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CDRA-4EU Testing to Assess Increased Number of ISS Crew

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The International Space Station (ISS) program is investigating methods to increase carbon dioxide (CO2) removal on ISS in order to support an increased number of astronauts at a future date. The Carbon Dioxide Removal Assembly – Engineering Unit (CDRA-4EU) system at NASA Marshall Space Flight Center (MSFC) was tested at maximum fan settings to evaluate CO2 removal rate and power consumption at those settings.

Nomenclature

AES	=	Advanced Exploration Systems
ARREM	=	Atmosphere Resource Recovery and Environmental Monitoring
4BMS	=	Four Bed Molecular Sieve
CDRA-4EU	=	Carbon Dioxide Removal Assembly, Revision 4 Engineering Unit
CO2	=	Carbon Dioxide
Delta-P	=	Pressure Drop
ECLSS	=	Environmental Control and Life Support System
E-Chamber	=	Environmental Chamber
HEO	=	Human Exploration and Operations Directorate
ISS	=	International Space Station
LSSP	=	Life Support Systems Project
MSFC	=	Marshall Space Flight Center
Pa	=	Pascal
ppCO2	=	Partial Pressure of Carbon Dioxide (torr)
RPM	=	Rotations Per Minute
SLPM	=	Standard Liters per Minute

I. Introduction

NASA is developing multiple CO2 removal strategies to support an increased number of astronauts on ISS (International Space Station). In conjunction with new technologies planned for flight experiments, a test program to explore an increase in CO2 removal rate with the current Four Bed Molecular Sieve (4BMS) system was also requested. The team performed tests on a 4BMS ground test system named CDRA Dash 4 Engineering Unit (CDRA-4EU). This system was constructed under the Atmosphere Resource Recovery and Environmental Monitoring (ARREM) Project operating under the Human Exploration and Operations (HEO) directorate.[1.] The system was developed to more closely mimic the current CDRA-4 configuration on ISS[2-4]. The CDRA-4EU configuration, which is located in the MSFC Environmental Test chamber (E-chamber) is used to develop technology for advanced exploration, and also to support on-orbit anomaly investigations as needed[5]. CDRA-4EU used the flight-model fan, designed and manufactured by Honeywell, that was paired with a commercial controller purchased from Celeroton.

II. Test Objectives

The team designed the test program to integrate the fan and controller prior to testing on the CDRA-4EU system.

A. Integration of Celeroton Controller into CDRA-4EU System

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B. Determine maximum CO_2 removal by increasing fan power
C. Evaluate power required to operate fan at higher speeds

III. Hardware and Test Facility

The CDRA, built by Honeywell (formerly AiResearch and Allied Signal) uses a fully regenerative thermal/pressure swing adsorption process to remove CO_2 from the ISS cabin air. The CDRA operates cyclically and employs two desiccant beds and two adsorbent beds. As one desiccant bed and one adsorbent bed operate in adsorption mode, the other two beds are desorbing (regenerating). Halfway through a cycle, the beds switch modes, providing continuous CO_2 removal capability.

CDRA-4EU (Figure 1) is located in the E-Chamber (Environmental Chamber) located in the MSFC ECLSS (Environmental Control and Life Support System) Development Facility. The E-Chamber provides the capability to replicate and control dry bulb temperature, $ppCO_2$ (CO_2 Partial Pressure), humidity, airflow and trace contaminant levels. Because CO_2 reduction was not required for this test series, CO_2 was vented to vacuum on all tests listed in this report.

