Plasma Pyrolysis Assembly Regeneration Evaluation

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Abstract

In April 2010 the Carbon Dioxide Reduction Assembly (CRA) was delivered to the International Space Station (ISS). This technology requires hydrogen to recover oxygen from carbon dioxide. This results in the production of water and methane. Water is electrolyzed to provide oxygen to the crew. Methane is vented to space resulting in a loss of valuable hydrogen and unreduced carbon dioxide. This is not critical for ISS because of the water resupply from Earth. However, in order to have enough oxygen for long-term missions, it will be necessary to recover the hydrogen to maximize oxygen recovery. Thus, the Plasma Pyrolysis Assembly (PPA) was designed to recover hydrogen from methane. During operation, the PPA produces small amounts of carbon that can ultimately reduce performance by forming on the walls and windows of the reactor chamber. The carbon must be removed, although mechanical methods are highly inefficient, thus chemical methods are of greater interest. The purpose of this effort was to determine the feasibility of chemically removing the carbon from the walls and windows of a PPA reactor using a pure carbon dioxide stream.

Background

The Plasma Pyrolysis Assembly (PPA) is designed to extract hydrogen from methane by partial pyrolysis:

$$2CH_4 \rightarrow 3H_2 + C_2H_2$$

If full pyrolysis occurs, unwanted carbon is formed:

$$CH_4 \rightarrow 2H_2 + C$$

The carbon that is formed can clog the gas ports and foul the microwave window within the reactor. It has been proposed that the reactor can be chemically cleaned with carbon dioxide through the reaction:

$$CO_2 + C \rightarrow 2CO$$

Acknowledgements

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Objectives

1. Determine parameters necessary for igniting CO_2 plasma in PPA
2. Determine the average quantity of carbon accumulated over six hours
3. Determine the feasibility of removing accumulated PPA carbon with a CO_2 plasma

Methods

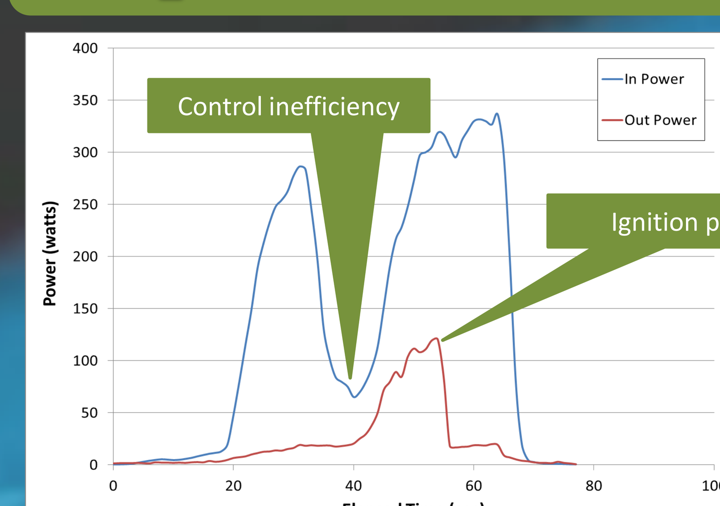
- CO_2 flow rate and reactor pressure were set to desired values
  - CO_2 flow = 50,100, or 200 SmLPM
  - Pressure = 15, 30, or 45 Torr
- Gradually increased microwave power until plasma ignited
  - Maximum power = 750 W
- Recorded power required for ignition

- Accumulated Carbon for 6 hours
  - PPA operated with a methane feed of 200 SmLPM and total hydrogen feed of 800 SmLPM
- System shutdown and reactor disassembled after 6 hours
- Pictures taken of inside the reactor and quartz window
- Reactor surfaces cleaned by scraping with a razorblade

- Two-day trials completed
  - Day One - Accumulate carbon for 6 hours
  - Day Two - Attempt regeneration for a given time period, CO_2 rate, and microwave power.
    - Times = 15, 30, 60, and 120 minutes
    - CO_2 rate = 100 SmLPM
    - Microwave Power = 600 W
- Pictures taken of inside the reactor and quartz window
- Remaining carbon collected and weighed

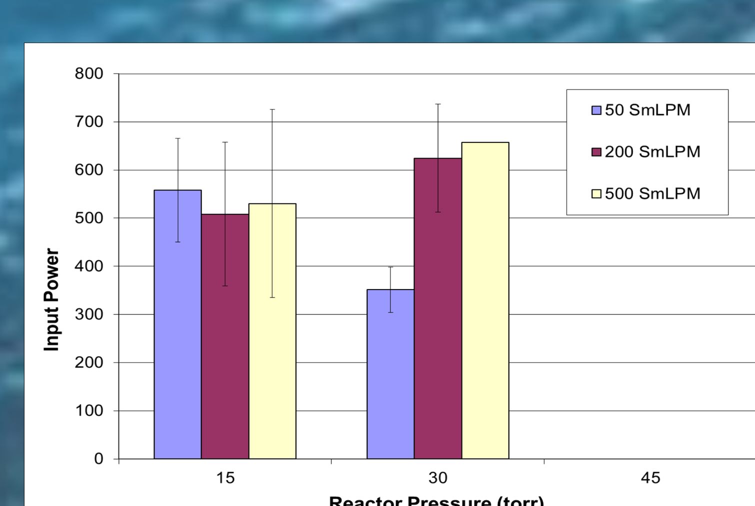
Results / Discussion

CO_2 Plasma Ignition



The sudden decrease in reflected power indicates when the plasma ignited in the PPA reactor.
Note: CO_2 ignition pressure = 30 torr, operating pressure = 45 torr

