Cold Trap Carbon Capture Filter for Carbon Fines Management – In-laboratory Performance and Efficiency Results

ICES-2023-351

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52nd International Conference on Environmental Systems 16-20 July 2023, Calgary, Canada

Outline

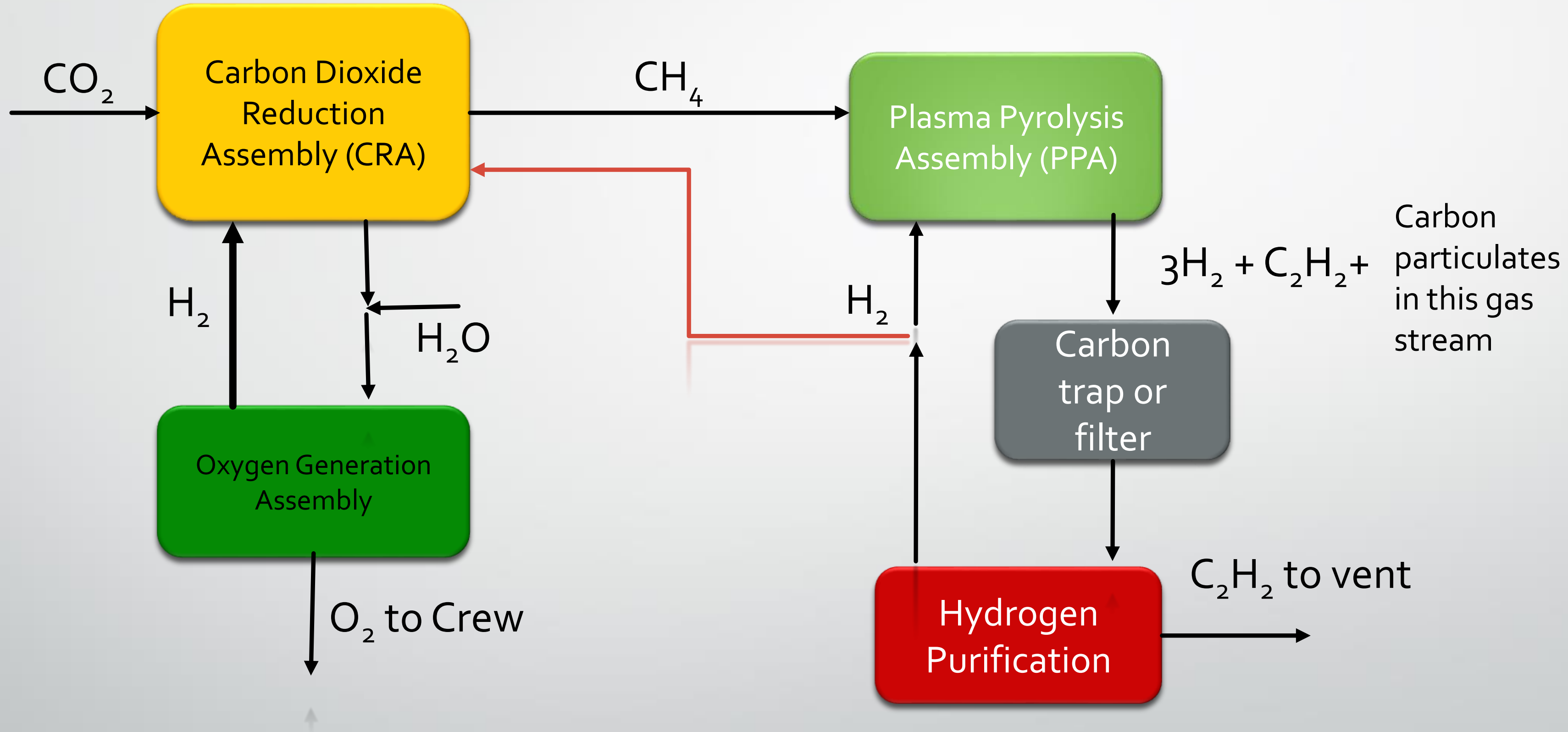
- Objectives
- Background
- Test Setup
- Results
- Conclusions
- Future Work
- Acknowledgements

Objectives

- Assess perform of the collection efficiencies of the two chambers, or collection stages, of the Cold Trap Filter under isothermal flow conditions.
- Assess performance of separate third stage HEPA filter

