# Closed Respiration-Ventilation System for Use with High Altitude Full Pressure Garment

CAPTAIN RICHARD G. WILLIS, USAF and
LIEUTENANT COLONEL STANLEY C. WHITE, USAF (MC)

IN order to appreciate the advantages of the closed respiration-ventilation system over the open system, we should perhaps review the mechanics of both and discuss their respective advantages and disadvantages.

In the open system, the helmet is separated from the rest of the suit by a neck seal. Pressurization and oxygen concentration for this area are controlled by a pressure regulator which delivers 100 per cent dry oxygen gas to the helmet automatically at the correct pressure for the ambient altitude. The suit is pressurized by the ventilation air which flows at a rate of from 1 to 10 cubic feet per minute (cfm) as selected by the user. The suit regulator automatically maintains the correct pressure in the suit for the ambient altitude by control of the suit ventilation air exhaust. In normal use, a constant flow of oxygen and air is exhausted from the suit. The wearer breathes oxygen and exhales it through a valve into the suit proper, where it exits with the ventilation air through the suit ventilation air exhaust port.

The open system requires an oxygen system which will automatically provide the helmet with about 1.0 cfm of 100 per cent oxygen gas at the proper pressure and a suit pressurization-ventilation system which will provide the suit with from 1 to 10 cfm of ventilation air (by selection) at the proper pressure.

In the closed system, there is no seal separating the helmet from the suit and the 100 per cent breathing oxygen is used for ventilation of the wearer. Oxygen is circulated continuously within the suit and helmet at a flow of from 4 to 6 cfm. The suit and helmet are pressurized automatically for the ambient altitude. Oxygen, carbon dioxide, water vapor, nitrogen, and any toxic gases are maintained at correct levels automatically within the system but in a subsystem external to the suit.

In a comparison of the two systems, it becomes apparent that the closed system should provide tremendous savings of oxygen because none is vented overboard. This being true, the point at which a closed system becomes more practical for use in aircraft is determined by the duration of the mission to be flown and the weight of the closed system used. Based strictly on a weight-penalty comparison of the two systems, this point is approximately at a 6-hour period; however, if consideration is given to other factors such as the ventilation requirements and the defogging problem of the open system, which does not exist in the closed system, it is apparent also

From the National Aeronautic and Space Agency, Langley Research Center, Virginia. Presented by Dr. White who is a member of the NASA space task group.

that the closed system may be much more desirable even for missions of from 1 to 2 hours' duration.

As an illustration of the desirability of having a closed system, let us compare the basic requirements of both the open system and the closed system for a four-hour mission. In the open system, 1200 cu. ft. of air and 280 cu. ft. of oxygen plus electric power to run the helmet visor heater for defogging would be required. If the ventilation air is provided by a blower instead of bottled gas, then we must provide the blower plus the electrical power to run it. To provide the required ventilation flow and pressure, the blower must be a large, high-capacity type. In the closed system, about 4 cu. ft. of oxygen, a small blower for circulating the gas, 1 pound of chemical absorbent and a means of cooling and heating the recirculated gas, would be required.

### PHYSIOLOGIC REQUIREMENTS

For men to exist at the low ambient barometric pressures of high altitudes, adequate provisions must be made for his physiologic requirements.

The first of these is 100 per cent oxygen under pressure. Man exists very well at the earth's surface breathing only 21 per cent oxygen at a pressure of 14.7 psi; however, as the altitude increases (pressure decreasing), the oxygen concentration must be increased until at 34,000 feet, man must breathe 100 per cent oxygen or become hypoxic. To maintain the man's blood oxygen concentration at the correct level, we must provide 100 per cent oxygen under pressure as we climb above 40,000 feet; however, at 43,000 feet, we have reached man's limit to pressure breathe and at this point we must provide sufficient counter-pressure to the body or hypoxia again occurs.

In the closed system, both the increased oxygen concentration and the counter-pressure are provided within the suit cavity. The suit is pressurized so as to maintain an isobaric pressure corresponding to 25,000 feet until the absolute pressure falls to 5 pounds per square inch absolute (psia) at which time the suit is maintained at five psia as long as the suit is above this ambient altitude. An alternate pressure schedule provides for the suit to be maintained at an isobaric pressure corresponding to 35,000 feet until the absolute pressure falls to 3.5 psia. At this point, the suit is maintained at an absolute pressure of 3.5 psia, although at this pressure, man is highly susceptible to bends and other decompression sicknesses and must be denitrogenated prior to flight.