Figure 1. CDRA-4EU

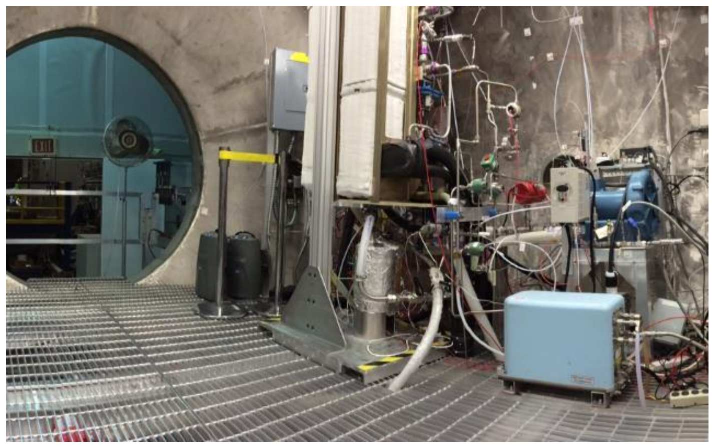

Figure 2. E-Chamber

IV. Commercial Controller Integration and Fan Curve Validation

MSFC possessed a flight-model fan, but no corresponding controller. A manufacturers search yielded a commercial controller suitable to operate the flight fan. Celeroton, a Swiss company based in Zurich, produces and sells ultra-high-speed electric motor-drive systems and controllers.

A. Celeroton Integration Component Validation of Fan Curve

The Celeroton controller (Figure 4) was integrated with the flight fan (Figure 3) and tested in a bench-top experimental test stand. The fan was tested with flow controllers, a flow meter, an appropriately ranged delta-pressure transducer, and a variable backpressure orifice. The fan curves for the flight fan were measured while developing a custom Lab VIEW program interface to command the controller. The results shown in the next section were measured at 25 °C inlet air temperature and atmospheric pressure.

Figure 3. CDRA Flight Fan.

Figure 4. Celeroton Fan Controller

B. Integration of Celeroton Controller into CDRA-4EU System

After successful integration on the component test stand, the flight fan and controller were installed into CDRA-4EU. Modifications were required to cable shielding and interface adapters before the Celeroton controller would operate reliably in the CDRA-4EU system. The controller was initially commanded to stop during half-cycle transitions, but due to a difference between the Honeywell fan speed measurement and the Celeroton controller algorithm, the fan software would stall. The manufacturer supplied new parameters, and the fan commanded to 40,000 RPM during half-cycle transitions.

A direct command set the fan to 110,000 RPM for the initial test. The fan remained at that value for 1 minute before manual adjustment by 5,000 RPM increments, as shown in Figure 5. Testing revealed no problems with the software, controller or fan operation. At the maximum 150,000 RPM operating limit, CDRA-4EU measured over 800 standard liters per minute (SLPM) of flow at the system inlet.

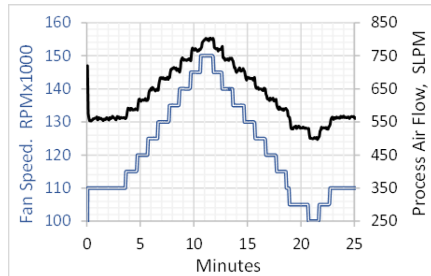

Figure 5. Process Air Flow vs. Fan Speed

C. Controller Transient Response

In a separate test, fan speed was commanded to increase in 10,000 rpm increments every 30 seconds. The data acquisition rate was set to one sample per second to observe the tolerance to which the controller could maintain fan speed. When subjected to 10,000RPM shifts, the fan responded in under 2 seconds and remained at the commanded level within +/- 10 RPM. See Figure 7. When commanded between 150,000RPM and 40,000RPM, the fan reached steady RPM levels in 10 seconds. See Figures 8 and 9.

