IMPERIAL

SPACE RESOURCES ROUNDTABLE

Dust Handling & Mitigation

On the Lunar Surface

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Agenda

1. Introduction
2. Surface Cleaning
3. Air Scrubbing
4. Conclusions

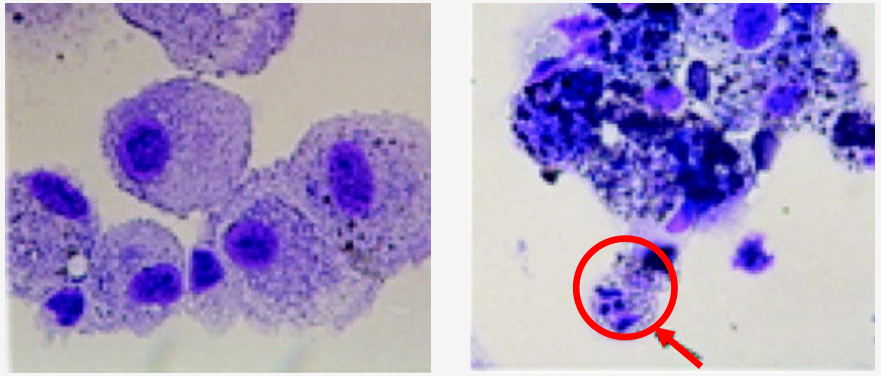
Introduction
Background

- Lunar dust presents challenges for mineral processing and operational health and safety
- Feeds must be classified to remove ultra-fine particles
- Regolith inhalation caused Apollo astronauts to experience allergic reactions and pulmonary irritation despite mitigation efforts
- Respirable particles (<10 μm) pose the greatest risk to health; they comprise ~7%

Dust-covered Gene Cernan, Apollo 17

Motivation
Regolith & Human Health

- Exposure to lunar regolith simulant leads to moderate alveolitis, inflammation, fibrosis, and septal thickening
- Lunar dust has cytotoxic effects on macrophages, potentially leading to cardiac fibrosis
- Reduced gravity increases particulate deposition in the lungs and extends clearance time
- Air filtration systems, such as HEPA filters, require frequent replacement, posing logistical and cost challenges for long-term missions.



Morphology of human alveolar macrophages 24 h after exposure to lunar dust simulants. Left: control macrophages cultured for 24 h. Right: Macrophages incubated with lunar dust simulant for 24 h. Arrow indicates morphology consistent with macrophage apoptosis (600X, dry objective). From Latch et al.

Latch, J. N., Hamilton Jr, R. F., Holian, A., James, J. T., & Lam, C. W. (2008). Toxicity of lunar and martian dust simulants to alveolar macrophages isolated from human volunteers. *Inhalation toxicology*, *20*(2), 157-165.

Motivation
Key Assumptions

- Permissible Exposure Limit (PEL) of lunar regolith: 0.05 mg/m^3
- Spacesuits to retain 227 g/suit/EVA
- Astronauts to perform EVAs in pairs: 454 g/EVA
- Dust fraction (<10 μm, ~7%) could become airborne: 31.8 g/EVA could enter air handling system
- Lunar habitat airlock volume assumed to be comparable to ISS: 68.6 m^3
- Total airborne dust concentration in airlock: 463 mg/m^3 (~926000% over PEL)
- Essentially all dust must be removed from the airstream to ensure levels remain below PEL

Agui JH, Stocker DP. *NASA lunar Dust Filtration and Separations Workshop Report.* National Aeronautics and Space Administration. Report Number: NASA/TM-2009-215821, 2009.

Introduction
Objectives

The objectives of this research are:

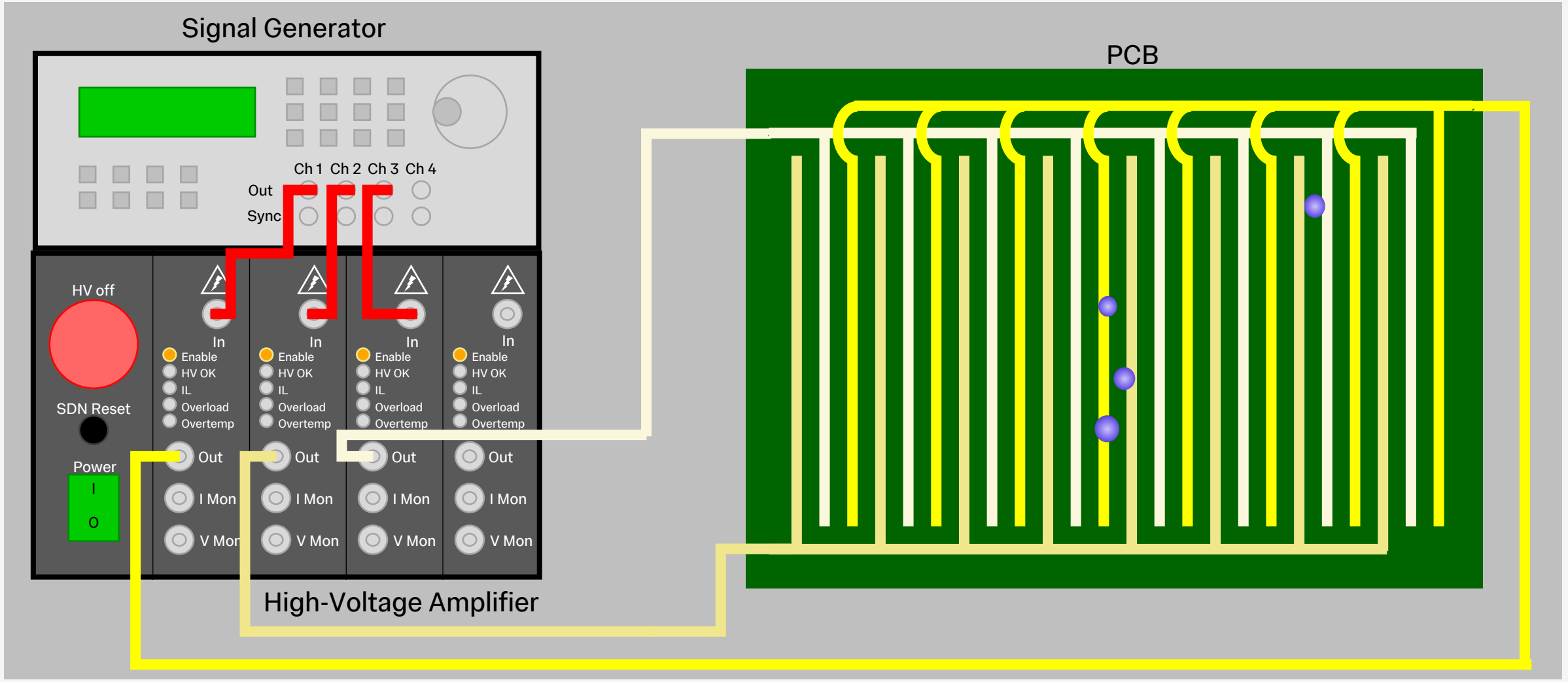
- to demonstrate means of cleaning dusty surfaces;
- to identify methodologies to minimise dust ingress into lunar habitats; and,
- to investigate sustainable approaches to protect HEPA filters and extend their lifespan