Five other environmental components remain to be controlled in the closed circuit system. The next is the nitrogen concentration within the system. This could be controlled by an initial purge of the system with oxygen before ascent to altitude but could be allowed to reach a partial pressure as high as 18 mm. Hg. Another is the carbon dioxide concentration of the system. The carbon dioxide content of the inspired air should be maintained below a partial pressure of 8 mm. Hg. for the best physiologic functioning of the man at all times. Next is the concentration of toxic gases such as methane from flatus. The total concentration of toxic gases should be maintained as close to zero as possible for the long term mission. Another environmental component is the relative humidity of the system. For maximum comfort and minimum tissue dehydration, the relative humidity should be maintained within 40 to 60 per cent. The last component of the environment to be controlled is the temperature of the circulating gases. The temperature of the system gases should be maintained at a comfortable level as they enter the ventilation suit within the pressure garment. This temperature should be thermostatically adjustable within from 50 to 80° F. as selected by the wearer.

With all of the specified environmental components maintained within their cited ranges, the partial pressure of oxygen available at the alveoli will never be lower than about 150 mm. Hg. (Table I). This oxygen partial pressure is about 50 mm. Hg. higher than man is accustomed to at ground levels, thus his blood oxygen content would never fall below the level at which man becomes hypoxic.

### POSSIBLE SOLUTIONS

A system which provides a suitable environment for a man using a high altitude full pressure garment must, of necessity, control all the components of such an environment if the man is to remain functional for more than short periods of time. These environmental controls may be grouped under (1) life controls, and (2) comfort controls.

*Life Controls.*—To maintain life in the closed system at low ambient barometric pressures, we must provide oxygen at the correct concentration and pressure and provide for the removal of toxic waste gases from the system. The required oxygen may be provided by a high pressure source, a liquid oxygen converter, chemical compounds, or a biological system. The system of choice depends upon a volume-weight penalty comparison, a control complexity comparison and a logistical comparison. Overall, the high pressure system (6 to 10,000 psi) seems to offer definite advantages for a closed one-man system since the required oxygen supply for such a system is relatively small.

TABLE I. PARTIAL PRESSURE OF GASES (EXCEPT OXYGEN) WITHIN THE ALVEOLI

| | | |
|---|---|---|
| Total Pressure of All Gases | | 258 mm. Hg. |
| Pressure of All Gases Except Oxygen | | |
| Water | 47 mm. Hg. | |
| Carbon Dioxide | 40 mm. Hg.* | |
| Nitrogen | 18 mm. Hg. | |
| Other Gases | 3 mm. Hg. | |
| Total | | —108 mm. Hg. |
| Total Pressure of Oxygen in Alveoli | | 150 mm. Hg. |

*Maximum $CO_2$ Partial Pressure

The removal of toxic waste gases is more difficult than providing the oxygen supply but may be accomplished in several ways such as by a calibrated leak in the system, by freeze-out in liquid gases, by a biological system, or by chemical absorbents. A casual inspection of the possible solutions might indicate that one system might provide both the oxygen requirements and for the removal of toxic waste gases; however, in practice, this is not necessarily true because one requirement may needlessly compromise the other, thus increasing the volume-weight penalty of the complete system. The size and type of the units selected will dictate the capacity of the system and the duration of time over which the system will be effective.

*Comfort Controls.*—To allow long-term use of the closed system, we must not only provide the life controls specified, but must also provide a comfortable environment for the man. The factors to be controlled for maximum user comfort are the temperature, relative humidity, and ventilation flow of the gases circulating within the system.

The temperature of the system's gases should be controlled by an automatic cooling-heating system. In such a system, the cooling could be accomplished with an expendable coolant system or with a vapor cycle system. The heating could be accomplished by use of an electrical heater or by utilizing the heat from aircraft equipment. The humidity of the system could be controlled by solid desiccants, liquid desiccants, by freeze-out in liquid oxygen or by cooling the system's gases below their dew-point. The ventilation flow would be provided simply and automatically by the circulation of the oxygen within the system.