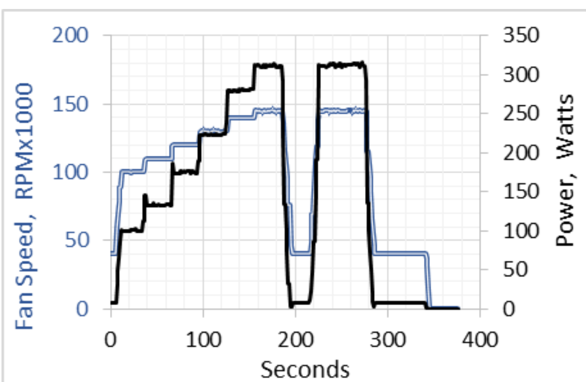

Figure 6. Fan Speed vs. Power in CDRA-4EU

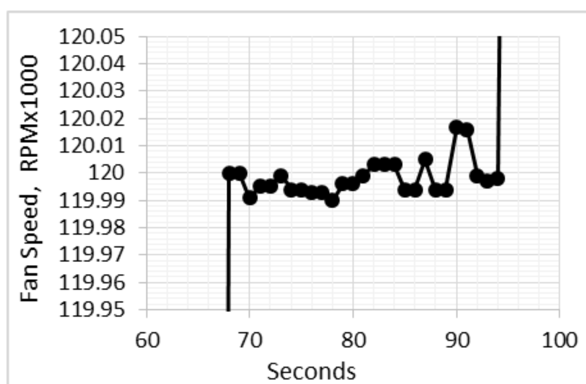

Figure 7. Steady State Controller Accuracy

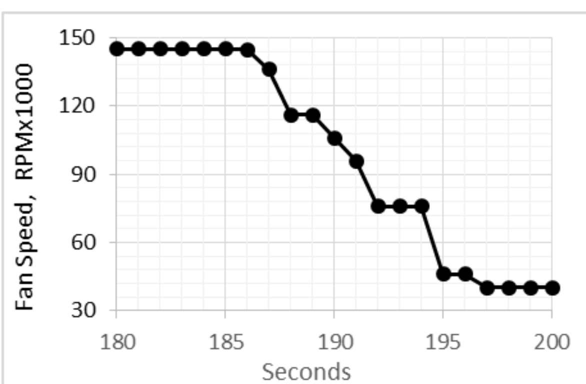

Figure 8. Controller Transient During Ramp-down

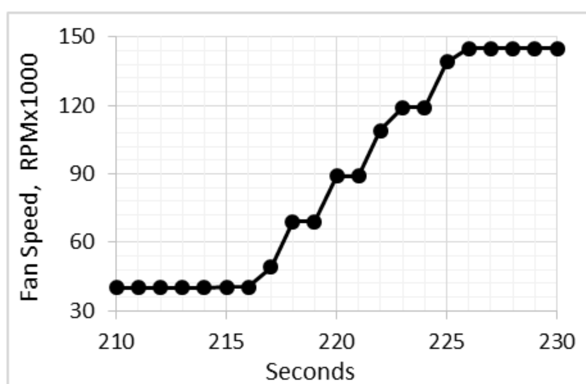

Figure 9. Controller Transient During Ramp-up.

A short half cycle was chosen for the first quantitative test of the flight blower because elevated process airflow and long duration half cycles could overwhelm the adsorbing capacity of the desiccant beds. A shorter half cycle also minimized the amount of time between manual fan adjustments. The fan was commanded to 110,000 RPM for the first 80 minute half cycle, and increased by 10,000 RPM increments at the beginning of each successive half cycle. See Figure 10.

<u>Operating Conditions</u>

677 SLPM (23.9 scfm)	Inlet Air Flow
8.2 °C (46.8 °F)	Inlet Air Dewpoint
14.1 °C (57.5 °F)	Inlet Air Temperature.
269 Pa (2.02 torr)	Inlet CO_2 partial pressure $ppCO_2$