Background/Motivation

Oxygen Recovery loop with proposed PPA and carbon Cold Trap filter



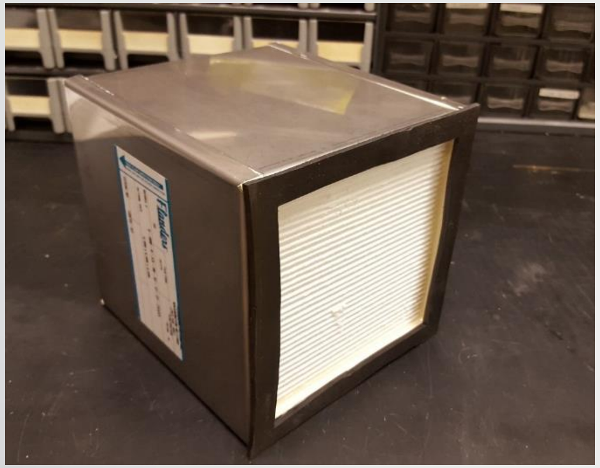
CRA with methane post-processing recovers 75-90% of O_2 from metabolic CO_2

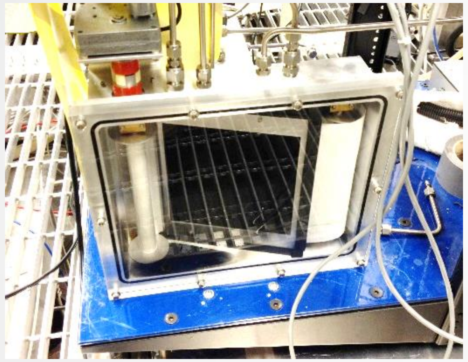
Background/Motivation

- The Plasma Pyrolysis Assembly is a methane processing technology that can be used to advance oxygen loop closure for spaceflight.
- It is estimated to recover > 86% oxygen from CO_2 on the ISS (Greenwood et al., 2018)
- The PPA decomposes the methane produced from the reaction of CO2 with hydrogen in the Sabatier reactor into hydrogen and various hydrocarbons: mainly acetylene, and smaller quantities of unconverted methane, ethylene, and ethane, and small quantities of solid carbon.
- The carbon particles formed are physically very small, with sizes as small as 100 to 200 nm (Wheeler et al., 2014)
- If not mitigated the carbon dust load could eventually foul the PPA reactor and downstream Environmental Control and Life Support Systems (ECLSS) subsystems, limiting and interrupting the air revitalization system.