### BEST POSSIBLE SOLUTION

The best possible solution would seem to be a combination of the several methods listed. Taken in order, the required environmental components and their regulation are as follows:

*Oxygen:* Oxygen would be furnished from a high pressure source (6 to 10,000 psi). This source would supply the 100 per cent oxygen required and would pressurize the suit automatically by means of a suitable pressure regulator according to the ambient altitude.

*Nitrogen:* Nitrogen would be removed initially by purging the system for five to ten minutes with 100 per cent oxygen after the system is closed and sealed. This could be done simply by means of a manually operated valve.

*Carbon Dioxide:* Carbon dioxide would be maintained below one per cent by circulating the system gases through granular LiOH which would quantitatively trap the $CO_2$ by absorption.

*Toxic Gases:* Any toxic gases present either from the man or from the suit materials would be removed by circulating the system gases through a chemical absorbent such as activated charcoal.

*Water Removal:* The relative humidity of the system would be controlled by circulating the system gases through a cooling mechanism after they leave the suit. The reduction in temperature of the system gases would condense the moisture out sufficiently to maintain the relative humidity between 40 and 60 per cent.

*Temperature:* A comfortable temperature of the system gases would be maintained by use of an electrical heater to reheat the gases to the de-

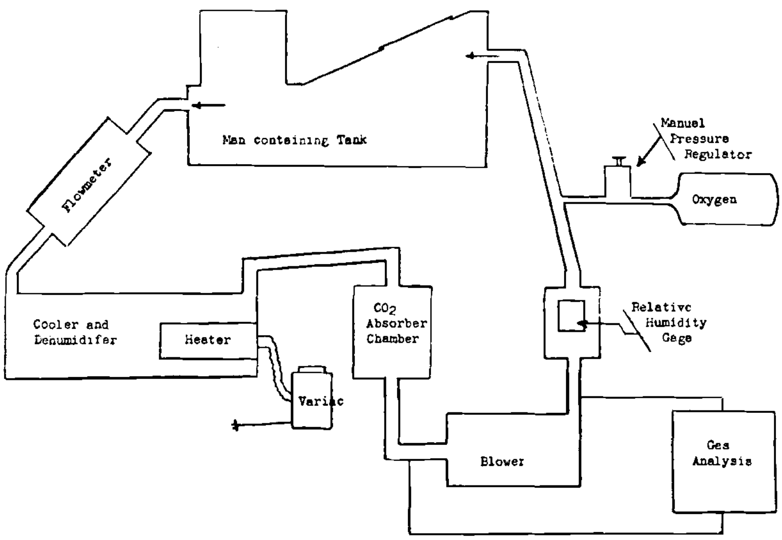


Fig. 1. Original schematic closed system used to test carbon dioxide absorption, oxygen consumption, and temperature and humidity control.

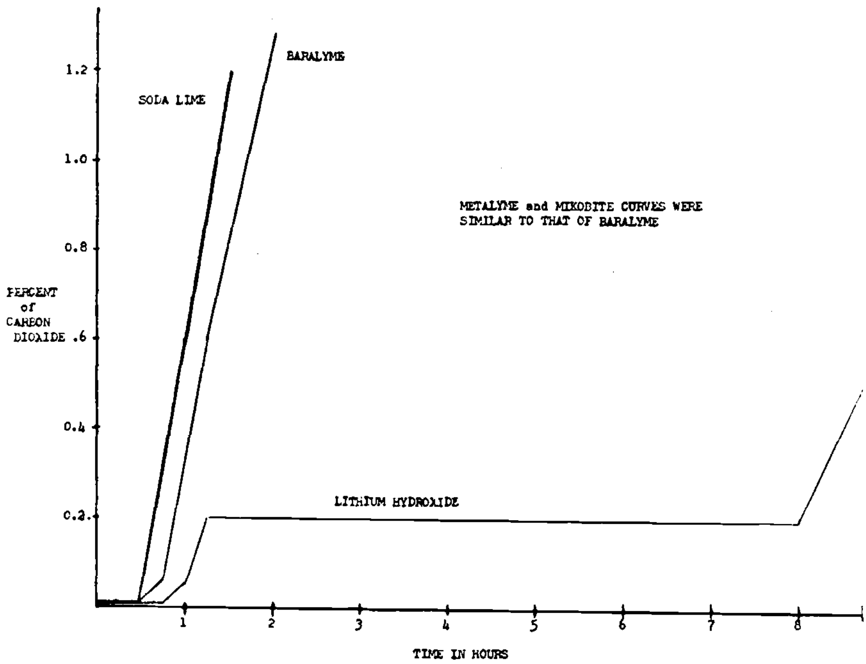


Fig. 2. Comparison of various chemical absorbents by time and by percentage of carbon dioxide maintained in atmosphere.

sired temperature after they leave the cooling mechanism.