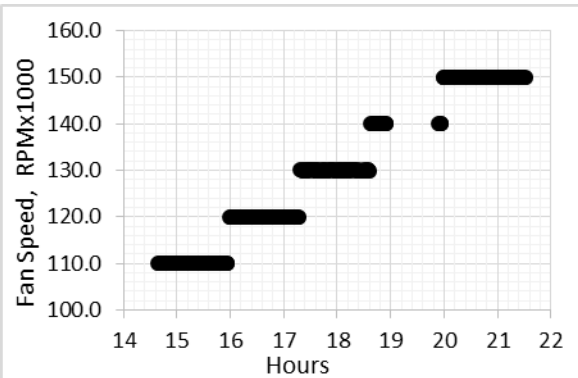

Figure 10. Fan Speed Profile

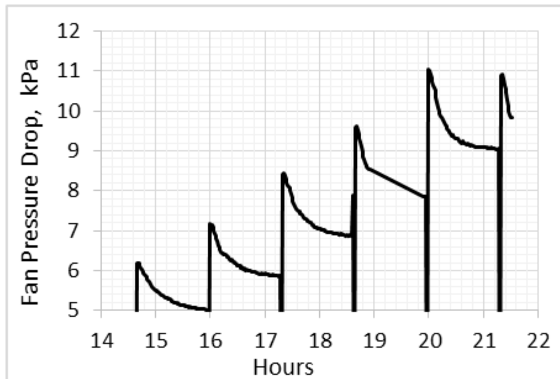

Figure 11. Fan Pressure Drop Half Cycle

Fan pressure-drop peaks at the beginning of the half cycle and slowly declines as the system reaches equilibrium shown in Figure 11. The value of pressure at the end of the plateau was used to construct the fan flow curve in the next diagram. See Figure 12. This test series demonstrated that 800 SLPM of process airflow was produced at the maximum fan speed operating limit. The controller-fan assembly responded without fault. The test operated continually, but a short communication error prevented data recording between 19 hours and 20 hours. The effective CDRA-4EU operating line (flow vs pressure drop) shown in Figure 13 will be used to anchor modeling of the 4-bed system.

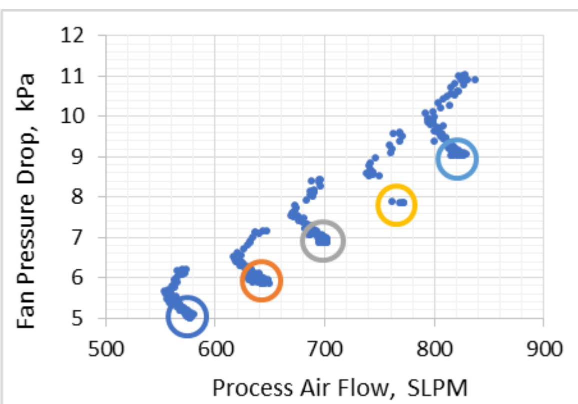

Figure 12. Fan Pressure Drop in CDDRA-4EU System Operation

Fan inlet temperature was 37 °C.

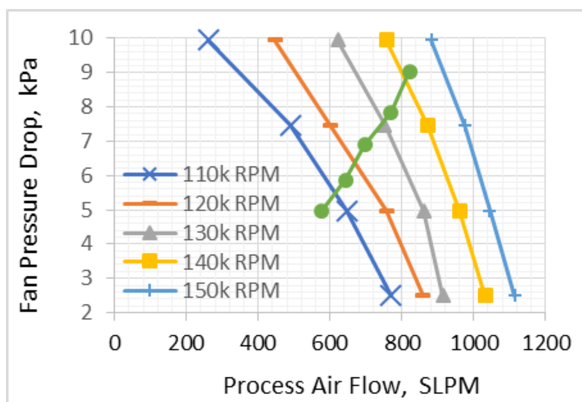

Figure 13. CDRA-4EU System Operation Overlaid with Component Fan Curve

25 °C inlet temperature for component.

V. Determination of CO2 Removal Using Flight Fan

A. CO2 Removal at Constant 150,000 RPM and Variable Process Air Flow

For test EC-27, the fan was commanded to 150,000 RPM for 4 full cycles (8 half cycles) in order to determine the maximum process air flow. Cyclic parameters stabilized and CO2 removal data was determined within 8 half cycles. Because the fan was controlled to a specific value, the system flow and pressure drop varied as a function of the 4BMS system behavior.

<u>Operating Conditions</u>	
150,000 RPM	Fan speed
816 SLPM (28.8 scfm)	Average Inlet Air Flow
6.9 °C (44.4 °F)	Inlet Air Dewpoint
12.4 °C (54.3 °F)	Inlet Air Temperature
267 Pa (2.0torr)	Inlet CO2 partial pressure ppCO2

