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

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Outline

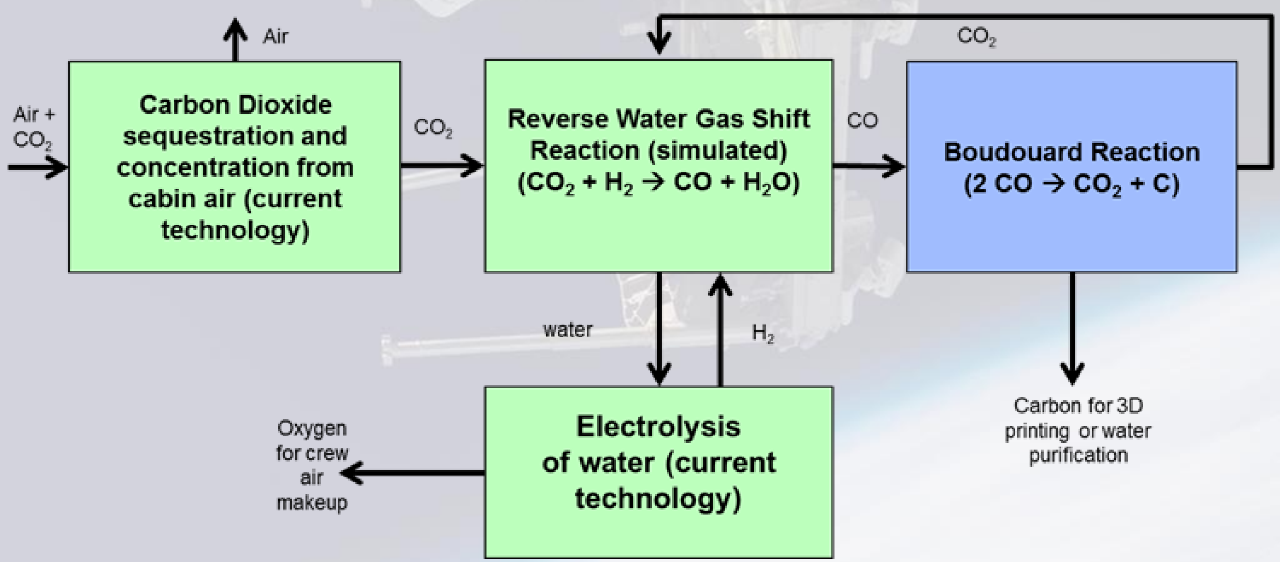
- Importance of oxygen recovery from carbon dioxide
- Self-cleaning reactor designs at KSC
- Results
- Future Work

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_2O
- CH_4 is vented, losing H_2
- H_2O 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: $CO_2 + H_2 \rightarrow C_{(s)} + 2\ H_2O\ (\rightarrow 2\ H_2 + O_2)$
- RWGS: $CO_2 + H_2 \rightarrow CO + H_2O\ (\rightarrow H_2 + ½\ O_2)$
- Boudouard: $2\ CO \rightarrow C_{(s)} + CO_2$ (Fe catalyst, H_2 enhancer)
- Need a method to remove C from catalyst as it forms