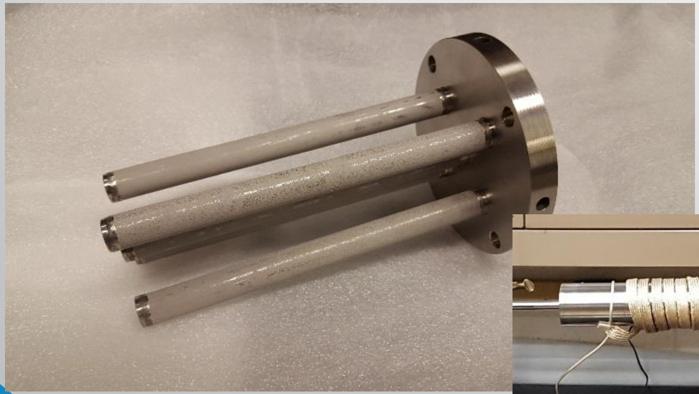
Previous and Ongoing filtration work

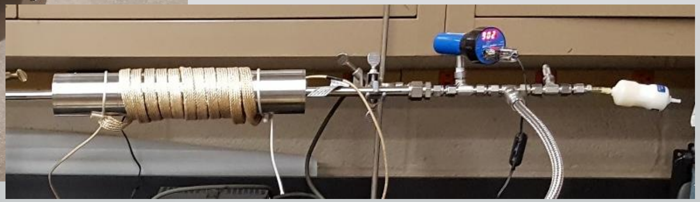
HEPA



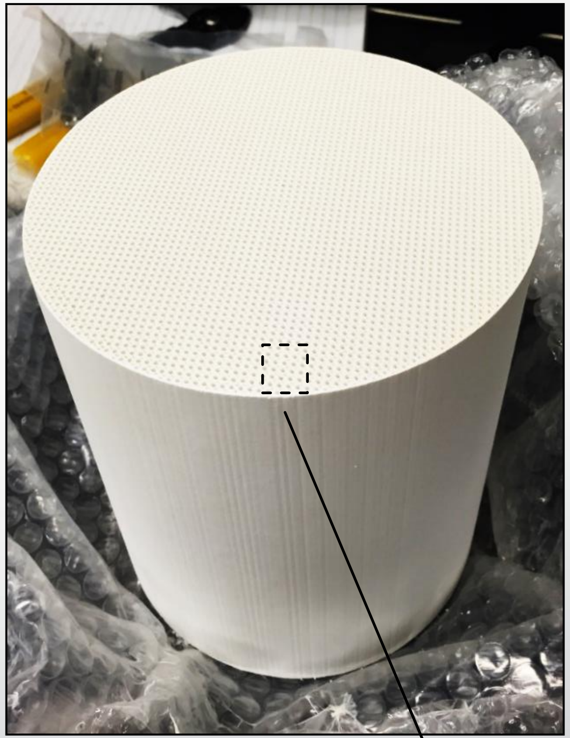


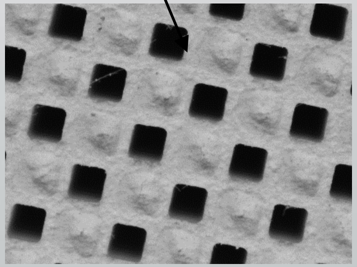
Scroll Filter





Porous
Sintered
Metal Filter





Ceramic
Diesel
Particulate
Filter (DPF)

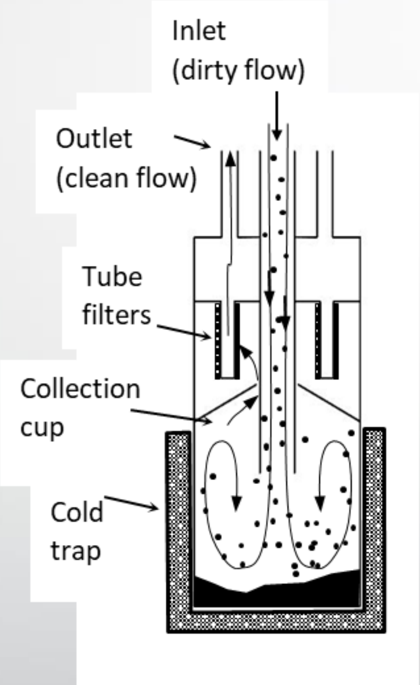
Previous and Ongoing filtration work

UMPQUA Regenerable Carbon Filter - Electrostatic and Media Filtration

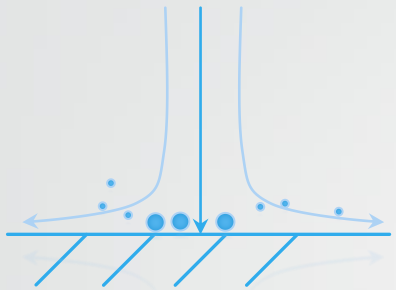
Previous Results

- Characterization –
  - Nano-rods is the prevailing structure. Graphene structure also observed (Wash. U.)
  - There may be multiple formation mechanisms and particle types formed
  - Carbon Generation rate ~ 40 mg/hr.
- HEPA test – filter retained all particles down into the pleats with an initial low pressure drop for 25 hours. Media became quickly loaded with rapid pressure drop rise. Heavy deposit on wall opposite to incoming jet flow from inlet tube.
- Diesel Particulate Filter (DPF) – initial low pressure drop but increases rapidly after about 6 to 8 hours. Plugging at micro-channel inlets. Regeneration successful at high temperatures.
- Scroll – low initial pressure drop and low rate increase. Pressure drop recovered to original pressure drop after media change. Estimated 12 hour cycle per media change.
- Porous Sintered Metal Filter – 100-hour test showed moderate pressure drop rise. Regeneration partially successful using CO_2 gas.
- Umpqua Regenerable Carbon Filter – Evaluation ongoing.