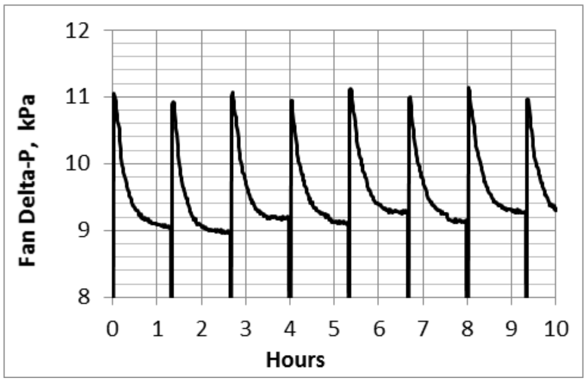

Figure 14. Fan Pressure Drop at 150k RPM

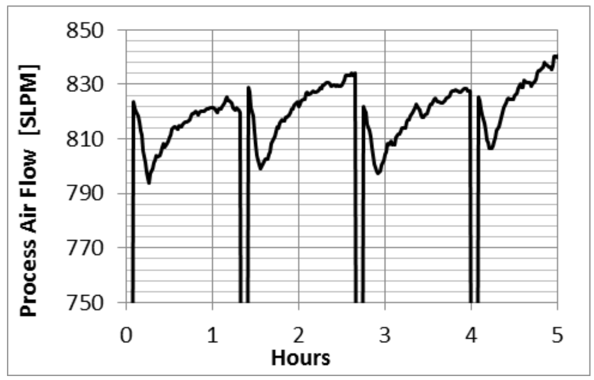

Figure 15. Process Air Flow at 150k RPM

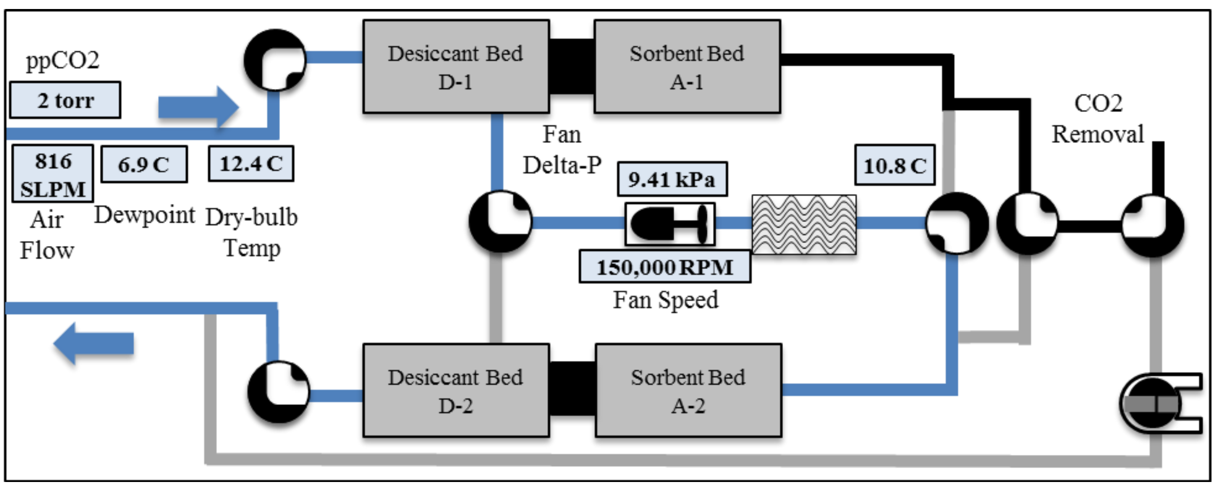

Figure 16. CDRA-4EU System Average Parameters for Test EC-27

B. CO2 Removal at Constant Process Air Flow not to exceed 150,000 RPM

During test EC-29, the process airflow was controlled to 790 SLPM by varying fan RPM. Process airflow rate is typically controlled to a specific valve for a CDRA-4EU test. This allows performance comparisons while varying other parameters and provides one-to-one comparisons for model validation. Results from the previous test were used to insure we would not exceed 150,000. The Lab VIEW control software was also programmed to prevent the fan from exceeding the 150,000 RPM limit.

CO2 was injected at 267 Pa ppCO2 (2 torr) at the CDRA-4EU inlet to obtain an approximation of the maximum possible CO2 removal. The inlet air dry-bulb temperature (10.2 °C) and dewpoint temperature (5.9 °C) were chosen to simulate conditioned air exiting the condensing heat exchanger at the CDRA location. At these inlet conditions and a constant process airflow of 801 SLPM (28 SCFM), the system CO2 removal rate averaged 4.74 kg/day. This removal rate exceeds the value required for 4 ISS crewmembers.