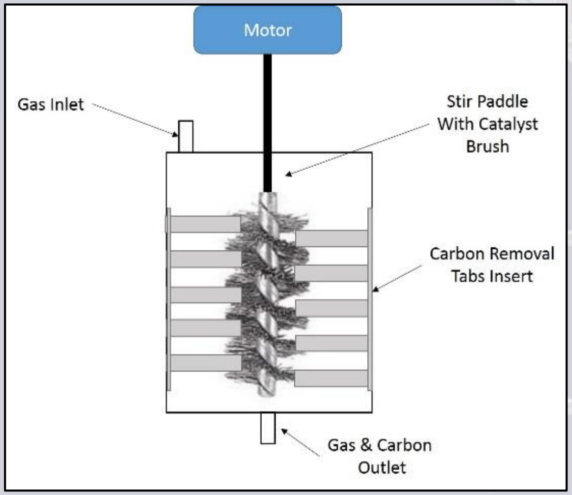


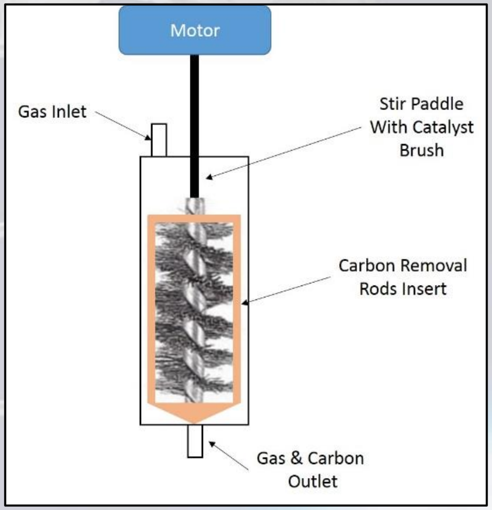
Design Concepts

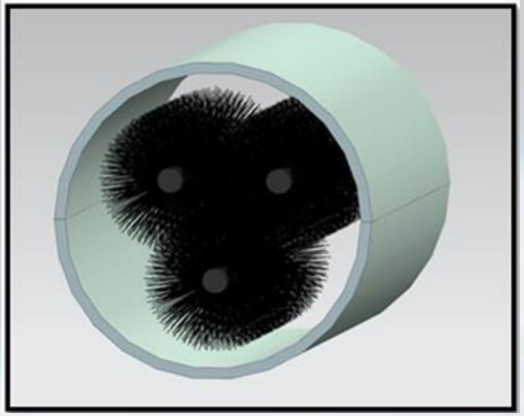
- Criteria: Expected Durability, catalyst surface area, mechanical interface, ease of use/fabrication, ability to evaluate design variations in same reactor.
- Did not seek to choose the best catalyst
- Most concepts centered around a catalyst that was either a brush or springs
- Others included planetary 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

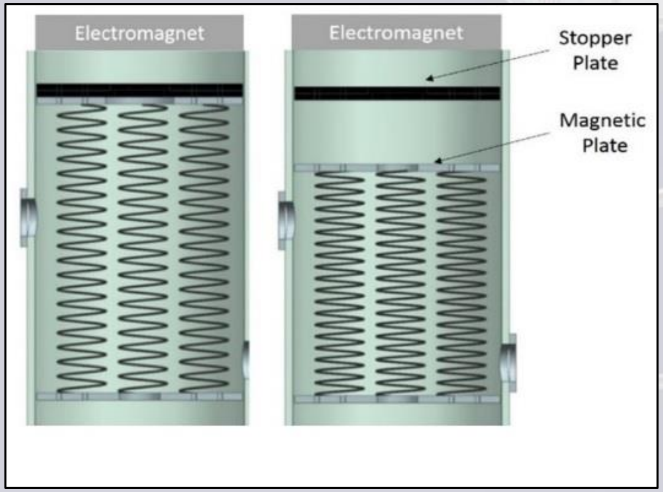


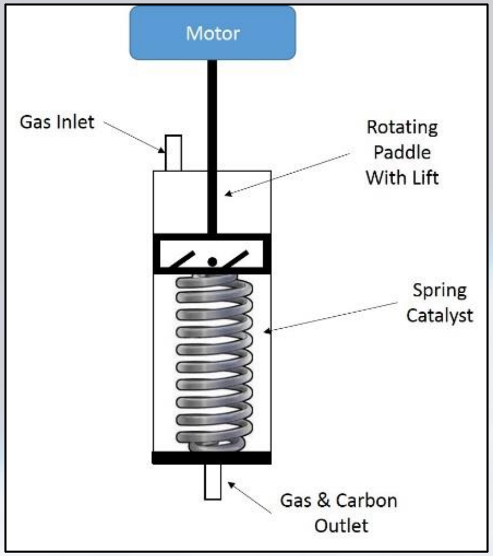




Spring Design Concepts

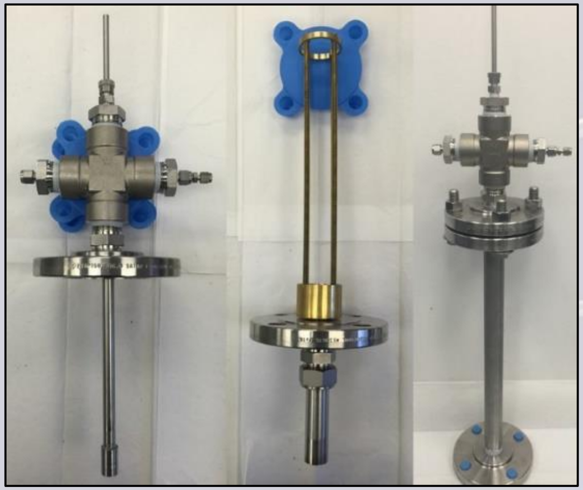
- Catalytic springs with different mechanisms that compress/release springs to remove carbon