Filter Concept

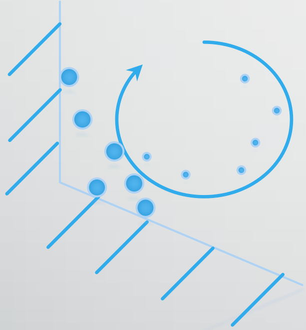


Filtration and Carbon Capture Mechanisms

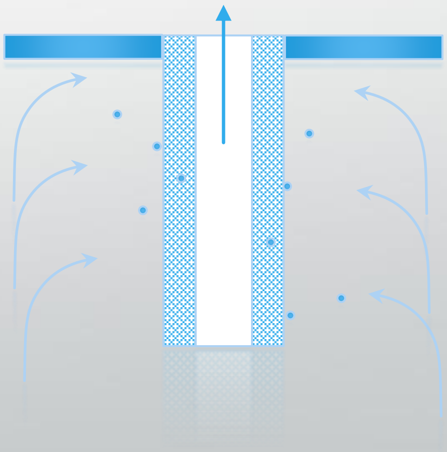


Impaction at stagnation point

Separation through mid-height baffle

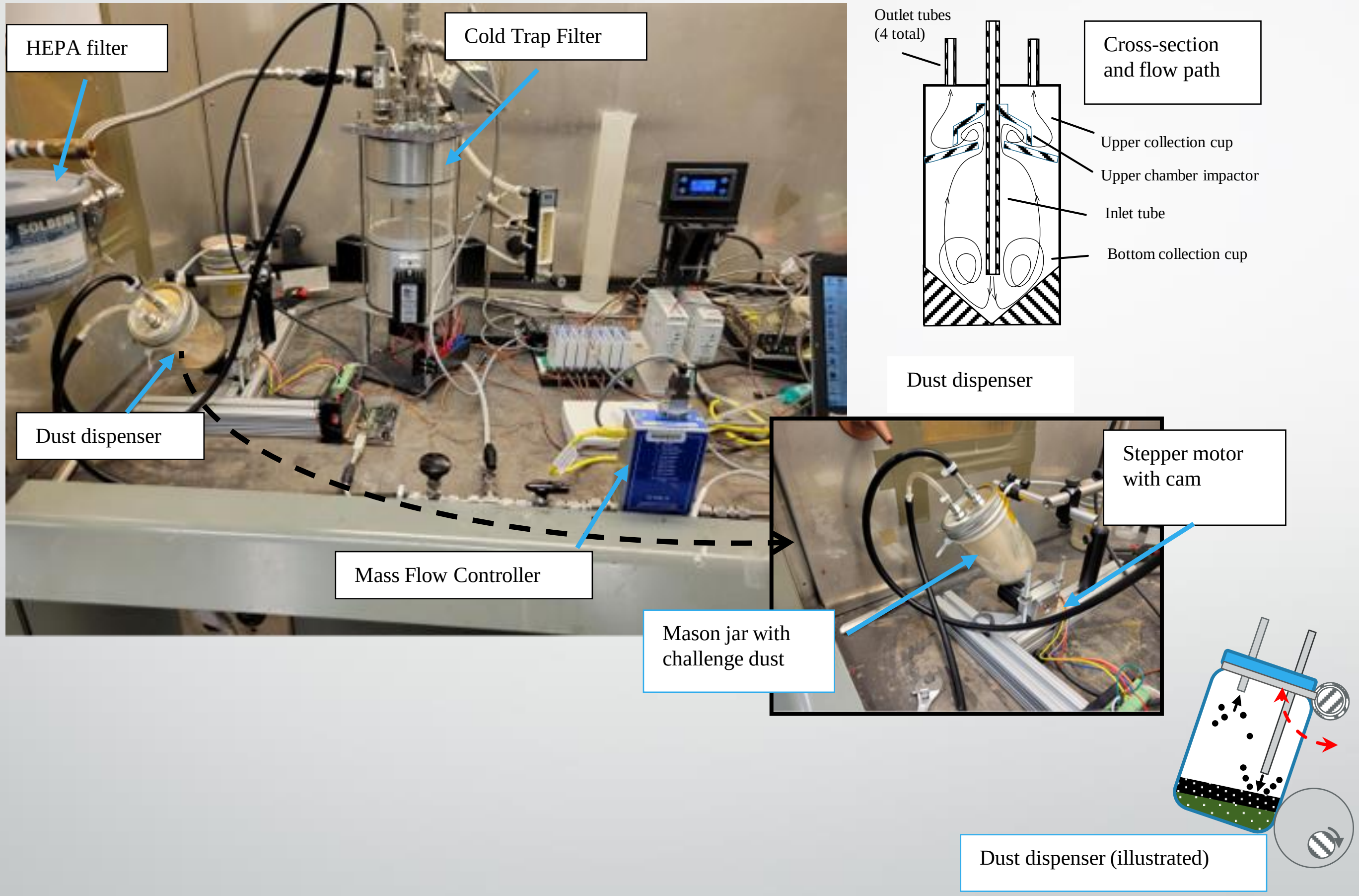


Centrifugal separation in recirculation bubble



Filtration through media filters at outlet

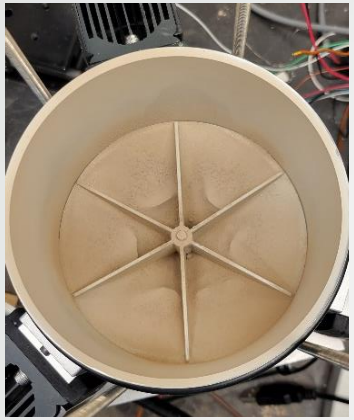
Test Set Up



HEPA filter
Cold Trap Filter
Dust dispenser
Mass Flow Controller
Outlet tubes
(4 total)
Cross-section
and flow path
Upper collection cup
Upper chamber impactor
Inlet tube
Bottom collection cup
Dust dispenser
Stepper motor
with cam
Mason jar with
challenge dust
Dust dispenser (illustrated)

Results

Mass Analysis

	Bottom cup	Upper cup	Impactor plate/cup between bottom and upper cup