Surface Cleaning

Dust Removal with the Electrostatic Travelling Wave

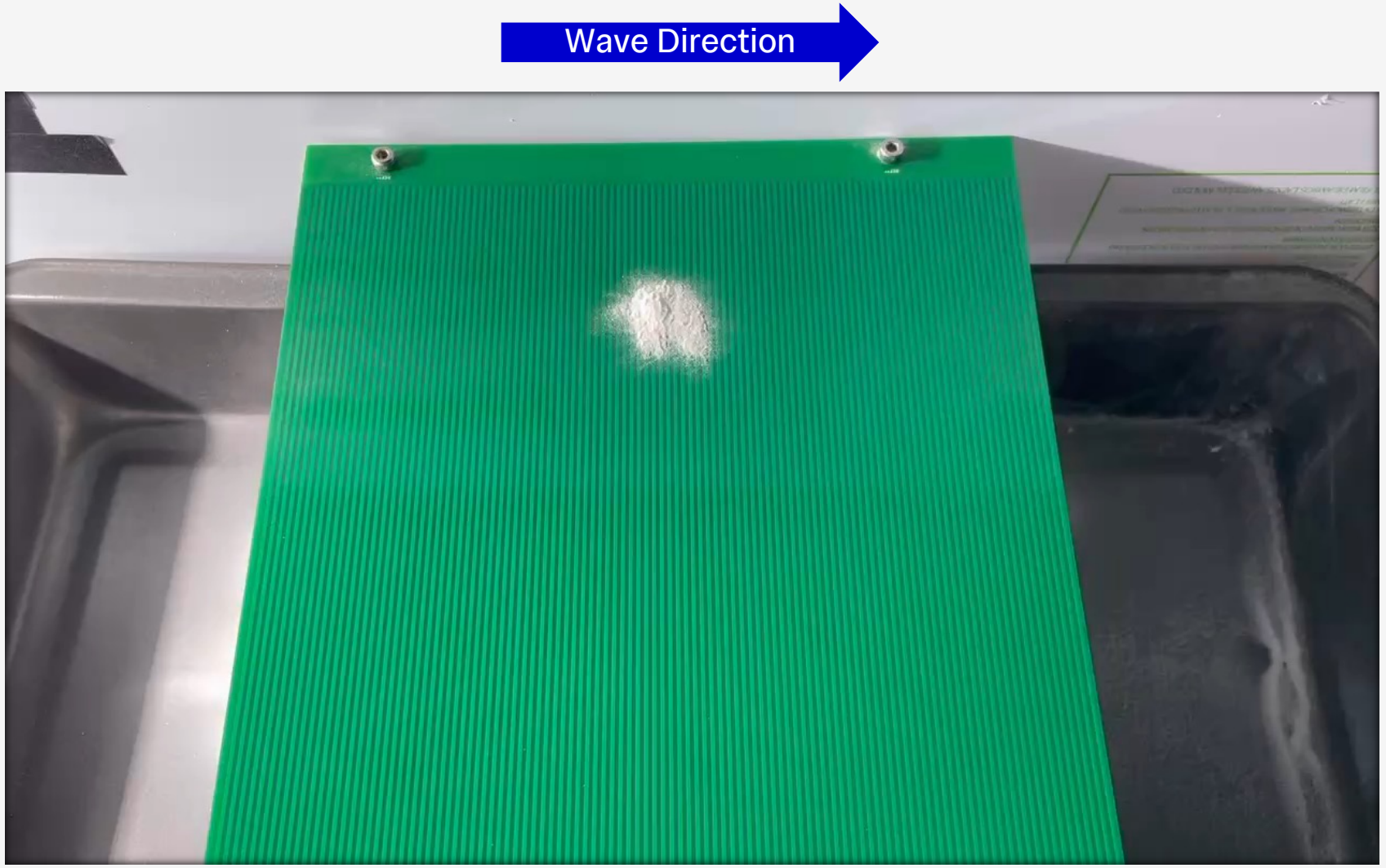
The ETW Method

A Brief Introduction



Frequency Dependence

Conveyance of -50+20 μm Ballotini

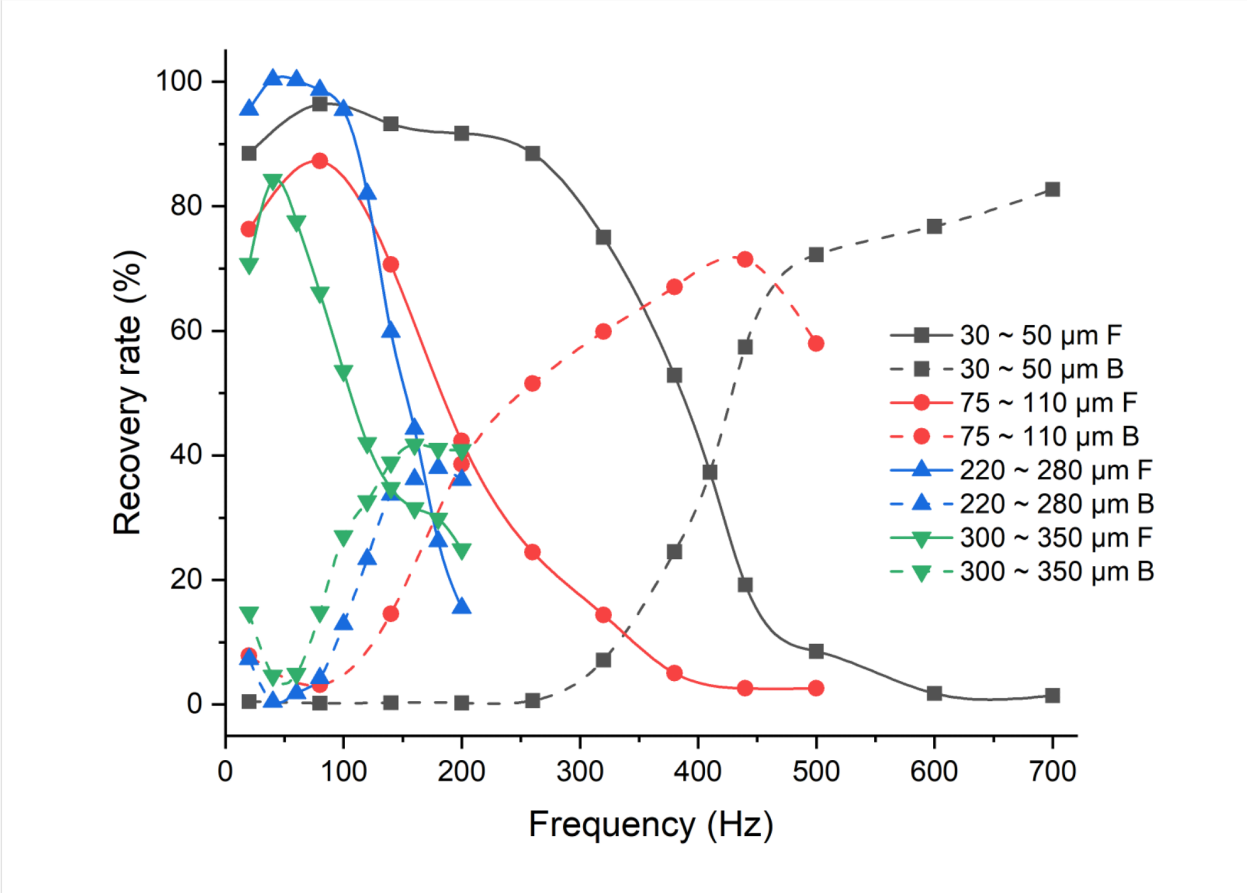


150 Hz

Frequency Dependence

Mass Recovery by Size

- Four size classes tested:
  - -50+30 µm
  - -110+75 µm
  - -280+200 µm
  - -350+300 µm
- Lower frequencies best convey the broadest cross section of particles
- Higher frequencies are less capable of initiating particle motion, with greater proportion of material retained on the board

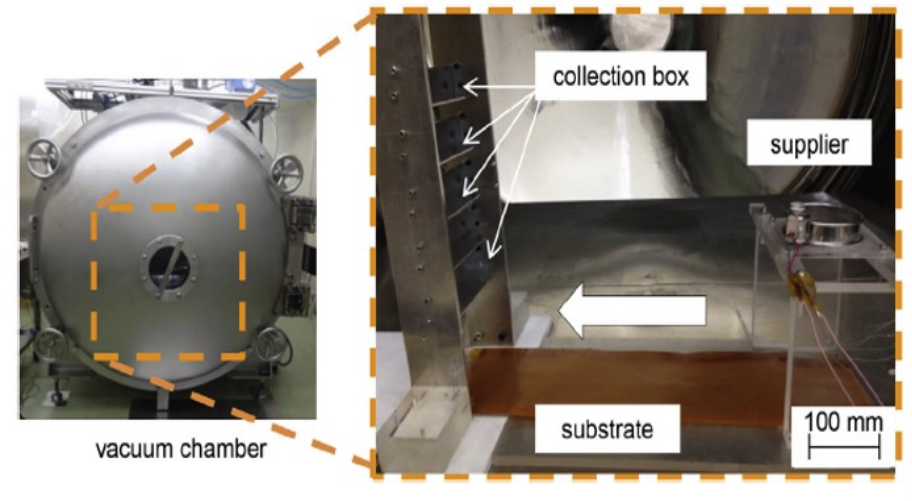


Comparison of all samples.