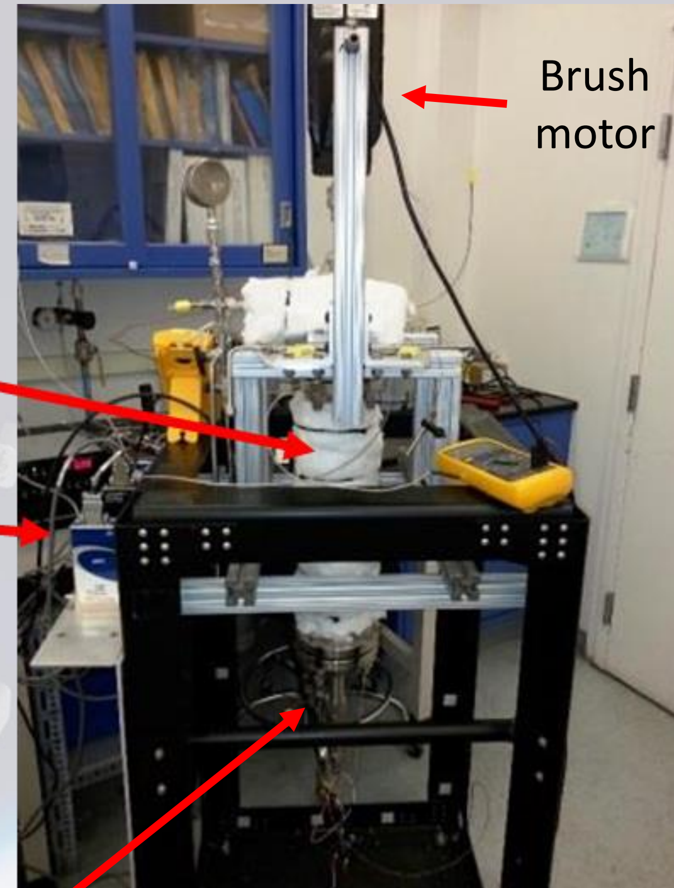
Initial design

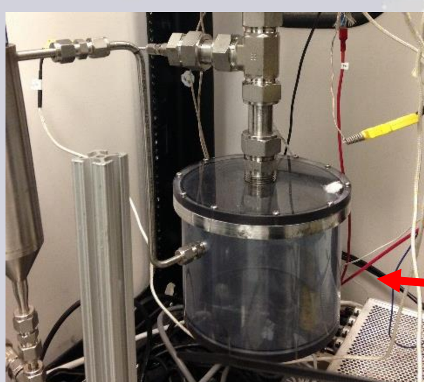
- Spinning carbon steel spiral brush with brass rods
- Stainless steel reactor body



Initial Design

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

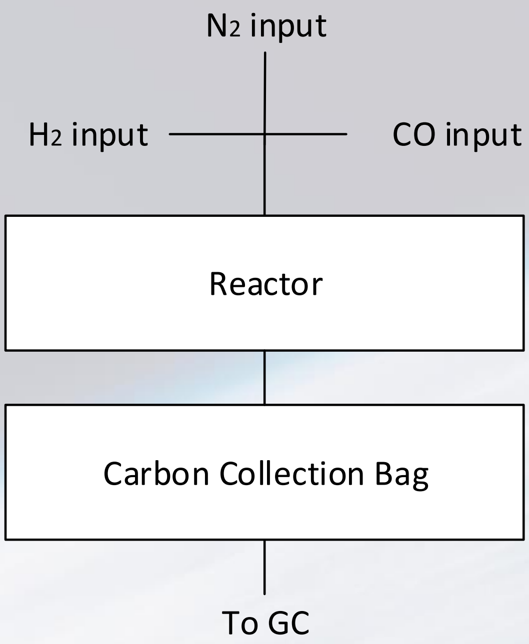




Methods

- CO, H_2, N_2 fed into reactor
- Reactor temperature 500-600 °C
- Carbon collected and weighed