ISOFTD challenge			
Carbon black challenge			

Mass Analysis

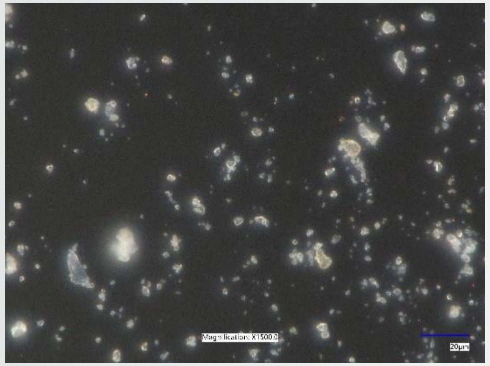
Component	ISO FTD			Carbon		
	Mass [g]	Collected Mass [%]	Component collection efficiency [%]	Mass [g]	Collected Mass [%]	Component collection efficiency [%]
Collection cup - bottom	3.36	64.86	64.86	1.03	19.29	19.32
Upper impactor				0.25	4.69	5.81
Upper cup	0.62	11.97	34.07	0.88	16.48	21.73
Total filter housing	3.98	76.83	76.83	2.16	40.52	40.52
Manifold	0.55	10.62		0.22	4.12	
HEPA	0.65	12.55	> 99*	2.95	55.24	> 99*
Total all components	5.18			5.33		

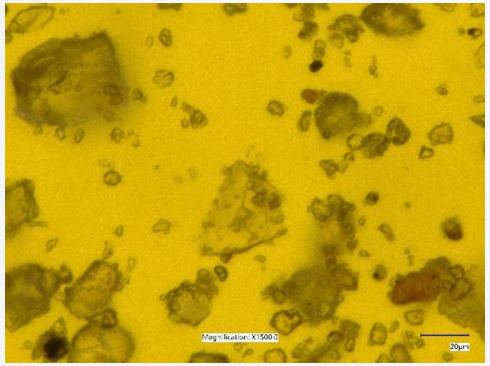
* Assumed >99%, HEPA was the last stage in filtration. No analysis of particle penetation was performed

Particle Analysis

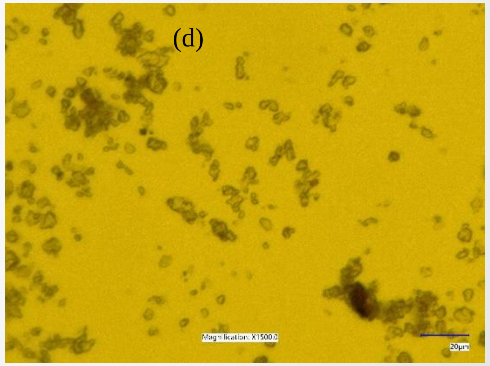
Source material | Bottom cup | Upper cup