<u>Operating Conditions</u>

801 SLPM (28.3 scfm)	Average Inlet Air Flow
5.9 °C (48.5 °F)	Inlet Air Dewpoint
10.2 °C (50.4 °F)	Inlet Air Temperature.
267 Pa (2.0 torr)	Inlet CO2 partial pressure ppCO2

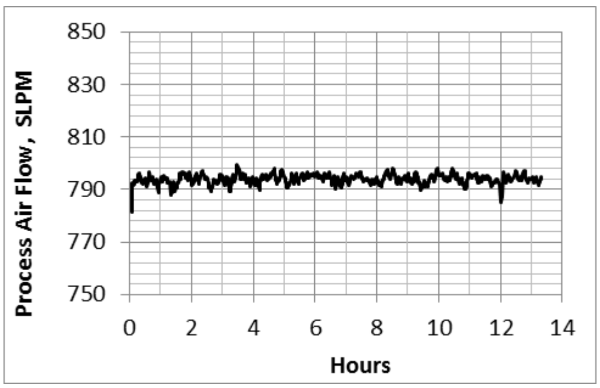

Figure 17. Controlled Process Air Flow

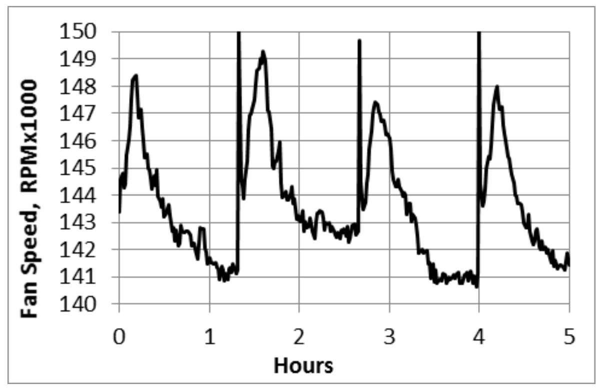

Figure 18. Fan Speed Variation to Maintain Air Flow

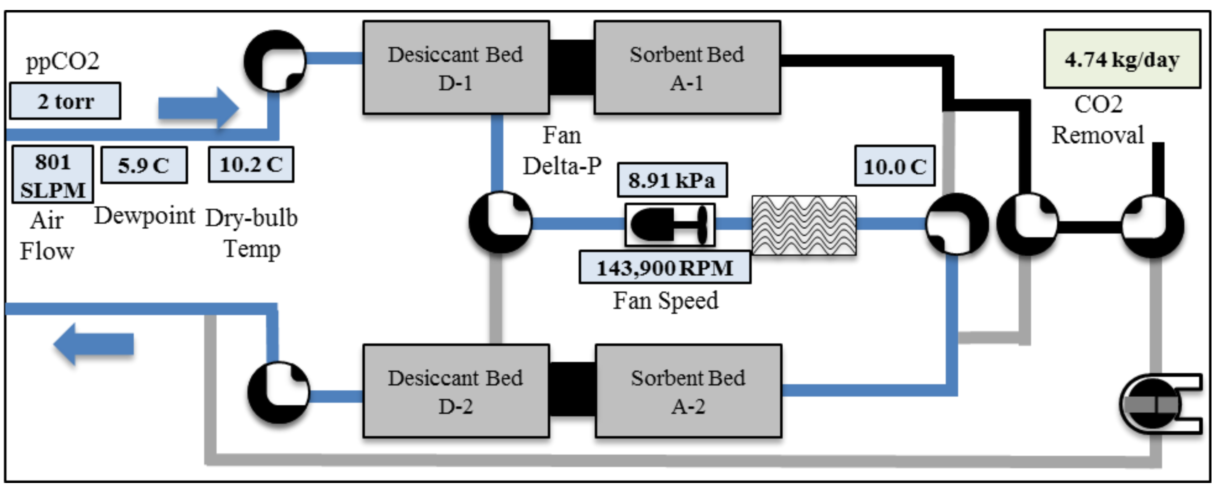

Figure 19. CDRA-4EU System Average Parameters for Test EC-29

C. CO2 Removal at Constant 140,000 RPM, allowing Variable Process Air Flow

Fan RPM was set to 140,000 RPM on test EC-31 and process airflow was allowed to vary. ISS operates the CDRA system using constant fan RPM rather than controlling process airflow. While no attempt was made to determine explicit rationale for a maximum fan RPM over extended duration, we used 140,000 RPM as a substitute until the systems and operational teams develop traceable rationale. At a constant fan RPM set to 140,000 RPM, CDRA-4EU removed 4.77 kg/day of CO2.