Reactor Schematic

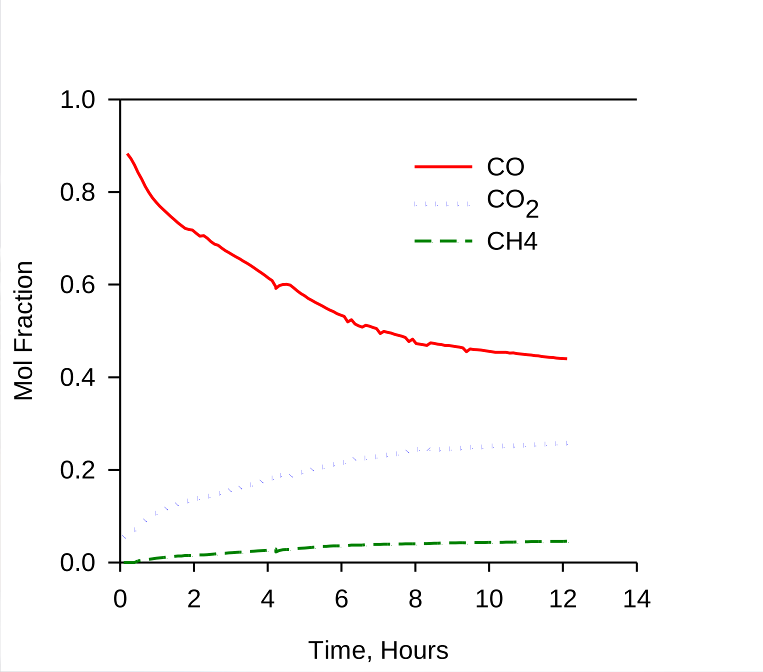


Parameters for Each Reactor

	1" REACTOR	2" REACTOR
REACTOR VOLUME, ML	76	300
CATALYST MASS, G	1.31	11.82
H_2 FLOW, SCCM	232	909
CO FLOW, SCCM	232	909
N_2 FLOW, SCCM	52	202

Methods

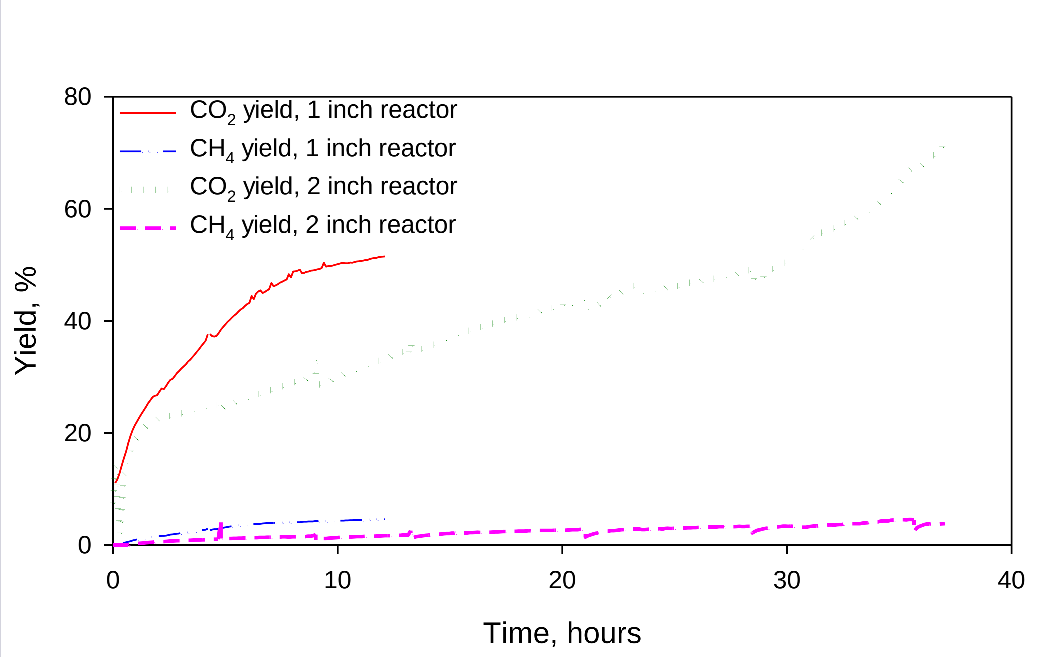
- Product Gas quantified with GC
- A total carbon balance was used with the GC data to calculate CO_2 yield