ISO FTD





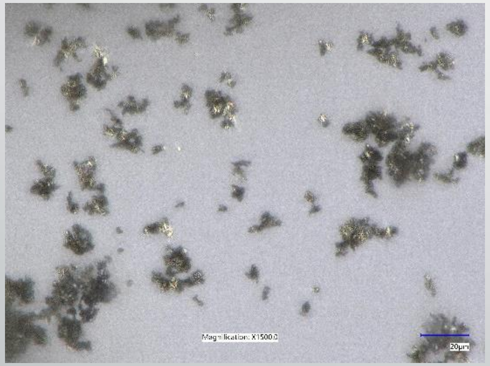
(b)

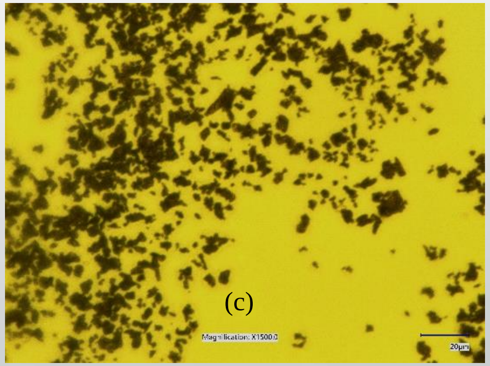


(d)

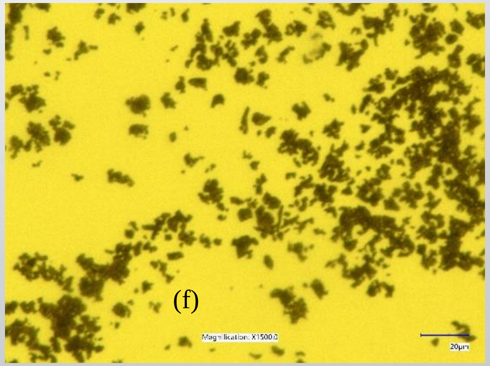
(e)

Carbon Black





(c)