Operating Conditions

801 SLPM (28.3 scfm) Average Inlet Air Flow
5.9 °C (48.5 °F) Inlet Air Dewpoint
10.0 °C (50.0 °F) Inlet Air Temperature.
264 Pa (1.98 torr) Inlet CO2 partial pressure ppCO2

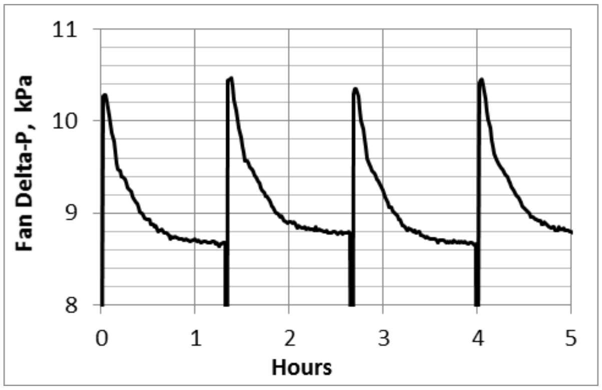

Figure 20. Fan Delta-P for Constant 140k RPM

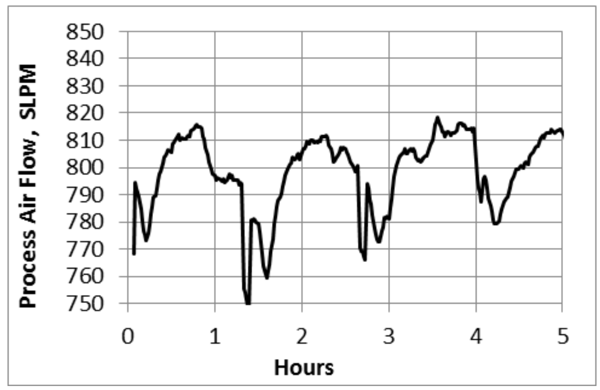

Figure 21. Process Air Flow for Constant 140k RPM

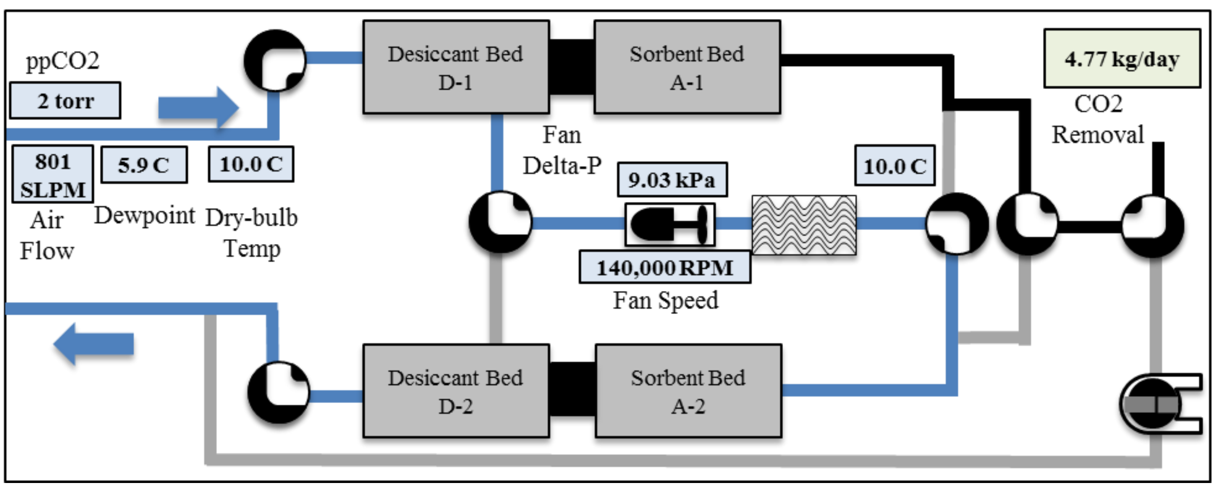

Figure 22. CDRA-4EU System Average Parameters for Test EC-31

VI. Fan Power Usage in System Operation

The final test series was conducted to determine fan power usage as a function of system flow. The operational team needs this data in order to trade additional CO2 removal at the cost of additional power. When this paper was written, CDRA on ISS operates at 600 SLPM (21 scfm) process airflow resulting from a 115,000 RPM fan speed. As airflow increased 25% from 600 SLPM to 800 SLPM, fan power doubled from 150 watts to 300 watts over this same flow range.