*Circulation of System Gases:* The gases would be circulated through the suit and system by means of an electrically powered positive displacement blower. This circulation would bring the gases in contact with their respective control mechanisms for positive control of the environmental components, provide the ventilation flow over the man's body and would defog the helmet visor with the warm oxygen flow.

## EXPERIENCE TO DATE

The preliminary examination of the requirements for such a system seemed to offer no serious obstacles for its construction as a laboratory tool except perhaps the selection of a suitable carbon dioxide absorbent. It was felt that an ideal carbon dioxide absorbent would have the following characteristics:

*Mandatory Characteristics:*

1. High capacity (1:1 weight ratio or better desired)
2. Highly efficient (rapid absorption in high gas flow)
3. Maintaining initial absorption rate (until practically expended)
4. Permit a high gas flow
5. Reaction controlled at desirable rate
6. Reactive over wide temperature and humidity range
7. Unreactive with respect to oxygen
8. Low heat of reaction

*Desirable Characteristics:*

1. Cheap and readily available
2. Non-toxic
3. Dust-free
4. Easily handled
5. Non-caustic
6. Non-inflammable and non-explosive

With these characteristics in mind, a program was initiated to test the characteristics of several well-known carbon dioxide absorbents. The materials were tested in a closed system utilizing a sealed tank as the man-containing suit (Fig. 1). Preliminary testing of several chemicals in four hour runs indicated that soda lime, Metalyme, Baralyme and Mikobite were unsatisfactory in that their absorption capacity rapidly decreased as they absorbed $CO_2$ (Fig. 2).

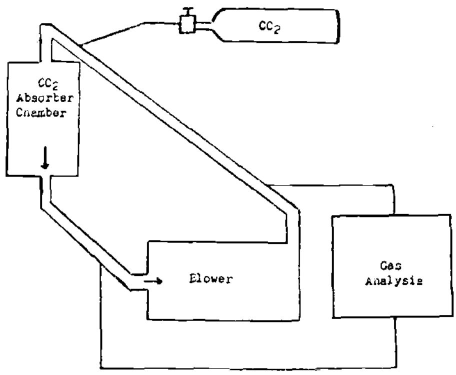


Fig. 3. Revised schematic system used for study of chemical absorption of carbon dioxide.

The closed system was then decreased in size by substituting a tank of 100 per cent $CO_2$ for the man-containing tank and all chemicals were retested at an increased $CO_2$ absorption rate (Fig. 3). The final results of this series of tests indicated that lithium hydroxide was the only $CO_2$ absorbent meeting the mandatory requirements of a suitable $CO_2$ absorbent for the system. In these tests, the weight ratio of lithium hydroxide to $CO_2$ absorbed was 1.5 pounds LiOH/ 1.0 pounds $CO_2$. This was the lowest ratio which would permit the $CO_2$ concentration to remain under 1 per cent for the selected period of twelve hours. Thus LiOH was selected as the absorbent of choice although it did not meet all of the characteristics of the final absorbent.

A more compact system was then constructed according to the recommended design, and utilizing LiOH as the $CO_2$ absorbent, was integrated with a developmental full pressure suit. With this system, several altitude runs have been made, lasting as long as seven and a half hours and at altitudes to 100,000 feet. No serious design errors have been encountered and the only remaining problem is to reduce the size of the cooling mechanism so as to package the system into a lightweight flyable kit suitable for present-day aircraft.

## SUMMARY AND CONCLUSIONS

Considerable economy of oxygen utilization in the use of full pressure altitude garments may be realized by a closed system over an open system. In addition, other advantages of the closed system are automatic defogging, reduced electrical power requirements, simplified regulator requirements and reduced dehydration of the man. The system described may easily be constructed, utilizing present knowledge, and will offer the possibility of extreme range high altitude missions not practicable with present equipment.