Methane Post-Processing and Hydrogen Separation for Spacecraft Oxygen Loop Closure

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Overview

• Background
• Hardware
• Test Setup
• Methods
• Results
• System Architecture Discussion
• Conclusion
• Acknowledgements
O₂ Recovery on ISS

- Sabatier Reaction: \( \text{CO}_2 + 4\text{H}_2 \rightarrow 2\text{H}_2\text{O} + \text{CH}_4 \)
- Water product electrolyzed for oxygen for crew
- Methane (\( \text{CH}_4 \)) vented resulting in net loss of hydrogen limits oxygen recovery to ~50%
Sabatier Plus Post-Processing

- O₂ recovery architecture incorporating Plasma Pyrolysis technology for methane post-processing
  - H₂ recovered from CH₄ and sent to Sabatier to recover additional O₂ from CO₂
    - 47% with SOA O₂ recovery
    - Potentially >86% total O₂ recovery with PPA

CO₂ → Sabatier Reactor → CH₄ and H₂O → Plasma Pyrolysis Assembly → H₂ → H₂O → Oxygen Generation Assembly → O₂ to crew

H₂ and C₂H₂ → Hydrogen Purification → Acetylene (C₂H₂) to vent
Plasma Pyrolysis Assembly (PPA)

- Developed by UMPQUA Research Co.
- Methane converted to hydrogen and acetylene by partial pyrolysis in microwave generated plasma
- Targeted PPA Reaction:
  \[ 2\text{CH}_4 \leftrightarrow 3\text{H}_2 + \text{C}_2\text{H}_2 \]
Metal Hydride Hardware

- Hydrogen Components, Inc. Metal Hydride Canister
- LaNi$_{4.6}$Sn$_{0.4}$ metal hydride
- Designed for hydrogen storage
UMPQUA Microwave Regenerative Sorbent-based Hydrogen Purifier (MRSHP)

- MRSHP was the product of a Phase III Small Business Innovation Research (SBIR) development by UMPQUA Research Company
- Molecular Sieve 13X to carry out $\text{H}_2$ separation
- Thermal/vacuum desorption with heat provided by microwave power
“Dry” Test Configuration

- "Dry" Configuration
  - Separator integrated with 2nd Gen. PPA
  - PPA operated from ultra-high purity H₂ and CH₄ bottles
  - 1 Crew Member processing rate
  - 4:1 ratio of H₂:CH₄
  - 52 torr reactor pressure
  - 550 W microwave power
  - Evaluated H₂ product and process effluent
- No water in separator feed stream
“Wet” Test Configuration

- “Wet” configuration
  - Precision Combustion, Inc. Sabatier Development Unit (SDU) upstream of PPA
    - SDU operated to produce 350 SmLPM CH₄ with minimal unreacted CO₂
    - Water vapor dewpoint of ~31°C
  - PPA operated identically to Dry configuration
    - PPA products contained all previously indicated compounds along with CO and H₂O
Metal Hydride – Method and Results

**Test Parameters:**
- Flow: from zero to 300 SmLPM
- Pressure: ~ 1 atm
- Temperature: 2 °C, room temp., 120 °C

**Results:**
- No effective capacity for H₂ at the conditions tested
  - Canisters are normally charged at 200 psig (13.6x the test pressure)
  - Likely that low pressure reduces driving force and reaction kinetics
Test Parameters:

- Flow: One Crew Member rate
- Pressure: ~720 torr
- Temperature: room temp.
- Dry runs with PPA fed from high purity gas bottles
- Wet runs with PPA fed from PCI SDU

<table>
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<tr>
<th>Microwave Desorption #</th>
<th>Microwave Power Level (Watts)</th>
<th>Duration (Hours:Minutes)</th>
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<td>5-Post Wet Adsorption</td>
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</tbody>
</table>
• Third MRSHP Dry Adsorption Run, representative of all three dry runs
• Combined acetylene adsorption breakthrough curves for Wet adsorption runs
MRSHP - Results

- Wet adsorption run #4 contrasting ethylene and acetylene breakthrough curves
MRSHP – Results from Bed Disassembly

- 13X sorbent discoloration near microwave antennas noted during bed disassembly
  - Figures A and B are the view down the bed as it was unpacked
  - Figure C shows the cross section of two discolored sorbent beads
• Proposed PPA system architecture utilizing electrochemical separation
  • Sorbent system would require desiccant and compressor
Conclusion

• Four hydrogen separation technologies (two Sustainable Innovations (SI) electrochemical cell stacks, the metal hydride, and the MRSHP) have been tested at MSFC since 2015

• Electrochemical cell stacks meet system requirements while simplifying system architecture and minimizing mass, power, and volume

• A fully integrated test with the PPA, OGA, and CRA, including a hydrogen recycle loop, is planned for 2017
Acknowledgements

Thank You…

• NASA’s Advanced Exploration Systems Life Support Systems Project
• Kenny Bodkin for maintaining test facility hardware
• Tom Williams for maintaining test facility software