Particulate filtration from Emissions of a Plasma Pyrolysis Assembly Reactor Using Regenerable Porous Metal Filters

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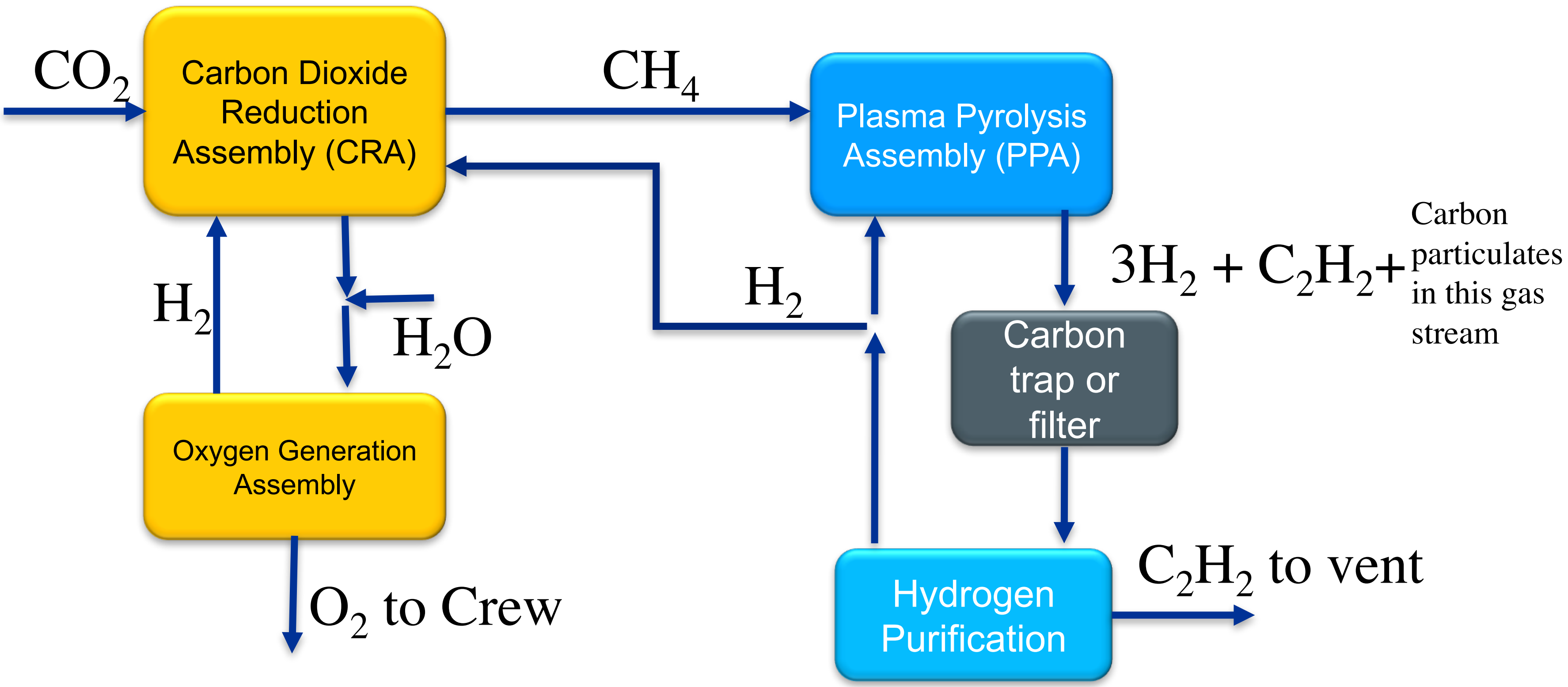
Outline

Carbon Dioxide Reduction System
Plasma Pyrolysis Assembly
Objective
Porous Metal Filter and regeneration concepts

Carbon Dioxide Reduction System



CRA with methane post-processing recovers 75-90% of O_2 from metabolic CO_2

Plasma Pyrolysis Assembly

Methane converted to hydrogen and acetylene by partial pyrolysis in microwave generated plasma

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

First Generation UMPQUA Microwave Plasma Methane Pyrolysis Assembly (PPA) delivered in May 2009

3^{nd} Gen. PPA, capable of 4-crew member (CM) flow rates, delivered October 2013

H_2/CH_4 Plasma

3^{rd} Gen PPA

Carbon Characterization

- **Carbon generation/load rates** measured by UMPQUA (SBIR) : 40 to 50 mg/hr (for 4 CM rate)

