Functional Performance of an Enabling Atmosphere Revitalization Subsystem Architecture for Deep Space Exploration Missions

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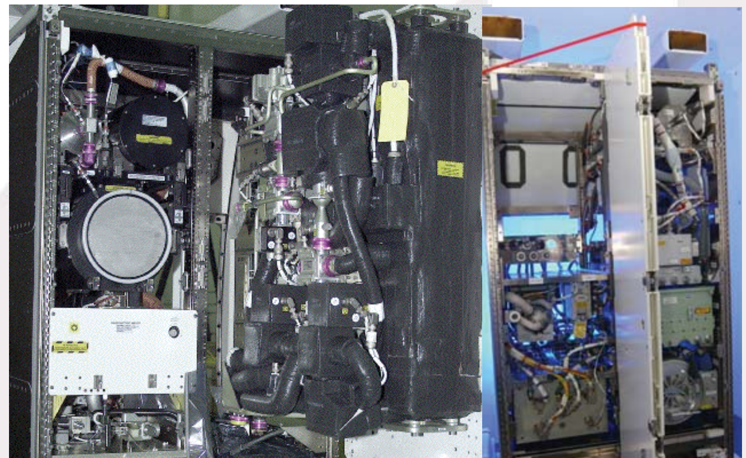
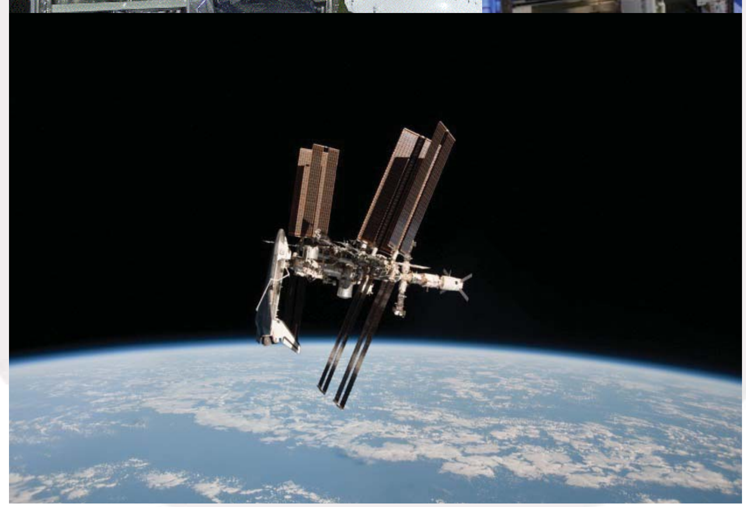
Technological Advancement Objectives

