Concurrent Carbon Dioxide Control and Oxygen Generation for Advanced Life Support

Heather L. Paul, *Johnson Space Center*
Keith L. Duncan, *University of Florida*
Helena E. Hagelin-Weaver, *University of Florida*
Eric D. Wachsman, *University of Florida*

The electrochemical reduction of carbon dioxide (CO_2) using ceramic oxygen generators (COGs) is well known and widely studied; however, conventional devices using yttria-stabilized zirconia electrolytes operate at temperatures greater than 700°C. Operating at such high temperatures increases system mass compared to lower-temperature systems because of increased energy overhead to get the COG up to operating temperature, and the need for heavier insulation.

Recently, the University of Florida developed novel ceramic oxygen generators for NASA's future exploration of Mars. To reduce landed mass and operation expenditures during the mission, in-situ resource utilization was proposed using these COGs to obtain both life-supporting oxygen and oxidant/propellant fuel by converting CO_2 from the Mars atmosphere. The results showed that oxygen could be reliably produced from CO_2 at temperatures as low as 400°C. These results indicate that this technology could be adapted to CO_2 removal from a spacesuit and other applications in which CO_2 removal was an issue.

Existing life support technologies are too heavy for an astronaut to carry for a reasonable duration without exhaustion. This work focused on two crucial parts of the life support system: CO_2 removal from spacesuits, and oxygen (O_2) supply for breathing. Current CO_2 removal technologies are not suitable for use on a Mars mission because of their weight and/or interaction with the martian environment. For example, current CO_2 removal systems employing lithium hydroxide canisters would require about 60 lbs of consumables for a 5-day Mars surface mission. Thus, to decrease weight penalties, it is imperative to move beyond such systems. Cycling beds and permeable membranes are also unsuitable since the high-CO_2 concentration in Mars' atmosphere precludes venting of CO_2 after its removal from a spacesuit. Finally, current technologies do not recapture vital O_2 from the CO_2 molecule.

In the proposed strategy, CO_2 is electro-catalytically reduced at the cathode of a COG, which transports the O_2 ions away leaving behind solid carbon. The O_2 ions then recombine at the anode to form O_2 molecules. The driving force is an electric potential applied across a dense oxide ion-conducting electrolyte, as shown in figure 1.

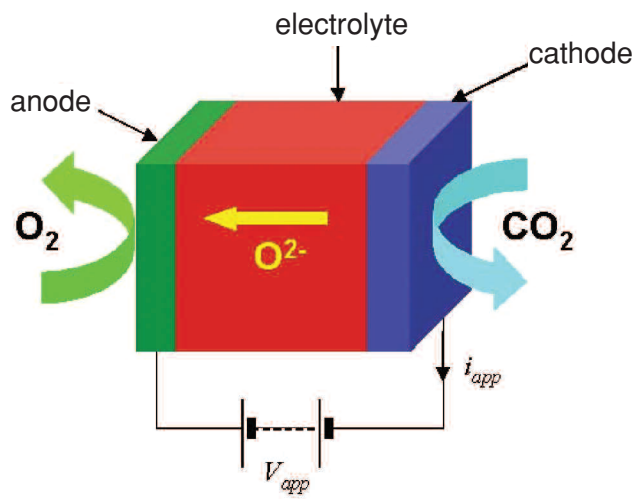

Fig. 1. Conceptual representation of a ceramic oxygen generator (COG).

Technical Approach

For the development of a viable low-weight COG for CO_2 removal in an advanced life support system: 1) a novel high (oxide ion)-conductivity electrolyte was used for lower operating temperatures; 2) a catalytic carbon deposition layer (CCDL) was employed to promote full CO_2 reduction while avoiding the problem of cathode "coking"; and 3) a pre-stage for CO_2 adsorption and concentration was designed to improve efficiency. These three facets will be integrated into a CO_2 removal system for advanced life support.

System Design

The CO_2 removal system has two stages, as shown schematically in figure 2 and prototypically in figure 3. Stage 1 is based on a system that was patented for nitrous oxide removal, and its purpose is to concentrate the CO_2 before it is released to the COG. Thus, the amount of O_2 pumped through the COG is limited to that liberated in the reduction of the CO_2, thereby reducing the power consumption. Figure 2a shows how the CO_2 (initial) removal and concentration is achieved. First, exhalate from the spacesuit is piped through one of two chambers, each containing a sorbent bed to remove CO_2 from the exhalate. By closing the valves v1 and v2 while opening the valves v3 and v4, the top chamber is excluded from the ventilation loop. Hence, CO_2 is removed from the exhalate stream by

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continued

the lower chamber only. Once sensor s2 indicates that the CO_2 concentration has attained a predetermined value, the operation is reversed so that CO_2 removal is handled by the top chamber while previously adsorbed and concentrated CO_2 in the lower chamber is desorbed and flows to the COG (stage 2) where it is reduced to carbon and O_2. The O_2 recovered by the COG can then be reintroduced to the ventilation loop as needed.

Stage 2, figure 2b, is the COG, which consists of a chamber housing tubular electrochemical cells, a removable CCDL, and its support. Each electrochemical cell is oriented so that the cathode side is inside the chamber and the anode side is on the outside of the compartment. A gas-tight seal, built into the chamber wall, isolates the cathode from the anode side of the COG. This allows O_2 produced at the anode to be readily collected and reintroduced to the ventilation loop. When carbon buildup surpasses an experimentally predetermined level, the removable CCDL can be replaced with another one. The carbon deposits may then be disposed of or reused.

