Exploration Life Support Air Revitalization System Technology Development for Human Test Subjects

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The baselined Crew Exploration Vehicle (Orion) Environmental Control and Life Support System (ECLSS) technology for controlling metabolically produced carbon dioxide (CO_2) and water vapor (H_2O) is a pressure-swing adsorption bed that uses a regenerable amine-based sorbent. The sorbent selectively scrubs H_2O and CO_2 gases from the cabin environment and vents them to the vacuum of space. Carbon dioxide and moisture removal amine swing-bed (CAMRAS) technology (developed by Hamilton Sundstrand, Windsor Locks, Conn.) has undergone extensive test and evaluation activities.

The CAMRAS technology uses a pair of packed beds of amine-based sorbent, which have an affinity for gaseous CO_2 and H_2O. Cabin air is forced through one of the beds, and the CO_2 and H_2O in the air adsorbs onto the sorbent media. Concurrently, the other bed is isolated from the cabin environment and exposed to space vacuum. The change in partial pressure of the CO_2 and H_2O due to space vacuum causes these gases to desorb from the sorbent media and vent to space, thereby regenerating the sorbent media. A spool valve on the CAMRAS hardware translates from one position to the opposite position, and the process is reversed: the bed exposed to vacuum is now exposed to the cabin environment, and the bed exposed to the cabin environment is now being regenerated. The packed beds are interleaved and thermally linked in the CAMRAS hardware. The adsorption process is exothermic and the desorption is endothermic. Heat is thus transferred from the bed that is adsorbing CO_2 and H_2O is transferred to the bed that is undergoing desorption. This arrangement provides a compact design, low-pressure drop, and relatively isothermal performance. Figure 1 presents a visualization of the CAMRAS hardware. The spool valve is located on top of the hardware, and the lower section contains the interwoven beds of sorbent media.

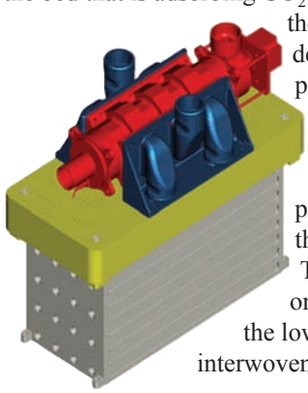

Fig. 1. *Carbon dioxide and moisture removal amine swing-bed.*

Following more than 2 years of crewless testing on the CAMRAS hardware using simulated metabolic loads, a three-part CAMRAS/Constellation Suit Integrated Test (CCSIT) series was developed where different technologies and hardware components will be integrated and tested as a subsystem rather than as individual components.

The initial CCSIT with the CAMRAS hardware in a relevant environment with humans occurred in 2008. Most tests involved either four or six test subjects at a time in a sealed-up test chamber configured for a volume similar to that of Orion. Test subjects were asked to perform activities at metabolic loads, including nominal activities, exercise, and sleeping. The test team maintained test chamber pressure at 14.7 psia, and introduced oxygen (O_2) into the chamber so as to maintain 21% O_2 levels throughout the length of the tests. Two CAMRAS units were used in parallel. Oxygen, CO_2, and H_2O levels in the air were continuously monitored. Figure 2 is a picture of the ECLSS hardware that was installed in the test chamber.

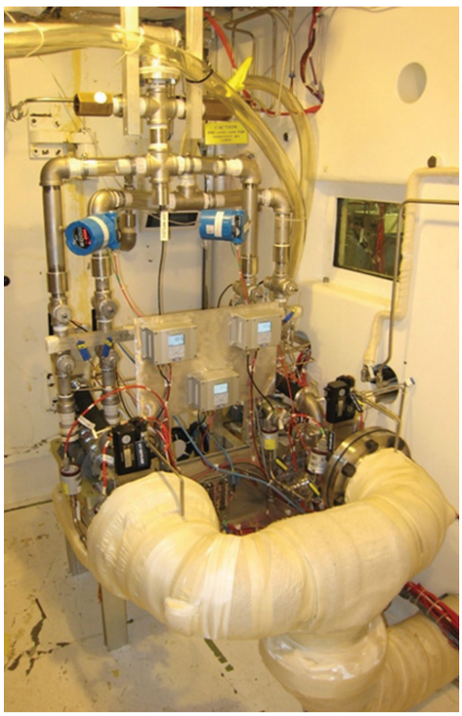

Fig. 2. *CAMRAS hardware in the test chamber.*

Nominal activities generally comprised either four or six test subjects sitting, standing, stretching, moving about, working on their computers, eating, and using the toilet. Subjects provided regular feedback to the test team on how the environment felt while inside the chamber. Tests lasted 6 to 10 hours, depending on how long it took to achieve steady-state levels of CO_2 and H_2O inside the chamber. The test team adjusted flow rate and cycle time of the CAMRAS valve during the test to target dew points between 35°F and 45°F. Results indicate that CO_2 levels were comparable to the crewless simulated tests, but that humidity levels were lower than expected. Because of this, the flow rates required to achieve the target dew points were lower than modeling and crewless tests had suggested.