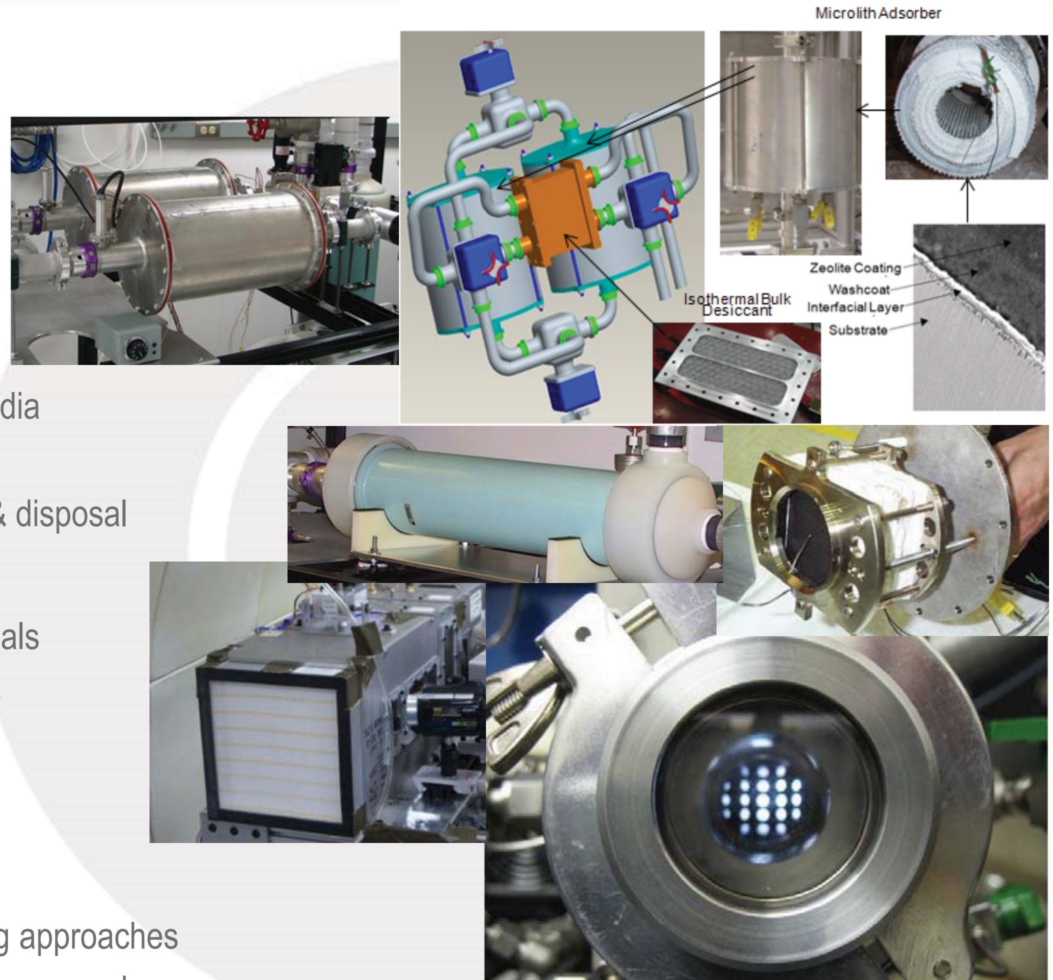
- To demonstrate an evolved ISS atmosphere revitalization (AR) subsystem architecture to enable deep space exploration
  - Improve reliability & maintainability
  - Reduce consumable mass
- To maximize commonality across missions and vehicles
- To mature process technologies for flight programs
  - Reduce technical risk and cost
- To develop modular resource recovery technologies





Strategic Improvements

- Cabin ventilation
  - Quiet fan design principles
- Carbon dioxide removal
  - Durable adsorbent media
  - Process air drying
- Trace contaminant control
  - Alternative high capacity adsorbent media
  - Structured oxidation catalysts
  - Low maintenance particulate filtration & disposal
- Oxygen supply
  - Long-lived electrolysis cell stack materials
  - Alternative process control approaches
- Oxygen recovery
  - Reduction byproduct processing
- Environmental monitoring
  - Alternative major constituent monitoring approaches
  - Alternative trace constituent monitoring approaches
  - Microbial & particulate monitoring techniques



Test Facility Overview

- Characteristics
  - 90.6 m^3
  - Stainless steel
  - Vacuum-capable
- Test support capabilities
  - Metabolic simulation
  - Trace contaminant injection
  - Temperature and humidity control
  - Space vacuum resource simulation
  - Gas sample acquisition and analysis
  - Major constituent monitoring
  - Total pressure and atmosphere composition control
  - Process control & data acquisition/archiving
    - LabVIEW
    - Payloads and Components Real-time Automated Test System (PACRATS)
- Analytical Instrumentation – VOC Analysis
  - Agilent 5890 GC with a flame ionization detector coupled with a Markes TT24-7 Thermal Desorption System autosampler
  - Agilent 7890 GC with flame ionization and mass selective detectors coupled with a Gerstel Thermal Desorption System
  - MKS Multigas™ 2030 Fourier Transform Infrared Spectrometer
- Analytical Instrumentation – Major Constituent Monitoring
  - Oxigraf Model O2 analyzer – solid-state laser diode absorption
  - Sable Systems CA-2A analyzer – solid-state infrared absorption
  - Sable Systems RH-100 monitor – solid-state thin film capacitance