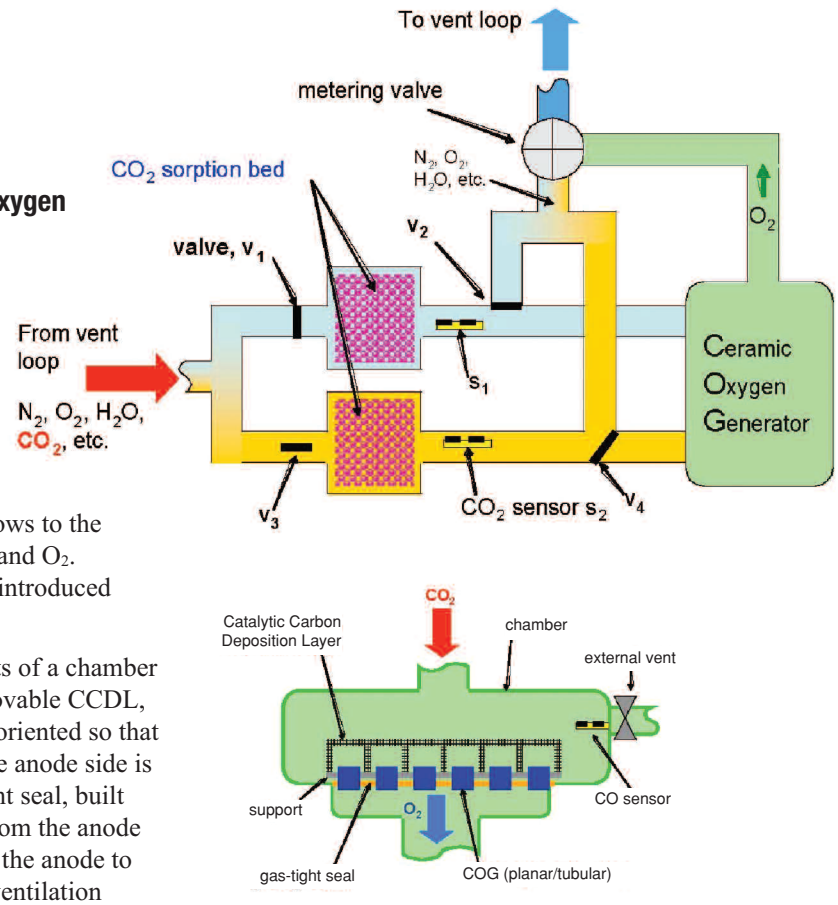

Fig. 2. CO_2 removal system (a) Stage 1: CO_2 removal from the ventilation loop; (b) Stage 2: CO_2 decomposition in the COG.

Conclusion

A concurrent O_2-generation and CO_2-control system for advanced life support was developed. The system consists of a novel high-oxide ion conductivity electrolyte suitable for low-temperature operation, a removable CCDL to promote full CO_2 reduction while avoiding the problem of "coking," and a pre-stage for CO_2 absorption to concentrate CO_2 from the exhalate before sending it to the COG. Based on earlier work, the device specifications are promising (thinner electrolyte, improved electrodes, and CCDL), and performance tests are currently being completed.

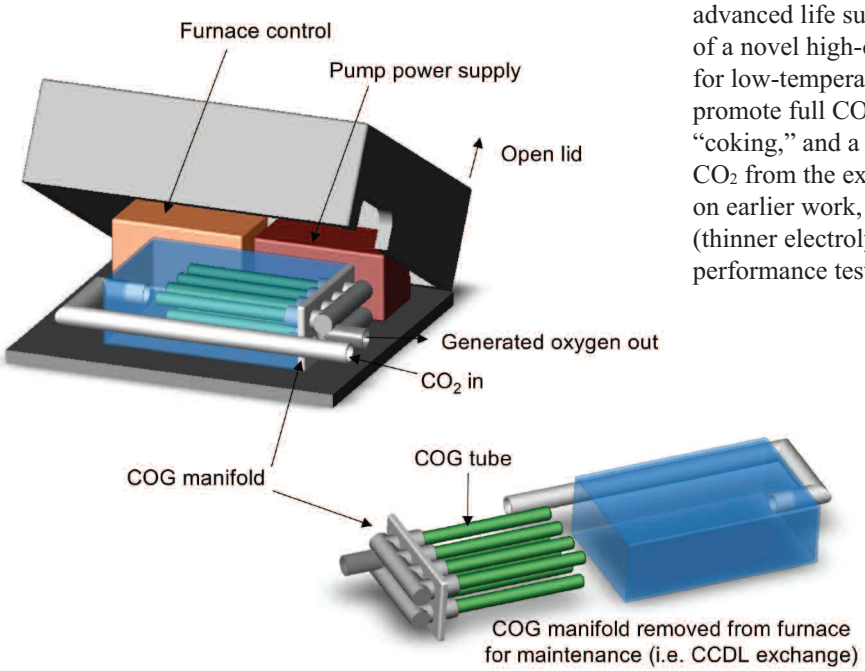

Fig. 3. Generator for Advanced Life Support System.