Exercise activities were conducted for many of the tests, where either one test subject would exercise for 30 minutes while the other three test subjects performed nominal activities or the test subjects would take turns exercising for 30 minutes each, with 15-minute breaks between test subjects. Test subjects who were exercising would wear a heart-rate monitor to verify they achieved a target exercise rate of 75% VO_2 max. The test team monitored power output, a measure of how much work the test subject was doing while exercising on the stationary bicycle, during the exercise period. When only one test subject exercised for a given test day, the team evaluated how long it took for the chamber air to return to pre-exercise CO_2 and moisture levels, including drying time for sweat-drenched clothing, and compared this with human-systems integration requirements values for H_2O generation rates. When test subjects exercised in series, the test team evaluated how high the dew point would get with the CAMRAS units operating at full capacity (50 cfm airflow through each CAMRAS unit, 3-minute cycle time for rapid regeneration). Condensation could occur if the atmospheric dew point exceeded the coldest inside surface of the habitable portion of the Orion crew module. Results indicated that for single-exerciser cases, maximum dew points varied from 42°F to 49°F and 60 to 75 minutes later the dew point returned to pre-exercise levels. For the multiple-exercisers cases, maximum dew points range from 51°F to 56°F and also took 60 to 75 minutes to recover to pre-exercise levels. The humidity and CO_2 levels for both the single-exerciser cases and the multiple-exerciser cases trended similarly with simulated exercise loads. Figure 3 shows one of the test subjects exercising on the bicycle.

Fig. 3. *Test subject exercising in the test chamber.*

Sleep scenario cases involved four test subjects entering the test chamber 2 hours prior followed by an 8-hour sleep period. One hour after waking, one test subject exercised for 30 minutes on the exercise bicycle to induce a significant change in humidity and CO_2 levels in a short amount of time and to determine how well the CAMRAS hardware could catch up with the dramatic change. Results indicate that humidity levels were erratic throughout the night, and a steady-state level was never achieved, although the CO_2 concentration achieved steady-state levels 2 hours after the test subjects went to sleep.

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continued

Additional tests involved test subjects on respirators that were specially designed to be plumbed directly to the ECLSS cabin process air loop plumbing. This was to simulate an emergency scenario where crew members would breathe directly off the ECLSS hardware if a toxic event occurred inside the cabin. One, four, and six test subjects donned and doffed respirators at different intervals. The objectives were to determine how dry the air would get if the only source of humidity is from respiration (vs. respiration, perspiration, and evaporation) and what pressure/flow effects occur when the fixed volume shrinks from approximately 570 ft^3 to approximately 6 ft^3. Results indicate that the dew point could get as low as –4°F (the relative humidity was less than 5%) in the case of only one test subject; the dew point was as high as 10°F for more test subjects. Pressure effects were also dramatic. The expandable respirator hoses changed shape during the test each time the test subjects inhaled or exhaled. This effect was especially pronounced when six test subjects were directed to inhale and exhale at the same time (figure 4). A second set of CCSIT operation uses CAMRAS hardware, prototype Constellation umbilicals, and spacesuit volume-simulator tanks. These crewless tests are performed in a vacuum chamber at simulated spacesuit operational conditions of 100% O_2 at a reduced pressure of 4.3 psia. CAMRAS performance and pressure drop/flow characteristics of the umbilicals are evaluated for different operation parameters.

Fig. 4. *Test subjects during in-line respirator tests.*

Phase 2 is also the first time that the CAMRAS hardware is tested in these extreme environmental conditions.

For the third phase of CCSIT operation, the CAMRAS hardware, spacesuit umbilicals, and pressure suits use an integrated hardware over the full range of mission scenarios. Tests include human test subjects in shirtsleeve cabin environments during sleep, nominal, and exercise metabolic loads; at various cabin pressures and O_2 concentrations; and in pressure-suit environments. All tests must be completed prior to the Orion Critical Design Review.

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