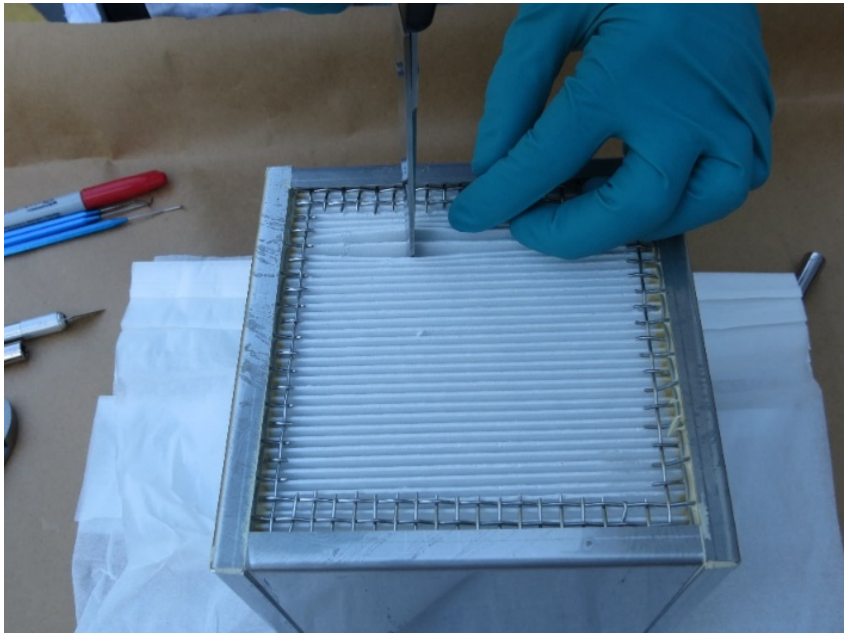
- **Characterization** - *Green, Robert D., et al. "Characterization of carbon particulates in the exit flow of a Plasma Pyrolysis Assembly (PPA) reactor." 45th ICES, 12-16 July 2015, Bellevue, WA*

    - Particles sampled in-line on various filter media.
    - Imaged using Scanning Electron Microscopy (SEM)
    - Carbon particulate size range is in 100 – 500 nm range (high aspect ratio and irregular shape).
    - Particulate samples are primarily carbon.
    - Individual particulates resembled graphene.

- Low pressure gas stream containing 2 combustible gases (hydrogen and acetylene) limits active filter techniques and compatible materials (seals)

Objective

Develop an effective carbon management system for long term remote and autonomous operation.



(a)

(b)

Sample recovered from in-line HEPA filter

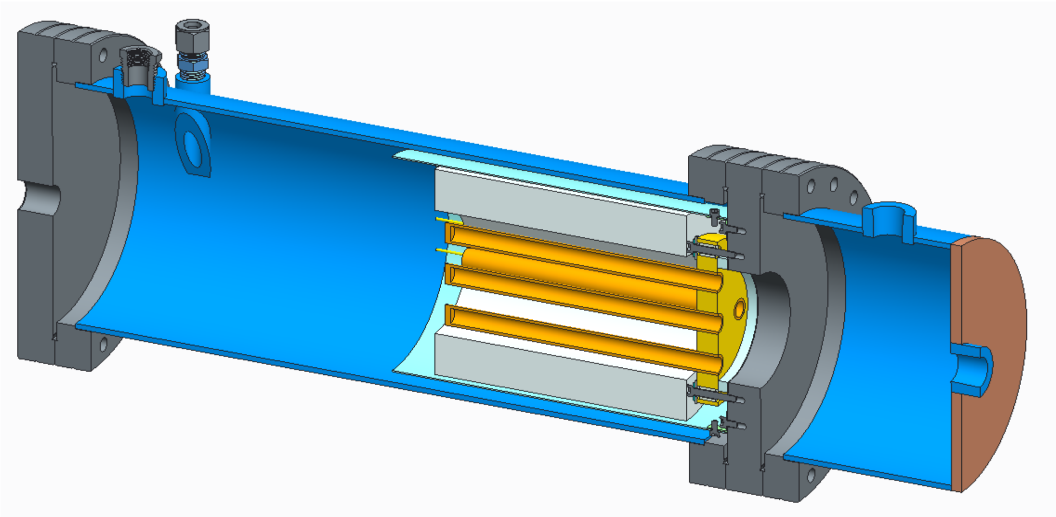
Porous Metal Filter

Use sintered porous Hastelloy cylinders from Mott.

