CO₂ Removal
and
Atmosphere Revitalization Systems
for
Next Generation Space Flight

ARC Air Revitalization Group

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Outline

• Design Objectives of Atmosphere Revitalization
  • Reliability
  • Low Power
  • Loop Closure
• ISS CO2 Removal
• Low Power CO2 Removal System
• Next Generation Atmosphere Revitalization
**Current ISS**

- **4BMS**
- **CO₂**
- **H₂O**
- **CH₄**

**Current ISS**

- **4BMS**
- **CO₂** vent to space
- **H₂O** vent to space
- **CH₄** vent to space

**BASIS:**

- One Human Equivalent Unit (1 kg CO₂ generated / day)
- 1.0 kg CO₂ / day
- Excess H₂ is vented also (about 0.05 kg / day)

**Future ISS**

- **4BMS**
- **CO₂** vent to space
- **H₂O** vent to space
- **CH₄** vent to space

**Future ISS**

- **4BMS**
- **CO₂**
- **H₂O**
- **CH₄**

**Future ISS**

- **4BMS**
- **CO₂** vent to space
- **CH₄** vent to space
- **H₂O** vent to space

**Future ISS**

- **Sabatier**
- **CH₄**, **H₂O** vent to space
- **H₂** vent to space
- **O₂**

**Future ISS**

- **Sabatier**
- **CH₄**, **H₂O** vent to space
- **H₂** vent to space
- **O₂**

**Future ISS**

- **Sabatier**
- **CH₄**, **H₂O** vent to space
- **H₂** vent to space
- **O₂**

**Future ISS**

- **Separator**
- **H₂O** vent to space
- **H₂** vent to space
- **O₂**

**Future ISS**

- **Separator**
- **H₂O** vent to space
- **H₂** vent to space
- **O₂**

**Future ISS**

- **Electrolyzer**
- **H₂**
- **O₂**

**Future ISS**

- **Electrolyzer**
- **H₂**
- **O₂**

**Future ISS**

- **Electrolyzer**
- **H₂**
- **O₂**
Increased Loop Closure

**Diagram Descriptions:**
- **4BMS**: CO₂ flows into the 4BMS module.
- **Sabatier**: CH₄ and H₂O react to produce CH₄, H₂O, and H₂.
- **Separator**: The separated H₂ and H₂O are further processed.
- **Electrolyzer**: H₂ is electrolyzed to produce H₂O and O₂.
- **Cabin Air**: CO₂ is removed from the cabin air.
- **CH₄ Reactor/Separator**: CH₄ and C₂H₂ are produced.
ISS CO2 Removal

desiccant bed (adsorbing)

CO₂ scrubber (desorbing)

heater

to vacuum

Desiccant bed (desorbing)

Blower/cooler

CO₂ scrubber (adsorbing)

cabin air
- Passive membrane drying technology for low power
- Structured residual dryers for low power and reliability
- Integrated CO$_2$ capture and compression for loop closure and low power
# Specifications

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew-size</td>
<td>4 (max)</td>
</tr>
<tr>
<td>CO$_2$ concentration</td>
<td>2600 ppm (average)</td>
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<tr>
<td>Cycle Time</td>
<td>60 minutes</td>
</tr>
<tr>
<td>Flow rate: process air inlet</td>
<td>850 slm</td>
</tr>
<tr>
<td>Temperature: process air inlet</td>
<td>8-10°C</td>
</tr>
<tr>
<td>Dewpoint: process air inlet</td>
<td>8°C</td>
</tr>
<tr>
<td>CO$_2$ delivery pressure</td>
<td>133 kPa</td>
</tr>
<tr>
<td>Adsorbent Cooling Method</td>
<td>process air and rack air for additional cooling</td>
</tr>
</tbody>
</table>
Test Stand

- Test platform for evaluation/characterization of AR components
- Air Flow range: 0-1275 slm
- Air Temperature: 5°C-20°C
- Air Dewpoint: 5°C-20°C
- Air Relative Humidity: 35%-100%
- Supplemental Air Flow Range: 0-1416 slm
- Supplemental Air Flow Dewpoint: -70°C
Dryer Orientation

- Tube flow - 850 slm, Shell flow - 722 slm (85% of tube flow), Inlet DP - 8°C
- 70% water-removal efficiency in horizontal orientation
- 81% water-removal efficiency in vertical orientation
Efficient Heating – In-line vs. proximal

Desiccant Air Pre-Heater
In line
Proximal
60-minute adsorption/desorption cycles

Average power for desiccant regeneration – 250 W
Passive membrane drying technology for low power
Structured residual dryers for low power and reliability
Integrated CO₂ capture and compression for loop closure and low power
2-Stage Compressor

- Built-in inlet and outlet valves with integrated valve actuation assembly
- Concentric design with stage 1 embedded inside of stage 2
- Coiled heater assembly for uniform heating of each stage
Operating Principle of TSAC

An adsorption-based compression cycle

loading (grams gas/gram sorbent)

low temp

2

cycle starting point

3

4

low-pressure intake

pressure

high-pressure setpoint

production

high temp

intake

cool, low pressure

pressurization

warming, rising pressure

production

warming further, steady pressure

depressurization

cooling, falling pressure
Adsorption vs. Mechanical Compressor

- No rapidly moving parts
- No vibration
- Proven reliability and sustainability
ISS CO2 and TCCS - separate loops
Next Generation

* Combine CO$_2$ and TC functions
* Structured sorbents for low pressure drop and longevity
• Design Objectives of Atmosphere Revitalization
  • Reliability
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• ISS CO2 Removal
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• QUESTIONS