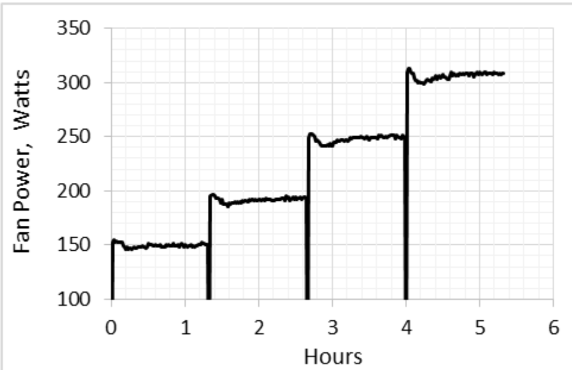

Figure 23. Fan Power vs Fan Speed

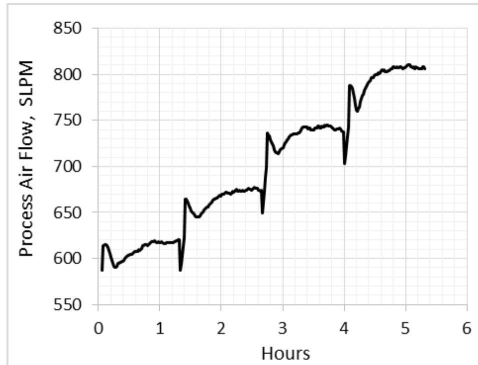

Figure 24. Process Air Flow vs Fan Speed

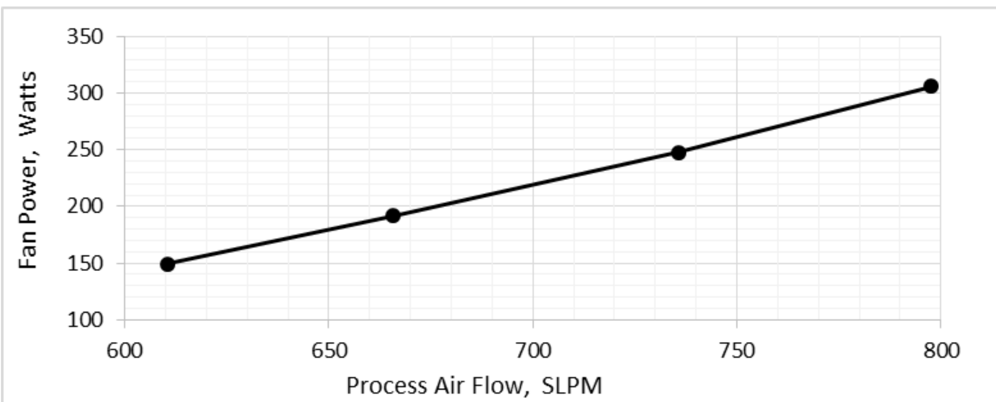

Figure 25. Process Air Flow vs Fan Power for Different Fan Speed Settings

VII. Conclusion

The commercial Celeroton controller was integrated in a straightforward manner with the flight Honeywell fan. Fan operational transients were responsive and +/- 10 RPM tolerance held at 115,000 RPM levels. The CDRA-4EU system repeatedly removed more than 4.7 kg/day CO2 at 624 Pa (2 torr) inlet ppCO2, but at the cost of nearly double the fan power. If elevated process airflow is requested for ISS operation, a test program on the life effects of extended operation of the fan at higher speed could be performed.

References

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