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 m³
  - 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 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

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

*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 CO₂ 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 CO₂ conditioning, storage, and reduction equipment.
- Investigate propagation of trace contaminants through the core ISS AR subsystem equipment with emphasis on the CDRA and CO₂ conditioning and storage equipment.
- Demonstrate the full resource recovery functional performance of the ISS AR subsystem including the CO₂ removal, CO₂ conditioning and storage, CO₂ reduction and post-processing, oxygen generation, and trace contaminant control functions.
Cycle 1 Testing Objectives

- Demonstrate integrated modified ISS subsystem operation
  - Oxygen generation
  - CO₂ removal
  - Trace contaminant control
  - Major constituent monitoring
  - CO₂ reduction with partial post-processing first stage to purify methane

- Demonstrate CO₂ management compressor operation
  - Observe how CO₂ removal process valve valve sequencing affects overall CO₂ reclamation efficiency for various modes of operation.

- Determine process fluid purities
  - Product CO₂ 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 CO₂ product may have on CRA performance.
Cycle 1 Integrated Process Architecture

Symbols:
- Packed bed
- Heater
- Cooler
- Reciprocative heat exchanger
- Heat exchanger
- Check valve
- Three-way automatic control valve
- Two-way hand-operated valve
- Depreciation analyzer
- Carbon dioxide analyzer
- Pump
- Compressor
- Blower
- Flowmeter
- Oxygen analyzer
- Electrolysis stack
- Accumulator
- Separator
- Office

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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

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**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

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**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
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

- **CO₂ Removal**
  - Tune process parameters
    - Increase total flow by 6.6% to 37 m³/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 CO₂ adsorbent materials as evaluations may indicate

- **CO₂ 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 CO₂ 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 CH₄ post-processing technologies

• Optically-based major constituent monitoring demonstrated steady, reliable performance.
Further Reading