PARAMETER	RANGE
Total pressure	400-933 Pa gauge
Oxygen partial pressure	20.58±0.14 kPa
Carbon dioxide partial pressure	400±67 Pa
Temperature	21±2.8 °C
Relative humidity	50±5%
Contaminant injection rate	230 mg/hour*

*Percent by mass: methanol (10.7), ethanol (67.1), 2-propanol (4.8), ethanal (7.6), dimethylbenzene (2.3), dichloromethane (1.3), 2-propanone (6.2)

ISS Architecture Testing Objectives

- Demonstrate functional performance of the basic ISS AR subsystem using the CDRA in CO_2 vent mode and the TCCS operating in parallel.
- Demonstrate the partial functional performance of the basic ISS AR subsystem when operating in a resource recovery mode that includes integration with CO_2 conditioning, storage, and reduction equipment.
- Investigate propagation of trace contaminants through the core ISS AR subsystem equipment with emphasis on the CDRA and CO_2 conditioning and storage equipment.
- Demonstrate the full resource recovery functional performance of the ISS AR subsystem including the CO_2 removal, CO_2 conditioning and storage, CO_2 reduction and post-processing, oxygen generation, and trace contaminant control functions.

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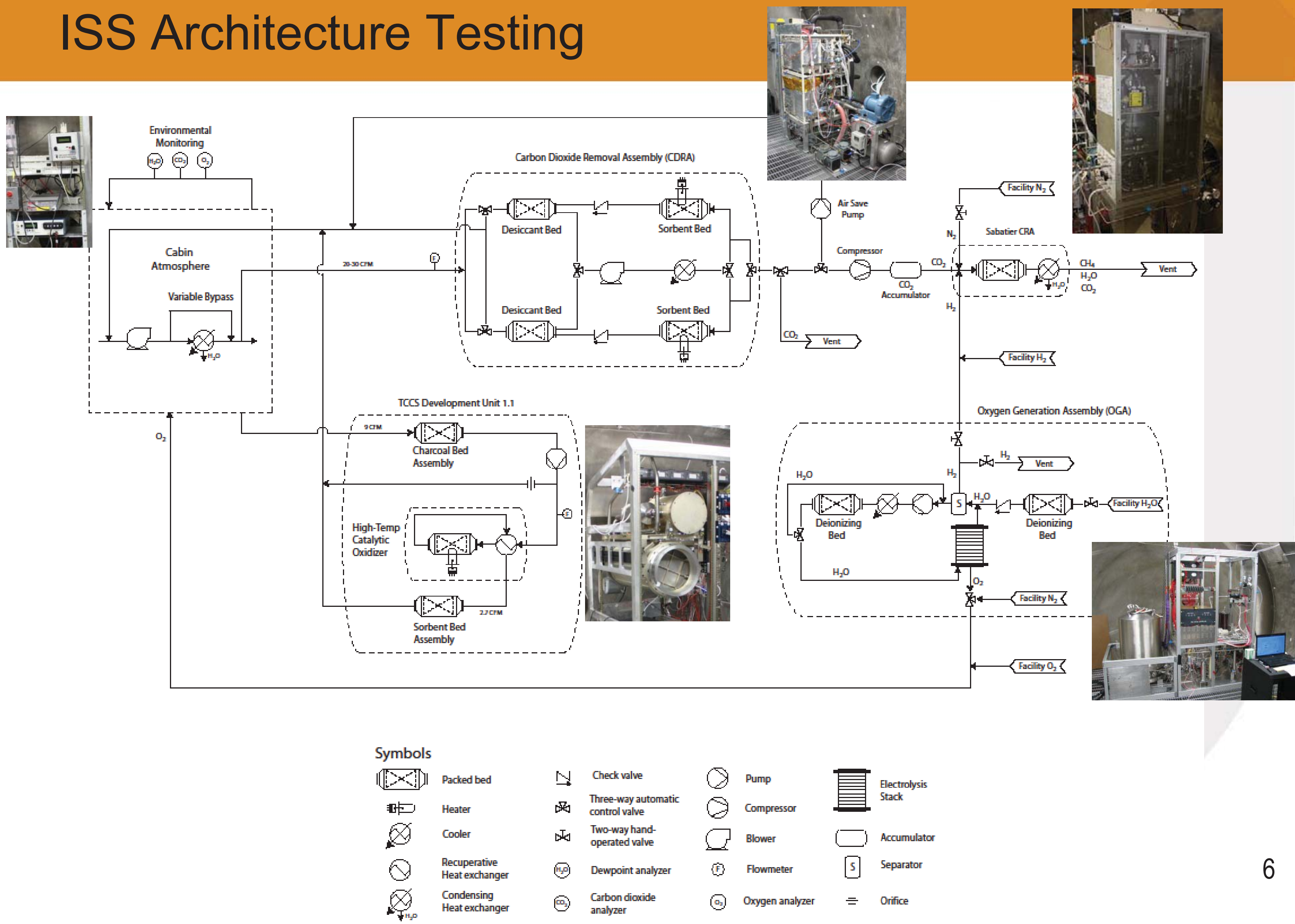
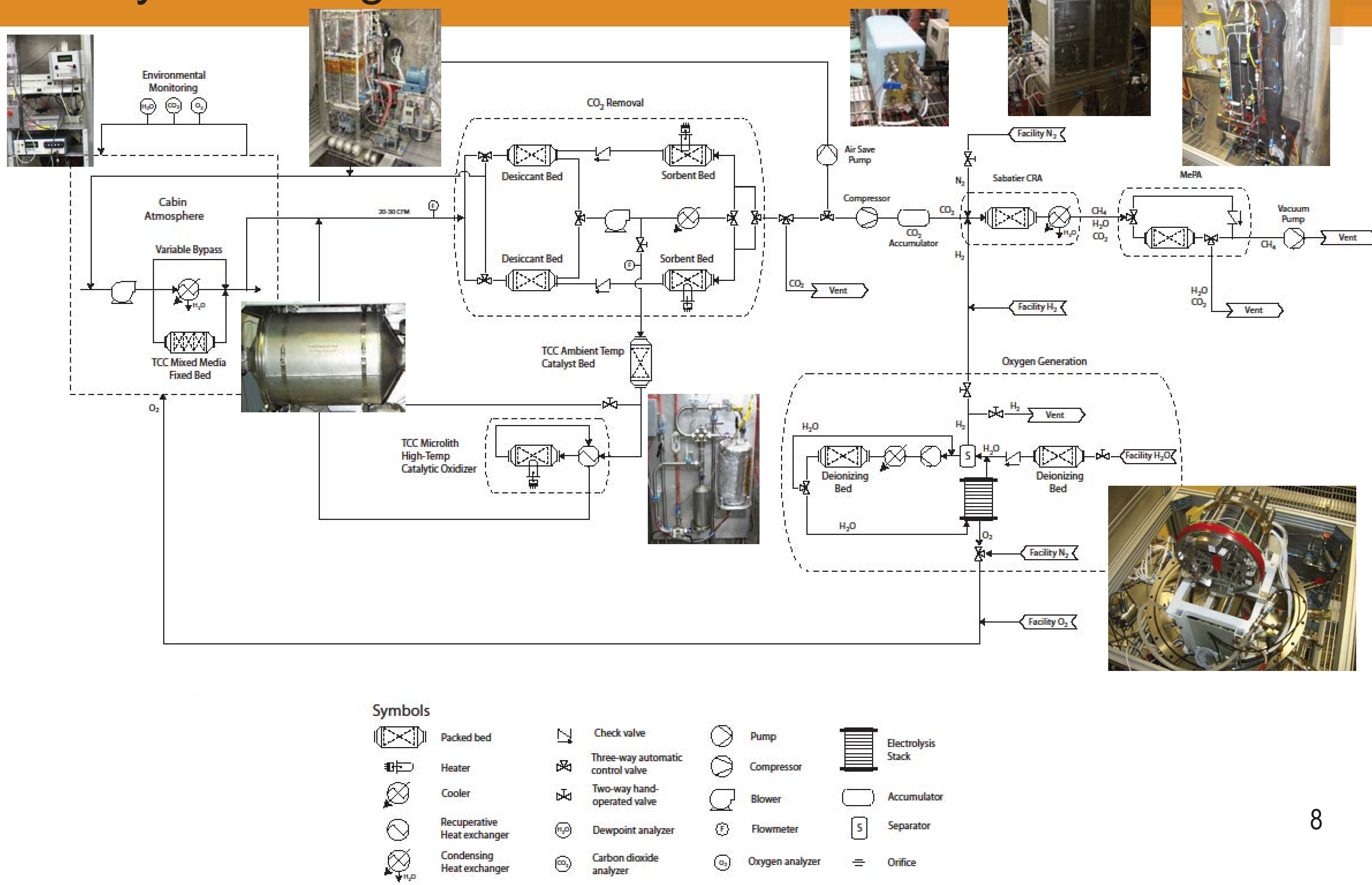
ISS Architecture Testing