$$yield = \frac{mol\ CO_2\ produced}{0.5 \times mol\ CO\ in}$$

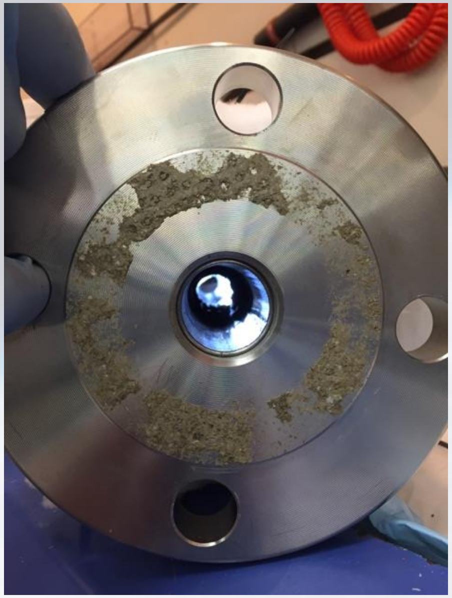
Results

- 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



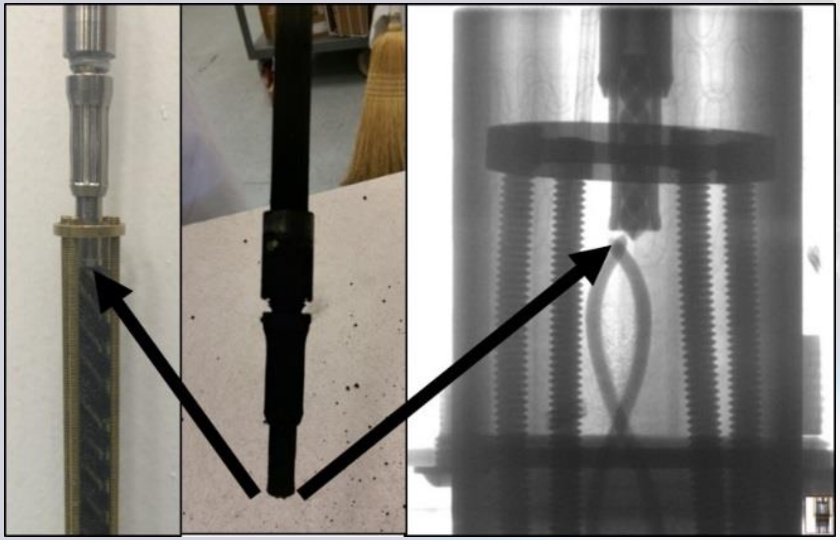
Results: 1 inch reactor

- 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



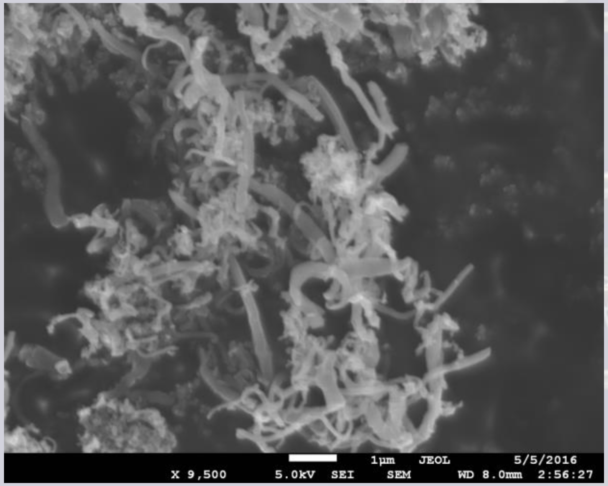
Results: 2 inch reactor

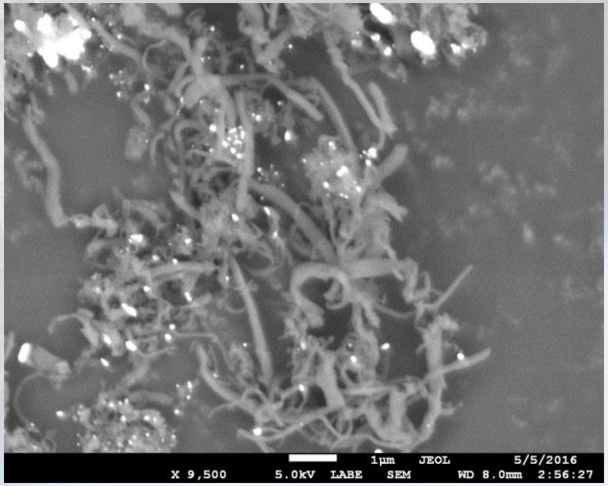
- Pressure inside the reactor began to increase after 27 hours, and reactor was stopped after 37 hours due to the pressure increase
- Reactor x-rayed to determine cause



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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