fluid in the tank, therefore reducing the temperature of the tank contents and pro tanto reducing the internal tank pressure. Thus, such pressure reducing valves on the tubes 12 and 16 tend continuously to reduce the system pressure, with the pressure being periodically built up and restored to the desired level when the pressure sensitive valve 50 selectively passes warmed gaseous air through the tube coil 25. Such combined mechanisms render the arrangement of FIGS. 1 and 2 capable of increasing or decreasing the system actuating pressure as conditions warrant.

It is to be understood that the above-described arrangement is only illustrative of the principles of the present invention. Numerous modifications and adaptations thereof will be apparent to those skilled in the art without departing departing from the spirit and scope of the present invention. For example, the valve 50 may alternatively be replaced by a "tee" connector, and a simple on/off regulating valve connected to the conduit 56. The on/off valve resides in a closed position and diverts the air output from the transfer valve 40 to the coil 25 when the system pressure is less than the threshold value. When the system pressure is adequate, the on/off valve opens, and the inherent resistance to flow of the check valve 58 inhibits air from flowing through the conduit path which includes the tank pressure increasing coil 25.

Also, the warming heat exchanging tube 60 may be placed intermediate the coil 25 and the check valve 58 to simplify mechanical construction of the composite breathing apparatus.

I claim:

1. In combination in an air supplying arrangement for supplying air to a human being, tank means for storing air in cooled liquified form, liquid air pickup tube means including input orifice means, means for mounting said input means within said tank means with said orifice means always disposed beneath the surface of the liquid air for any spatial orientation of said tank, means connected to said input tube means for vaporizing air passing from said orifice means and said pickup tube means, and air output supplying means connected to said vaporizing means for supplying air to a human being.

2. A combination as in claim 1 further comprising additional tube means passing through said tank means and connected to said vaporizing means and said output supplying means for increasing the pressure within said tank means.

3. A combination as in claim 2 further comprising a pressure responsive valve connected to said vaporizing means for selectively supplying air to said additional tube means or to said output supplying means, said pressure responsive valve means including means responsive to the pressure differential between the pressure of the ambient medium and the input pressure thereto for selectively directing air to said additional tube means for maintaining the tank interior pressure within a fixed range above that of the ambient medium.

4. A combination as in claim 2 further comprising heat exchanging means connected intermediate said pressure increasing tube means and said output supplying means.

5. A combination as in claim 2 further comprising pressure reducing means connected to said input tube orifice means.

6. A combination as in claim 1 further comprising pressure reducing means connected to said input tube orifice means.

7. In combination in an air supplying apparatus for supplying air to a human being, tank means for storing air in liquid form, first and second pickup tubes each including an air input end, means for mounting said tubes within said tank means for free translation of said tube air input ends about opposite ends of said tank means under the force of gravity, heat exchanging air vaporizing means connected to said tubes, output air supplying means connected to said vaporizing means for supplying air to a human being, and transfer valve means automatically connecting only the pickup tubes having an input end within the liquid air mass to said output air supplying means.

8. A combination as in claim 7 further comprising said transfer valve means including two input ports and an output port, said output port being connected to said output air supplying means, said vaporizing means including first and second heat exchanging elements each mounted for exposure to the ambient medium and connecting a different one of said pickup tubes with a different one of said valve input ports, means for mounting said valve in a fixed relationship with said tank means, said valve means including orientation responsive means for automatically connecting at least one of said input ports associated with a pickup tube having an input end within the liquid air mass to said output port.

9. A combination as in claim 8 wherein said valve orientation responsive means comprises first and second disc-shaped elements having a central aperture therein mounted in said valves with a space therebetween, said output port being included in said valve intermediate said disc-shaped elements, first and second spherical balls respectively disposed between said first and second disc-shaped elements and the periphery of said valve, said input ports being eccentrically mounted in said valve periphery between a different one of said disc-shaped elements and the valve extremity, the diameters diameters of the balls, the diameters of the apertures in said disc-shaped members, and the space between said disc-shaped members being adjusted such that the balls are prevented by mutual interference from simultaneously blocking the apertures in said first and second disc-shaped members.

10. A combination as in claim 8 further comprising additional conduit means for increasing the pressure within said tank means mounted within said tank means and connecting said valve outlet port and said output air supplying means.

11. A combination as in claim 10 further comprising a pressure responsive valve connected to said valve output port for selectively supplying air to said additional conduit means or to said output air supplying means.

12. A combination as in claim 11 further comprising air warming means connected to said output air supplying means.

13. A combination as in claim 8 further comprising means for effecting a pressure reduction connected to said first and second pickup tubes.

14. A combination as in claim 7 wherein said means for mounting said first and second tubes comprises first and second coiled tube sections respectively connected thereto and affixed to said tank means.

15. In combination in an air supplying arrangement for supplying air to a human being, tank means for storing air in cooled liquified form, outlet means disposed at opposite ends of said tank means for passing air from said tank under pressure actuation, transfer valve means including two input ports and an output port, said valve input ports each being connected to a different one of said tank outlet means, means for mounting said transfer valve means in a fixed relationship with said tank means, air output supplying means connected to said valve output port for supplying air to a human being, said transfer valve means including orientation responsive means for connecting the valve input port associated with the lowermost tank outlet means with said valve output port and for isolating said valve input port associated with the uppermost tank outlet means.

16. A combination as in claim 15 further comprising heat exchanging means connected between each of said tank outlet means and sad transfer valve means.

17. A combination as in claim 15 further comprising additional heat exchanging means communicating with the contents in said tank means connected between said valve output port and said output air supplying means.

18 A combination as in claim 17 further comprising pressure reducing means connected to said tank outlet means.

19. In combination in an orientation responsive valve, an outer housing, first and second members including a central annular aperture mounted in a spaced relationship within said housing, a first valve port connected between said first and second spaced members, first and second spherical balls included for relative translation between said first and second spaced members and said valve outer housing, respectively, said balls being adapted for relative translation toward or away from said first and second members under the action of gravity, the diameters of said balls being greater than the diameter of said central apertures in said first and second members, the diameters of said balls, the diameters of said apertures in said first and second members, and the spacing between said first and second members being adjusted such that the balls are prevented by mutual interference from simultaneously blocking the central orifices in said first and second members, and second and third valve ports being respectively mounted between said first and second members and said outer housing at locations removed from the axis of translation of said balls.