Continuously Regenerable Freeze-Out Carbon Dioxide Control Technology

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Carbon dioxide (CO_2) removal technology development for portable life support systems (PLSS) has traditionally concentrated on the areas of solid and liquid chemical sorbents and semipermeable membranes. Most of these systems are too heavy in gravity environments, require prohibitive amounts of consumables for operation on long-term planetary missions, or are inoperable on the surface of Mars due to the presence of a CO_2 atmosphere. This technology development effort matured an innovative CO_2 removal technology that meets NASA's planetary mission needs while adhering to the important guiding principles of simplicity, reliability, and operability.

A breadboard cryogenic CO_2 scrubber for an ejector-based cryogenic PLSS was developed, designed, and tested (figures 1 and 2). The scrubber freezes CO_2 and other trace contaminants out of expired ventilation loop gas using cooling available from a liquid oxygen (LOX)-based PLSS. The device was designed for continuous regeneration, with solid CO_2 being removed from the cold freeze-out surfaces, then sublimated and vented overboard. Continuous regeneration allows indefinite scrubber duration for as long as LOX is available from the PLSS.

Simplicity, reliability, and operability are universally important criteria for critical hardware on long-duration lunar or Mars missions. The cryogenic scrubber breadboard has no moving parts, requires no additional consumables, and uses no electrical power, contributing to its simplicity and reliability. It is easy to use; no operator action is required to prepare, use, or shut down the cryogenic scrubber and it does not require charging or specific regeneration periods. The versatility of the concept allows for operation on Earth, the Moon, and Mars.

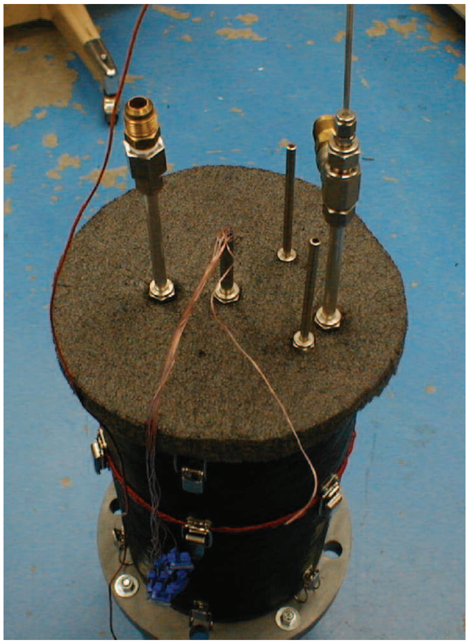

Fig. 1. Assembled cryogenic scrubber breadboard.

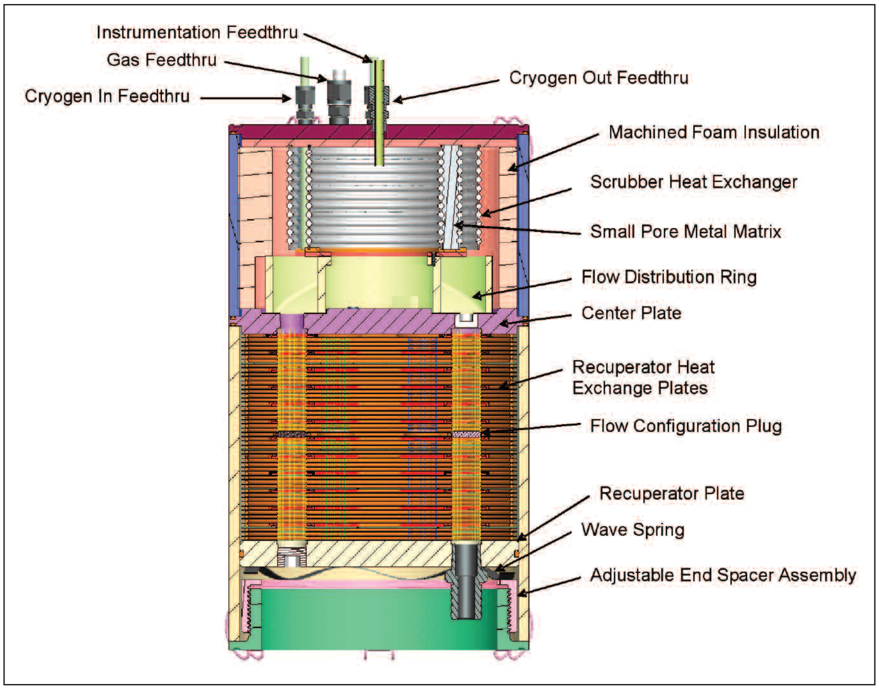

Fig. 2. Breadboard details.