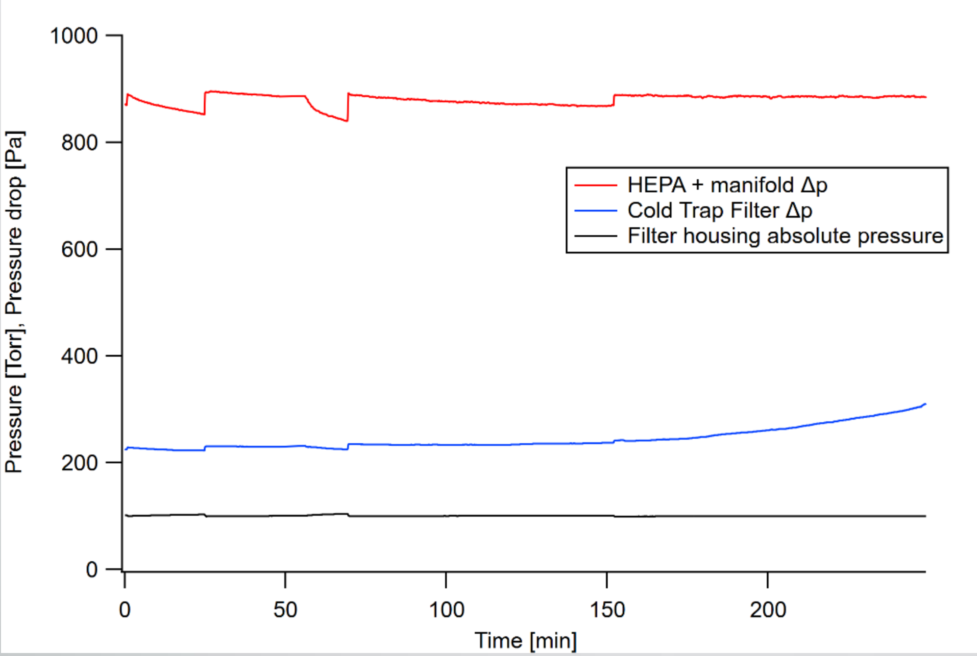


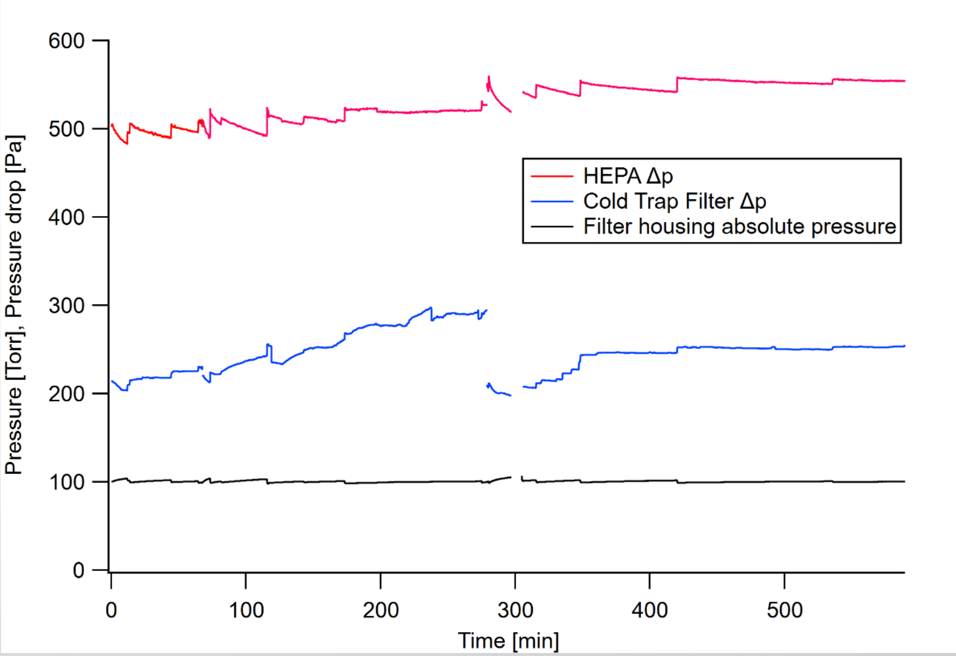
(f)

Particle Analysis

	ISO FTD		Carbon	
	Bottom Cup	Upper Cup	Bottom Cup	Upper Cup
Mean diameter	7.14	3.41	1.60	1.46
Mininum circular diameter	1.22	0.83	1.12	0.23
Maximum circular diameter	47.59	9.16	2.05	2.15
Mean Aspect ratio	1.57	1.64	1.48	1.61
All values in µm				

Flow performance





Conclusions

- The filter performed well or moderately well when challenged with ISO FTD, capturing at least 76% of the dust inside the filter housing. However only a little better than 40% of the carbon dust was captured.
- The ISO FTD test data clearly showed large particle capture and separation occurring in the bottom collection cup, whereas the carbon test data showed about the same size particles in both the bottom and upper collection cups.
- The carbon dust images also revealed a strong indication of carbon particle breakup.
- The pressure drop, rose slowly initially and then accelerated in value in the ISO FTD case whereas, aside from a transient pressure drop buildup, the pressure drop rise in the carbon tests was generally slow.
- There was almost no rise in pressure drop across the HEPA filter with ISO FTD loading, but a noticeable pressure drop rise with carbon loading.
- Improvements in the internal design of the Cold Trap Filter may provide more holding capacity and collection efficiency

Future Work

- Integrated testing of the cold trap filter with the PPA at the NASA Marshall Space Flight Center (MSFC) will also be planned.
- Combination of the Cold Trap Filter, for bulk carbon capture, with other effective filtration technologies such as the regenerable porous metal filter could provide a complete filtration system for PPA carbon capture.

Acknowledgements

- The support from NASA's Life Support System (LSS) project under the Exploration Systems Development Mission Directorate (ESDMD)) is greatly appreciated.

- The authors would also like to thank Mr. Daniel Gotti (USRA) for the design of the Cold Trap Carbon Filter.

Background/Motivation

Oxygen Recovery loop with proposed PPA and carbon Cold Trap filter