Average Input Power Vs. Pressure

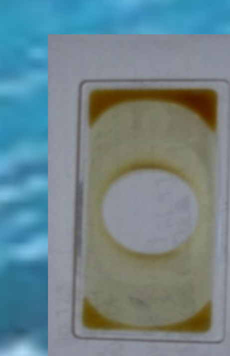


Testing indicated that CO_2 plasma was more easily ignited at lower pressures. It was not possible to ignite the CO_2 plasma at 45 torr.

Window Regeneration

After 6 Hour Carbon Accumulation

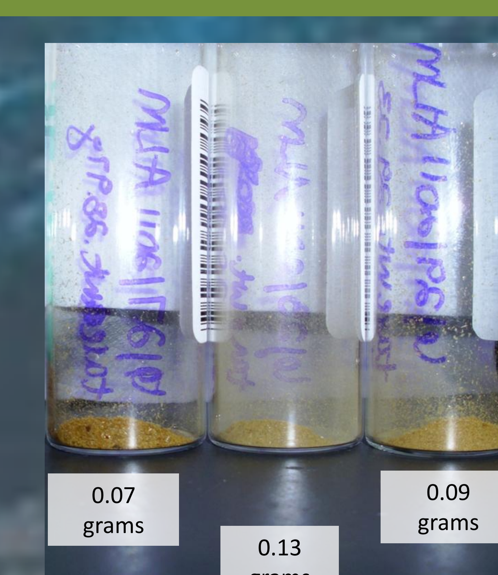
After 12 Hour Carbon Accumulation



After 18 Hour Carbon Accumulation

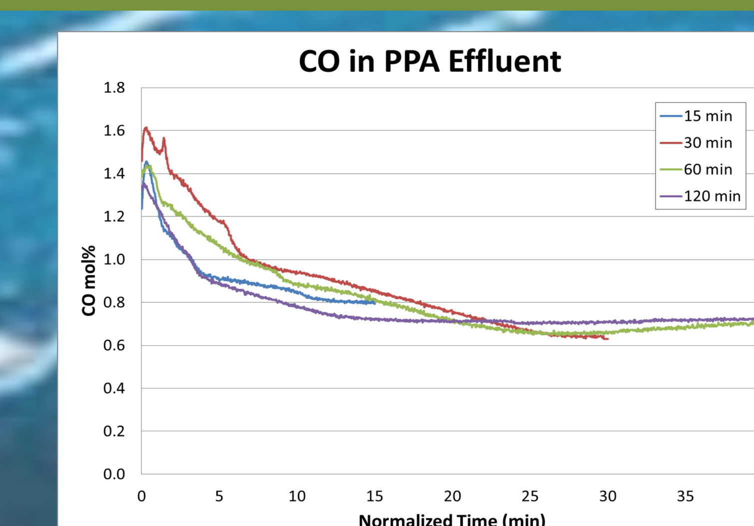
After 15 Min Regeneration Window was almost completely clean

Carbon Collected



Carbon accumulation was found to be fairly consistent between 6 hour repeats.

Regeneration Results

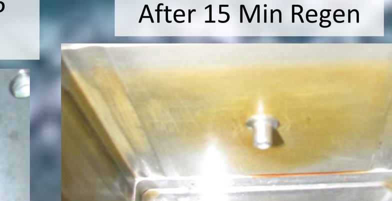


Carbon monoxide was produced in similar quantities and for similar lengths of time for each trial.

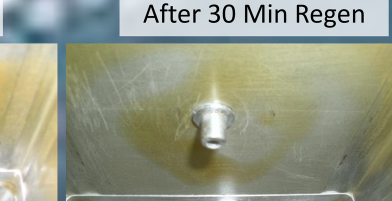
Before and After

Inside reactor after 6 hour Accumulation

After 15 Min Regen



After 30 Min Regen



After 1 Hour Regen

After 2 Hour Regen

Increasing the time for regeneration increased the quantity of carbon removed from the reactor. For longer regeneration times, residual carbon was more easily removed by mechanical means.

Conclusion

This testing showed that a CO_2 plasma could be ignited at pressure as high as 30 torr and a CO_2 flow rate of 200 SmLPM. Carbon deposition from nominal PPA operation is repeatable. Finally, it has been shown that surfaces of the PPA can be regenerated with a CO_2 plasma while generating minimal quantities of CO.

Future Work

Future work will include the following efforts:

- All data points must be repeated to ensure statistically significant results.
- Testing should be completed to determine the maximum carbon removal and time necessary for completion.
- Longer accumulation times must be attempted before regeneration.