Yu, Y., Cilliers, J., Hadler, K., Starr, S., & Wang, Y. (2024). Dry particle size separation using electrostatic traveling wave methods. *Separation and Purification Technology*, *336*, 126275.

Applications
For the ETW Method

- Cleaning dust from solar panels and thermal radiators
- Removing settled/adhered dust from ductwork in air handling systems
- Clearing accumulated dust in airlocks following EVAs
- Material conveyance and sizing for ISRU



Lunar simulant particle transport and separation (Adachi et al., 2017)

Field test of EDS in Saudi Arabia (Faes et al., 2019)

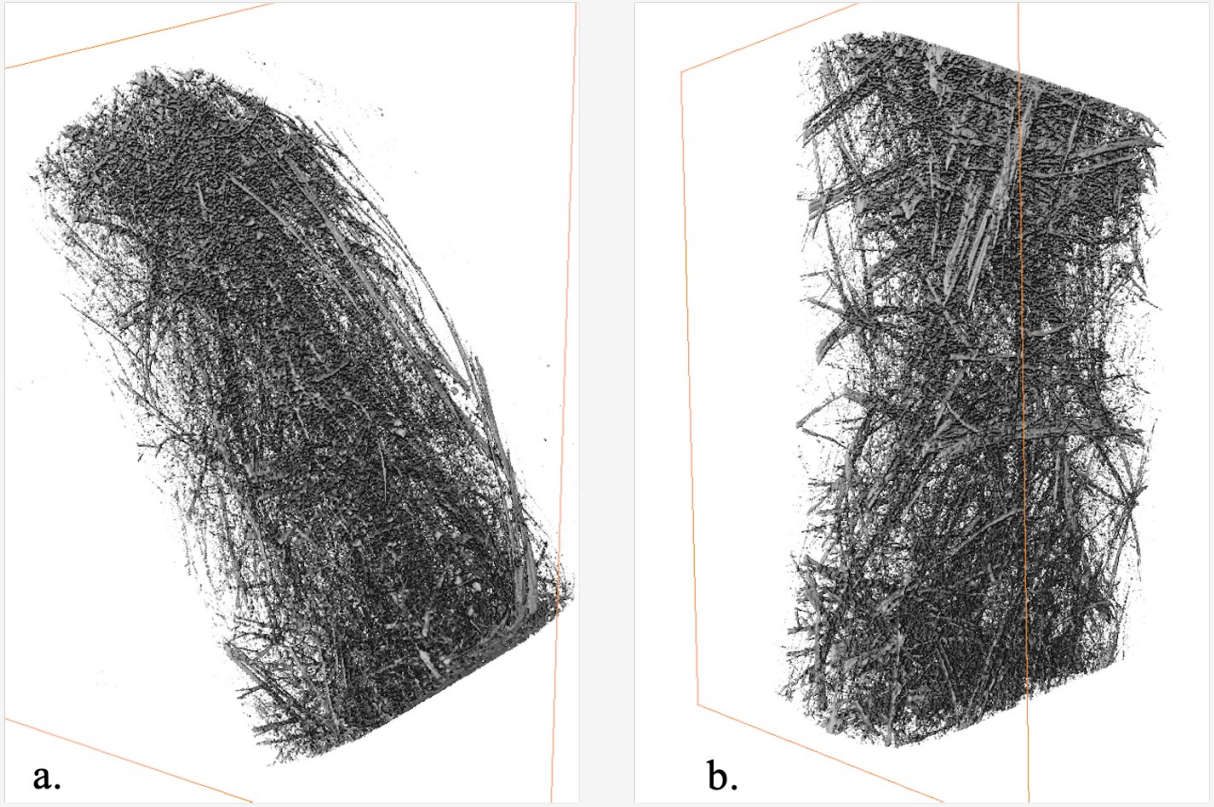
Cleaning Dusty Air

Pre-Treatments to Prolong HEPA Filters

Dust Removal
Filters & Cyclones

Pre-Filters
- The introduction of air pre-filters to an air handling system would reduce the loading on the gold-standard HEPA filters
- Pre-filter materials could be produced from recycled, grown, or locally-derived materials

Gas Cyclones
- Gas cyclones are an alternative to pre-filters
- They are attractive in that they have long service lives and have no consumable components
- Cyclones can be 3D printed from a number of materials



Micro-CT cross sections of needlefelted basalt fabrics. (a) commercially-available basalt fibre; (b) basalt fibres produced from lunar regolith simulant (MoonFiber).