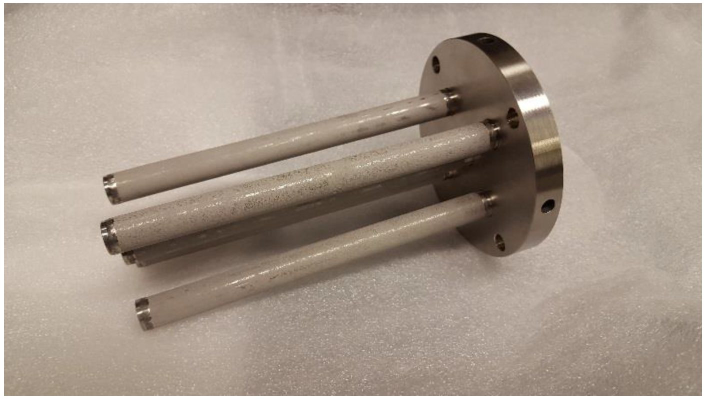
Design housing to be heated with opening or removal.

Oxidize in CO_2 feed stream

First Generation Filter



Design and image of the porous metal filter. The five filter elements are 8" long and ½" in diameter. Heating tape was used for regeneration.



First Generation Results

After hours of testing a borascope was used to inspect the filter elements.
With positive feedback, filtration was continued.

First Generation Lessons

The heating tapes were only rated to 650C.

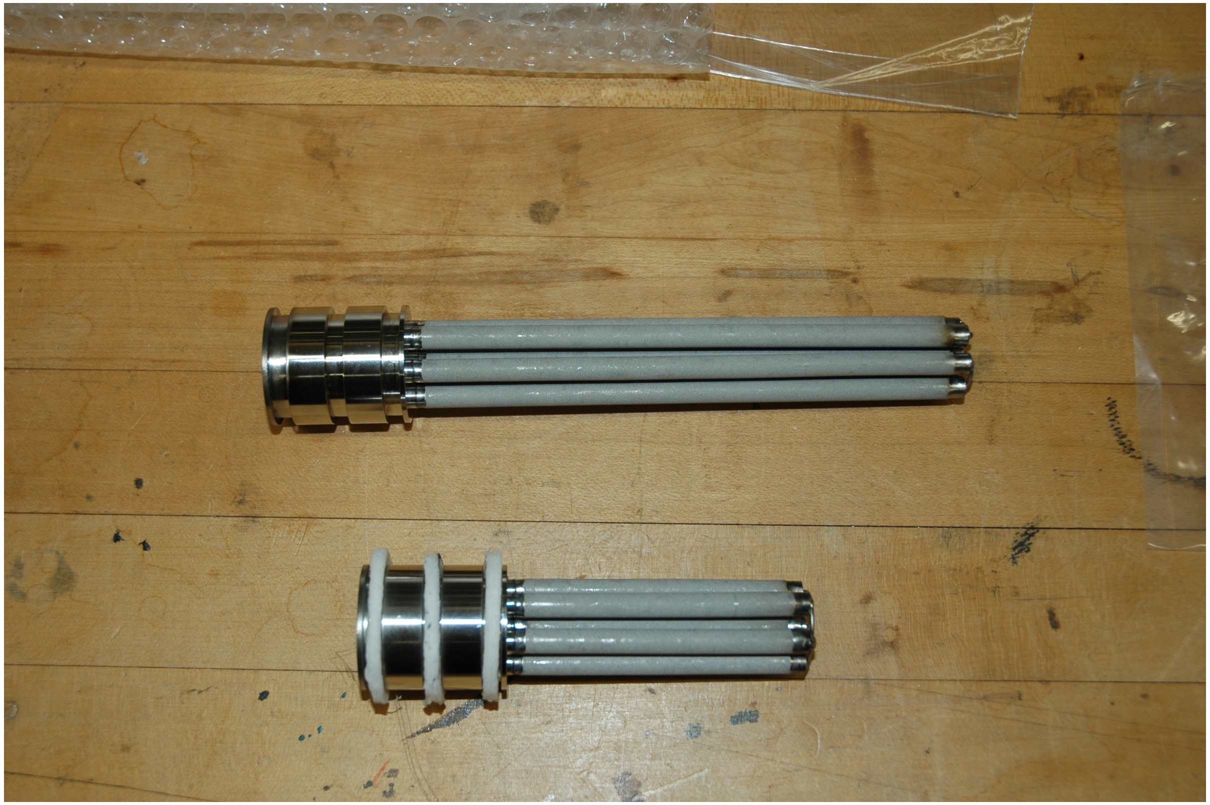
Desired regeneration temperature range was 450-650C.