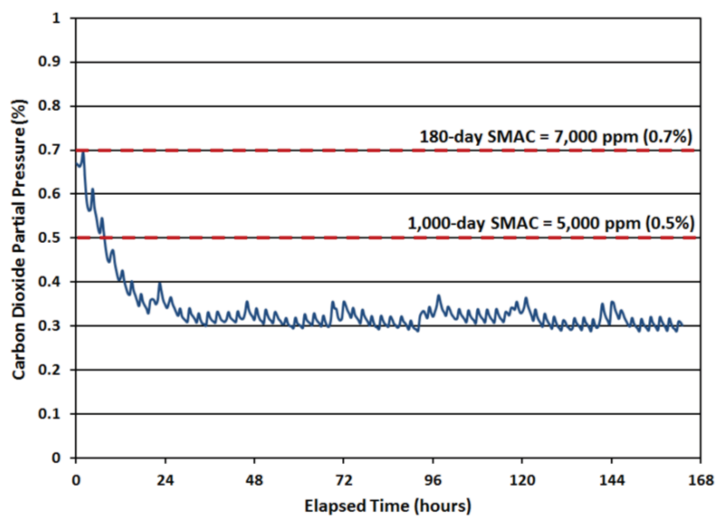
Cycle 1 Testing Objectives

- Demonstrate integrated modified ISS subsystem operation
  - Oxygen generation
  - CO_2 removal
  - Trace contaminant control
  - Major constituent monitoring
  - CO_2 reduction with partial post-processing first stage to purify methane
- Demonstrate CO_2 management compressor operation
  - Observe how CO_2 removal process valve valve sequencing affects overall CO_2 reclamation efficiency for various modes of operation.
- Determine process fluid purities
  - Product CO_2 from the CDRA-4 sorbent beds.
  - Product oxygen and hydrogen from the OGA.
  - Product water from the Sabatier-based CRA.
- Determine the effect cabin atmosphere leakage and/or atmospheric major constituent inclusion on the CDRA CO_2 product may have on CRA performance.

