Self-Cleaning Boudouard Reactor for Full Oxygen Recovery from Carbon Dioxide

• Presenter: Janelle Coutts, Ph.D., Engineering Services Contract, Kennedy Space Center, FL
• Paul E. Hintze, Ph.D. and Anthony C. Muscatello, Ph.D., Applied Science Branch, NASA Kennedy Space Center
• Tracy L. Gibson, Ph.D., James G. Captain, Griffin M. Lunn, Robert W. Devor, Ph.D., Brint Bauer, and Steve Parks, Engineering Services Contract, Kennedy Space Center, FL
Outline

• Importance of oxygen recovery from carbon dioxide
• Self-cleaning reactor designs at KSC
• Results
• Future Work
O$_2$ Recovery from CO$_2$

- Only 50% of O$_2$ can recovered from respiratory CO$_2$ on the ISS
- Sabatier reactor makes CH$_4$ and H$_2$O
- CH$_4$ is vented, losing H$_2$
- H$_2$O from cargo limits H$_2$ availability to 50% recovery
- RFP seeks at least 75% recovery
- Deep space missions (Moon, Mars moons, Mars surface, asteroids, etc.) need closer to 100% recovery
Bosch Reaction

- Bosch Reaction: \( \text{CO}_2 + \text{H}_2 \rightarrow \text{C}_{(s)} + 2 \text{H}_2\text{O} \rightarrow 2 \text{H}_2 + \text{O}_2 \)
- RWGS: \( \text{CO}_2 + \text{H}_2 \rightarrow \text{CO} + \text{H}_2\text{O} \rightarrow \text{H}_2 + \frac{1}{2} \text{O}_2 \)
- Boudouard: \( 2 \text{CO} \rightarrow \text{C}_{(s)} + \text{CO}_2 \) (Fe catalyst, \( \text{H}_2 \) enhancer)
- Need a method to remove C from catalyst as it forms
Design Concepts

• Criteria: Expected Durability, catalyst surface area, mechanical interface, ease of use/fabrication, ability to evaluate design variations in same reactor.
• Did not seek to choose the best catalyst
• Most concepts centered around a catalyst that was either a brush or springs
• Others included planetary gears (like a pencil sharpener), ball bearings
Brush Design Concepts

• Catalytic brush with mechanism for carbon removal
• Variations included the number of brushes and method of carbon removal
Spring Design Concepts

• Catalytic springs with different mechanisms that compress/release springs to remove carbon
Initial design

- Spinning carbon steel spiral brush with brass rods
- Stainless steel reactor body
Initial Design

- Tested steel wool reactor for comparison
- Tested 1” and 2” ID reactors
- Collected carbon in HEPA filter bag as it was generated
Methods

- CO, H₂, N₂ fed into reactor
- Reactor temperature 500-600 °C
- Carbon collected and weighed

### Parameters for Each Reactor

<table>
<thead>
<tr>
<th></th>
<th>1&quot; Reactor</th>
<th>2&quot; Reactor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor Volume, ML</td>
<td>76</td>
<td>300</td>
</tr>
<tr>
<td>Catalyst Mass, G</td>
<td>1.31</td>
<td>11.82</td>
</tr>
<tr>
<td>H₂ Flow, SCCM</td>
<td>232</td>
<td>909</td>
</tr>
<tr>
<td>CO Flow, SCCM</td>
<td>232</td>
<td>909</td>
</tr>
<tr>
<td>N₂ Flow, SCCM</td>
<td>52</td>
<td>202</td>
</tr>
</tbody>
</table>
Methods

- Product Gas quantified with GC
- A total carbon balance was used with the GC data to calculate CO₂ yield

\[
\text{yield} = \frac{\text{mol CO}_2 \text{ produced}}{0.5 \times \text{mol CO in}}
\]
Results

• 1” reactor ran for 12 h
  – Reached 51% CO$_2$ yield, collected 27% of C in filter bag (5.5g in filter bag, 20.5 g total)
  – Found to be damaged upon disassembly

• 2” reactor run for 37 h before failure
  – Reached 73% conversion, collected 25% of C in filter bag
  – Equivalent to 1 crew CO$_2$ $\rightarrow$ O$_2$/day
  – Multiple modules + RWGS can recover ALL the O$_2$ on ISS
Results: 1 inch reactor

- After 12 hours of test time, the reactor jammed
- Brush bristles had become knotted and brush was starting to fall apart
- Some carbon still in reactor
Results: 2 inch reactor

• Pressure inside the reactor began to increase after 27 hours, and reactor was stopped after 37 hours due to the pressure increase

• Reactor x-rayed to determine cause
Carbon Analysis

- Carbon analysis with SEM/EDA indicated iron was present
- Source is likely the brush

Secondary electron, left, and backscatter electron, right, images of carbon collected from the two inch reactor. The bright spots in the right image are iron.
Future Work

• New design: Catalytic wall with non-catalytic scraper
• Using pipe inserts as catalyst so it will protect the reactor wall
• Different inserts could be made of different catalysts
Acknowledgments

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