Regeneration was slow due to low temperatures on the filter elements and large mass to heat.

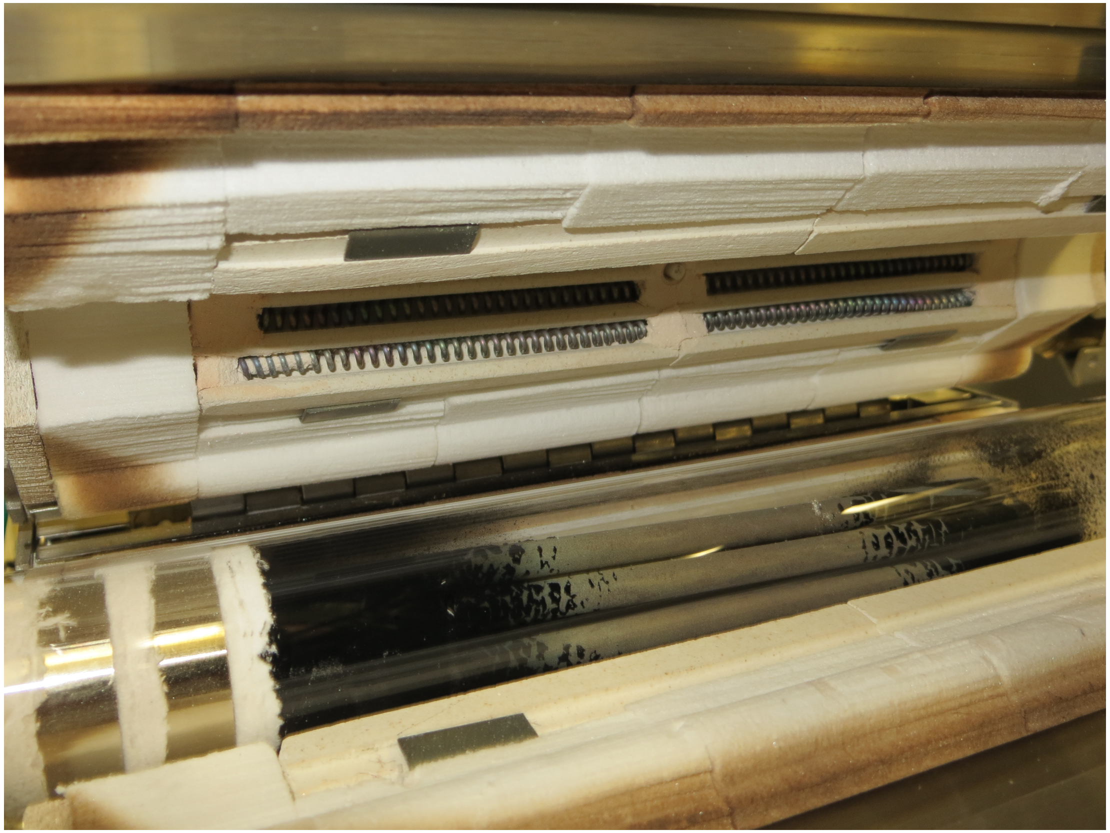
The welded flanges were warped, making sealing difficult.

Second Generation Porous Metal Filter

Two units were designed with different lengths to compare filter lifetime due to collected carbon impacting the pressure drop over the filter. Each filter has 7 elements of 0.25” diameter. One is 3” and the other is 6”.