Cycle 1 Integrated Process Architecture

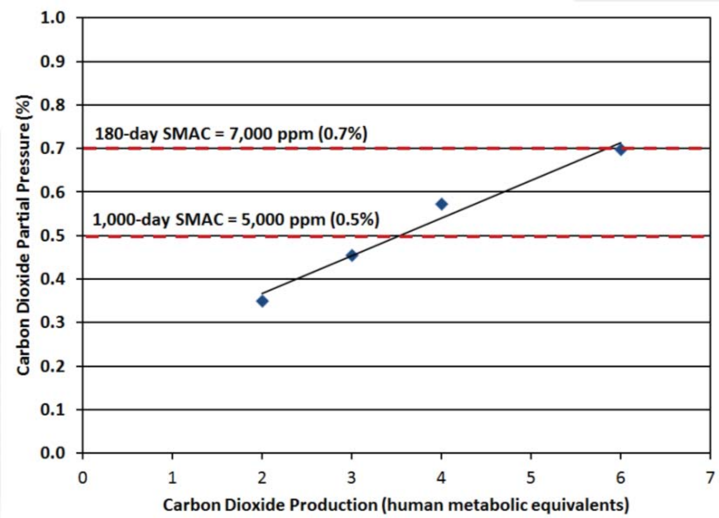


Results: CO_2 Removal



ISS Architecture

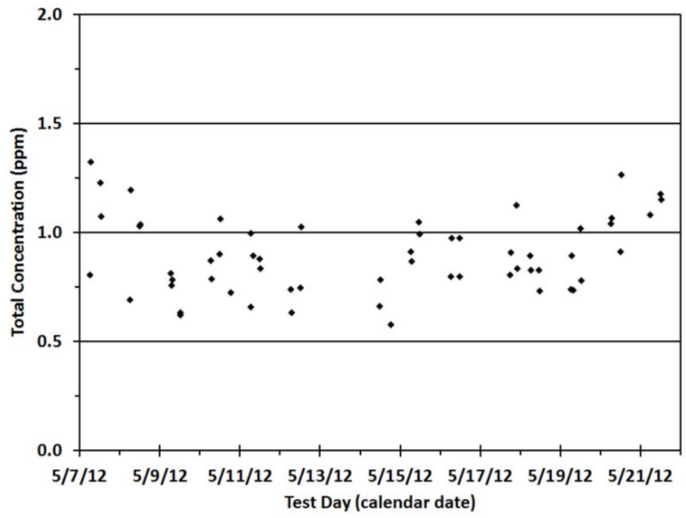
- ASRT zeolite 5A
- 34.6 m^3/h flow
- 3-CM load
- 59% removal efficiency
- 0.34% CO_2 partial pressure

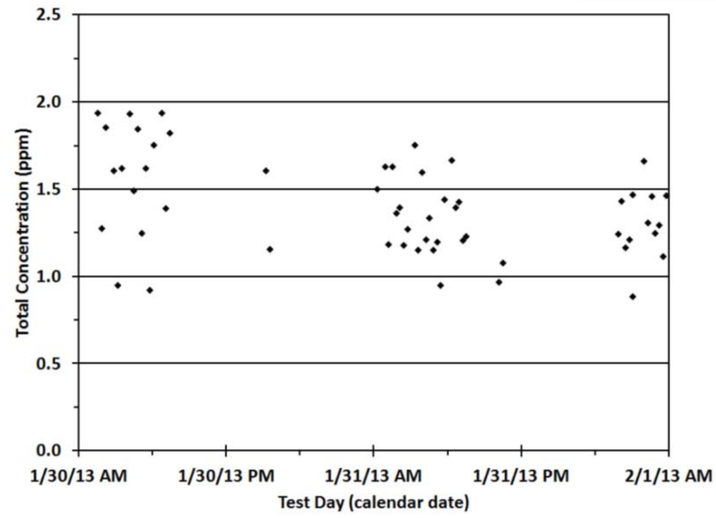


Cycle 1 Architecture

- RK-38 zeolite 5A
- 28.8 m^3/hour flow
- 2-CM to 6-CM load
- 59% removal efficiency
- 0.45% CO_2 partial pressure

Results: Trace Contaminant Control





ISS Architecture

- Stand-alone TCC assembly
  - Carbon bed containing B-S Type 3032
  - Catalytic oxidizer containing Engelhard catalyst pellets
- 15.3 m^3/h through carbon bed/4.6 m^3/h through catalytic oxidizer
  - 88% mean single pass removal efficiency
- Indication of ethanol breakthrough of the carbon bed near end of testing
- 1.14 ppm mean total contaminant concentration

Cycle 1 Architecture

- Distributed TCC components
  - Carbon bed containing Chemsorb 1425 integrated with ventilation duct
  - Catalytic oxidizer containing Microlith™ catalytic reactor core integrated with CDRA
  - Eliminates electrical box and post-sorbent bed
- 8.5 m^3/h through carbon bed
  - 91.2% mean single pass efficiency
- 5.9 m^3/h through catalytic oxidizer
- 1.34 ppm mean total contaminant concentration