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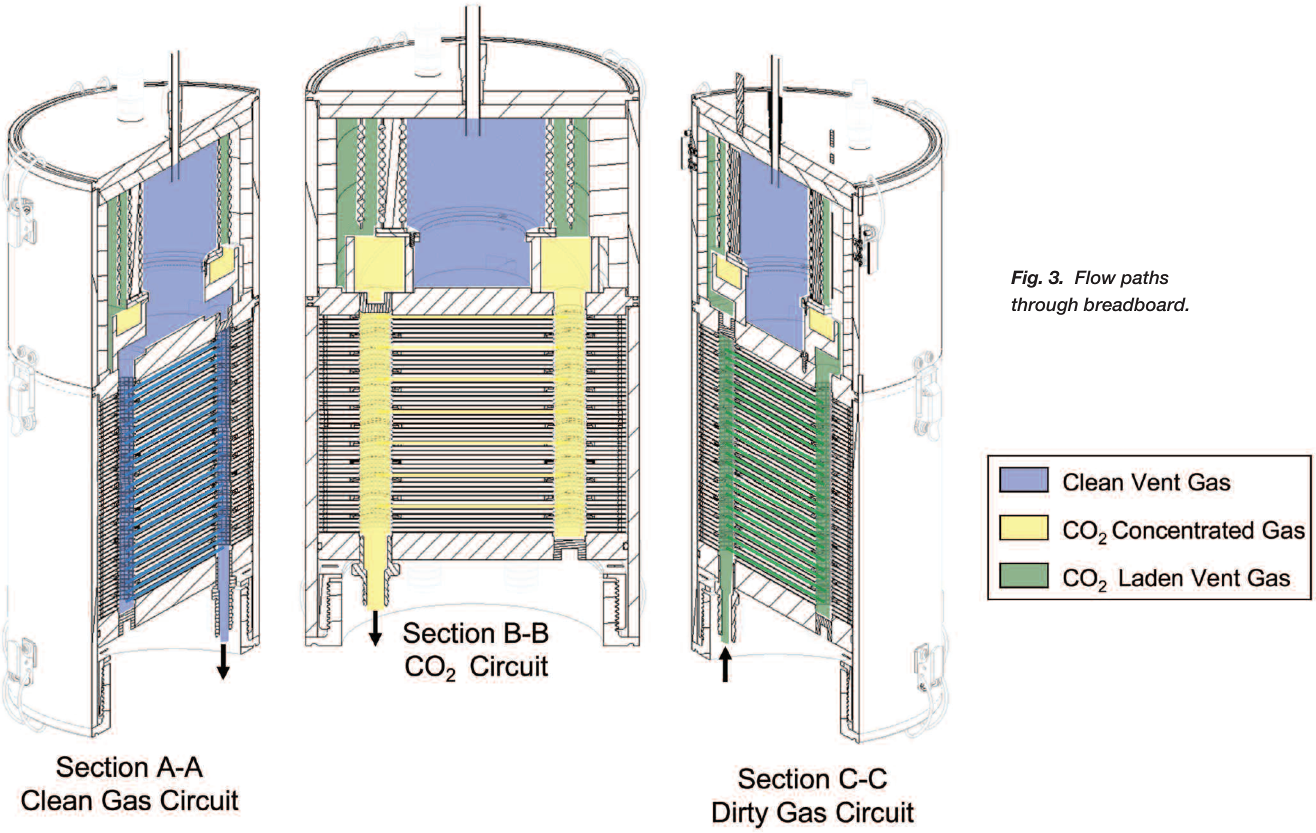

Fig. 3. Flow paths through breadboard.

Figure 3 shows the flow paths for the design. CO_2-laden ventilation gas enters the recuperator at the bottom of the device (shown in green, in section C-C of figure 3). The gas flow spreads out across the recuperator heat exchange plates to the other green tube. In this area, the CO_2-laden ventilation gas exchanges heat with the cold, cleaned ventilation gas exiting the scrubber and with the CO_2 snow being ejected from the scrubber, each on a different circuit within the recuperator. The ventilation gas entering the freeze-out portion of the device is cooled as it flows around the spiral cryogenic heat exchanger toward the center of the breadboard. The gas flows through the flow distribution ring and over the cooling coils where CO_2 is frozen out. A small-pore metal matrix behind the cooling coils allows the clean ventilation gas to pass through while preventing the CO_2 snow particles from continuing through the ventilation loop. The cold, clean ventilation gas returns through the flow distribution ring and into the recuperator, cooling the incoming ventilation gas (section A-A of figure 3). The CO_2 builds up until it is jarred loose from the cryogen heat exchanger or blown loose with an air impulse. It is sucked down through the flow distribution ring into the recuperator in the CO_2 concentrated gas circuit where it is sublimated, and then vented out the suit pressure relief device, which vents constantly for an ejector-based ventilation loop, providing the driving suction to remove the CO_2.