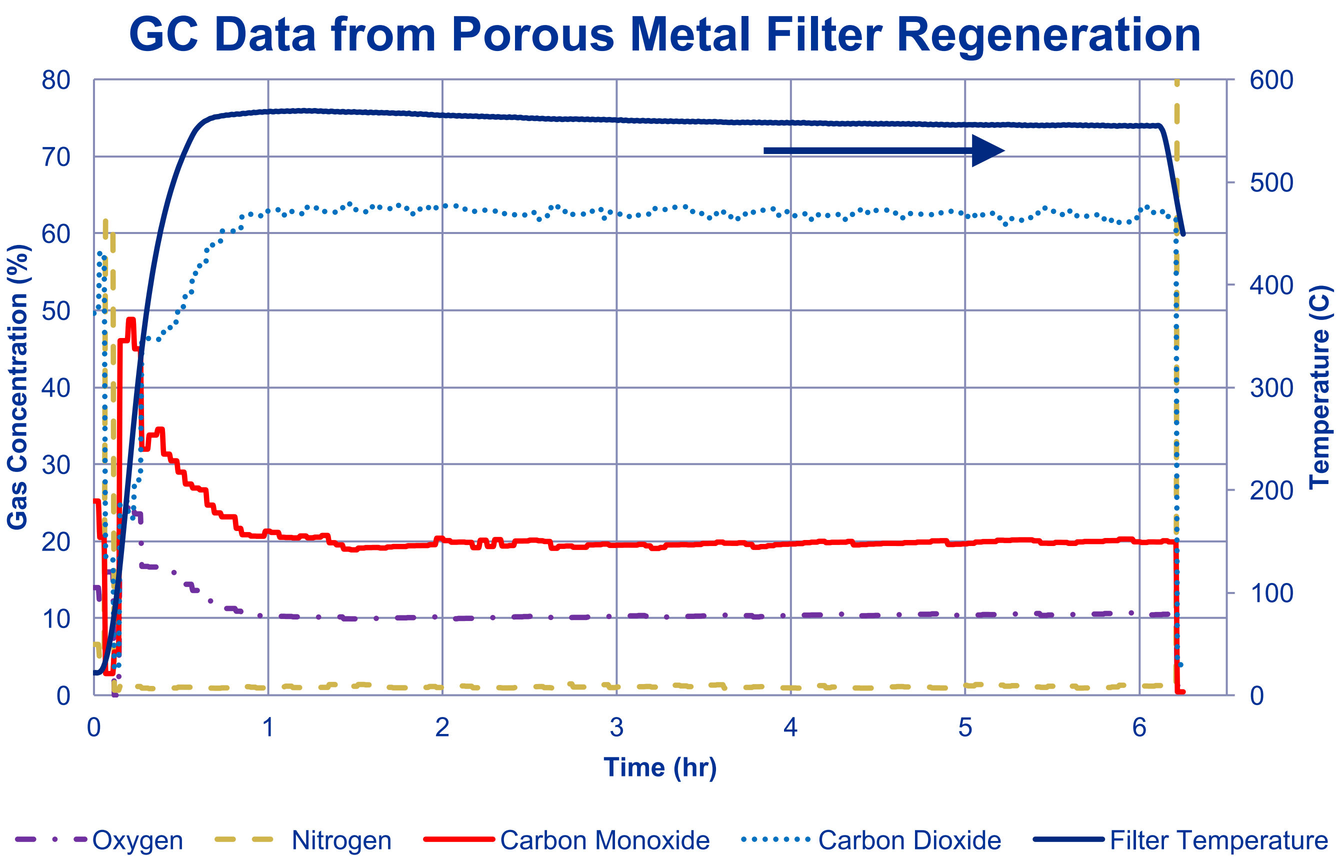


Second Generation Porous Metal Filter



The filters were mounted inside a quartz tube gasketed with Fiberfrax ceramic felt. The tube was mounted in a Mellen furnace rated to 1000C to allow excess heating capacity.

Second Generation Porous Metal Filter



GC data was collected during regeneration of the filter. The oxygen in the system is believed to be a byproduct of a PPA preheat.

Second Generation Results

The smaller filters were designed to try to match the 4-8 hour regeneration cycle of the PPA to avoid unnecessary downtime.

For the first few cycles this work until 6” filter performance degraded to the point that it would not even last that long.

Pressure drop met the ground facility requirements but far exceeded flight guidelines.

Third Generation Porous Metal Filter

An all welded housing was selected to avoid any issues with sealing. Close inspection of the filter elements is no longer required given 2 generations of observation. Inlets are still large enough to accommodate a borascope probe.

Filter elements/diameter are maximized to stay under 2.5" diameter but provide significant surface area.

The pores on the filter element are larger, moving on from 0.5 micron elements used previously to 5 microns. Filter efficiency is not expected to be substantially impacted but pressure drop should rise considerably.

Concerns that oxidation of Hastelloy in CO_2 may cause swelling of the filter elements should be less impactful.

Third Generation Porous Metal Filter

Third generation porous metal filter before welded assembling

Conclusions

Using a porous Hastelloy filter provides a durable material for long term repeated regeneration cycling.

Available porosities show good efficiency in filtering carbon from the PPA gas stream.

Oxidation under CO_2 is a viable means of using available resources to prolong system lifetime.