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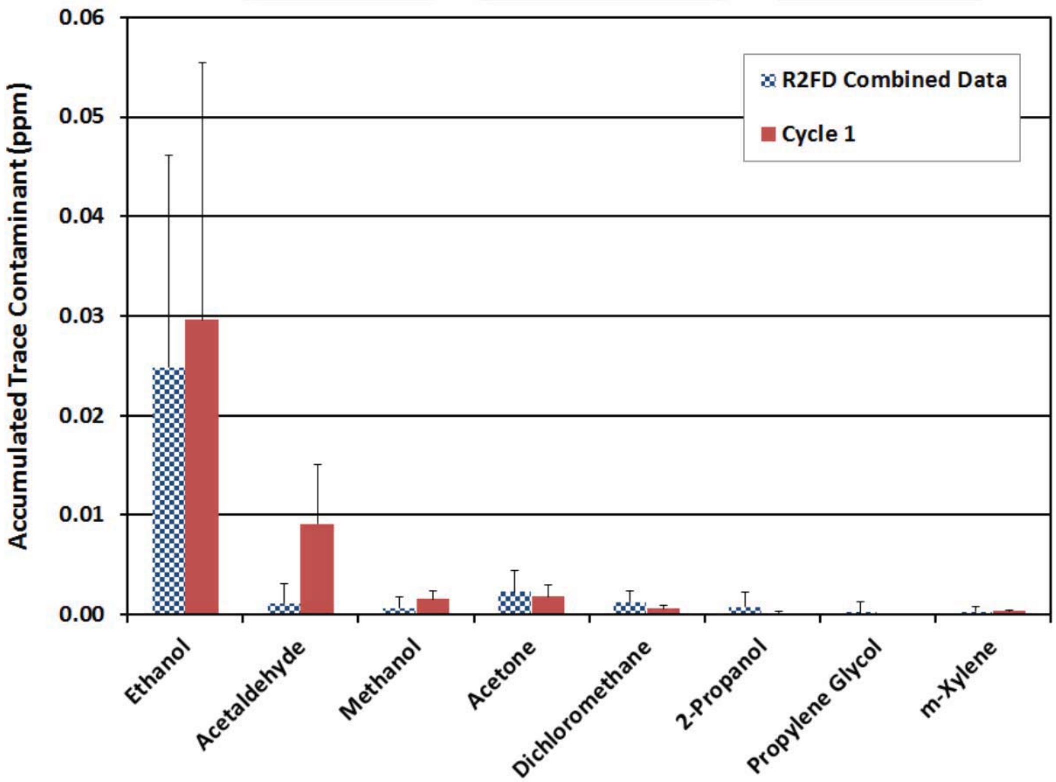
Results: CO_2 Reduction

- Water production rates consistent across architectures
  - ~2 ml/minute
- Consistent VOC loading in CO_2 feed
  - <0.03 ppm
- Suspected CO_2 reduction reaction poisons <<0.01 ppm
  - No indication of performance degradation during testing phases



Improvements for the Future

- Trace Contaminant Control
  - Full treatment of the ventilation flow with activated carbon cartridges mounted in main duct
- CO_2 Removal
  - Tune process parameters
    - Increase total flow by 6.6% to 37 m^3/h to accommodate TCC catalytic oxidizer flow
    - Investigate half-cycle time and bed regeneration temperature modifications
  - Modify the process design as appropriate
    - Incorporate results from bulk/residual drying technology studies to optimize the desiccant bed
    - Incorporate advanced CO_2 adsorbent materials as evaluations may indicate
- CO_2 Reduction
  - Incorporate and demonstrate post-processing stages to increase resource recovery
- Oxygen generation
  - Evaluate operational approaches and candidate replacements for a hydrogen sensor to simplify the hardware

Conclusion

- An ISS-derived AR subsystem architecture is feasible
  - Equivalent or better performance demonstrated
- Mass and volume reduction can be achieved
  - 12 kg and 15 liters by using distributed TCC components
  - Potential exists for CO_2 removal bed component size reduction
  - Simplified oxygen generator operational approaches may yield further mass and volume reduction
- Opportunity exists to demonstrate a higher degree of resource mass closure by incorporating CH_4 post-processing technologies
- Optically-based major constituent monitoring demonstrated steady, reliable performance.

Further Reading

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