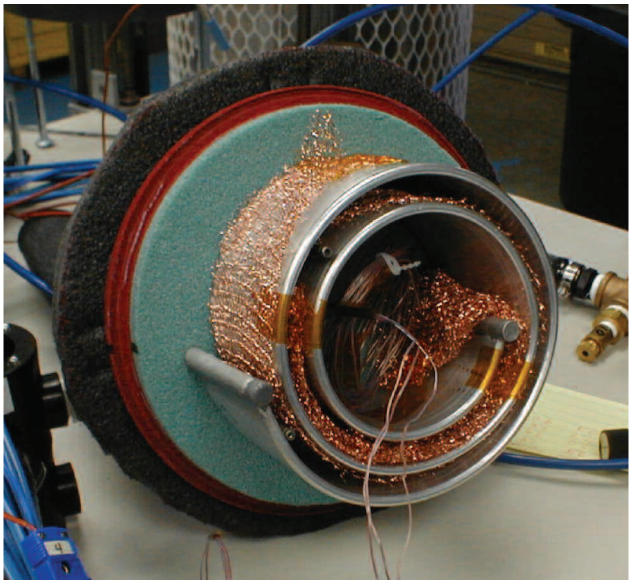

Fig. 4. Cryogenic heat exchanger.

Figure 4 shows the spiral cryogenic heat exchanger. Cryogen flows through the inside of this aluminum extrusion while the ventilation gas flows over the outside toward the middle. CO_2 freezes out onto the surface of the heat exchanger and drops down to the flow distribution ring below it. Also visible in the photograph are the air knives. These are used to pulse air through the spiral and dislodge solid CO_2 from the heat exchanger. The air knives are tubing with thin slots facing each other. When pressurized air is applied to the air knives, it exits the slots in a stream to fracture and entrain solid CO_2.

The breadboard that was developed, based on literature investigation, data gathering, experimental feasibility studies, and initial testing, met the design goals of:

- Modularity
- Accessibility
- Cost Efficiency
- Thermal Efficiency
- Subatmospheric Pressure Compatibility

During critical function and proof-of-concept testing, 27 sub-atmospheric tests were completed. MathCAD and spreadsheet models were correlated to the test data and used to make recommendations for further development.

The performance of the cryogenic scrubber breadboard was robust, removing adequate quantities of CO_2 with little sensitivity to internal leaks or impacts to the scrubber. The inability to easily remove solid snow from surfaces with sufficient heat exchange capability was a fundamental problem with this concept. Figure 5 shows how the flow passages of the heat exchanger became blocked due to CO_2 buildup. Additionally, it was determined that suit ventilation flows are too small to effectively vent released snow, even with optimal orientation in an Earth-gravity environment.

Based on the testing performed during this project, the best option for a cryogenic scrubber is to freeze and store the CO_2 for the duration of the extravehicular activity, rather than continuously regenerating it. Similar work, completed in 2002, successfully demonstrated storing 4 hours' worth of CO_2 in a chilled metal matrix and regenerating it after the 4 hours of scrubbing. This approach could be easily extended to an 8-hour capacity and retain the simple and reliable aspects of the process, but it requires increased operational overhead because it must be regenerated between uses. Similar to the breadboard tested, this approach would use no power, have no moving parts, and require no special consumables.

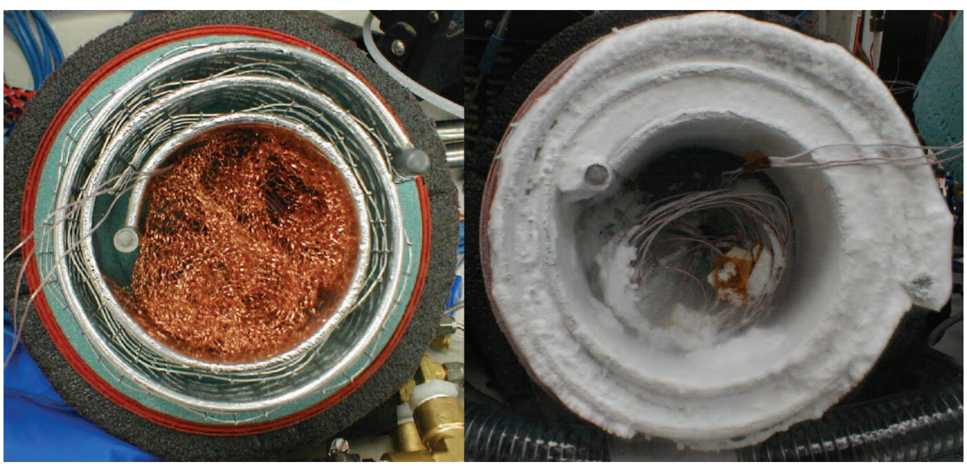

Fig. 5. Before and after pictures of CO_2 plugging flow passages.