Materials & Methods

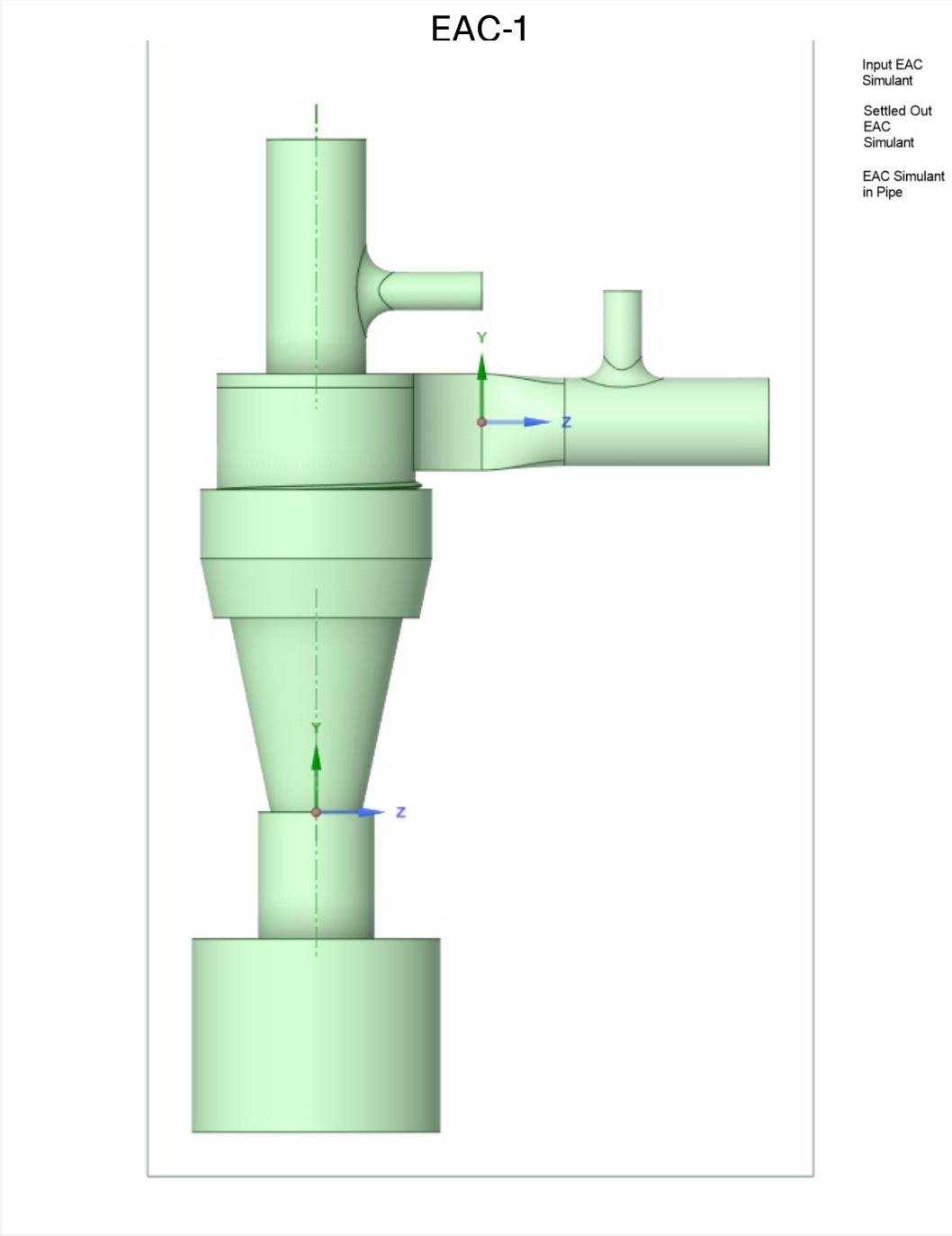
Simulants & Equipment

Simulants:

- EAC-1 (full size range) used for filtration studies and LHS-1D (dust fraction) used in cyclone and filtration study

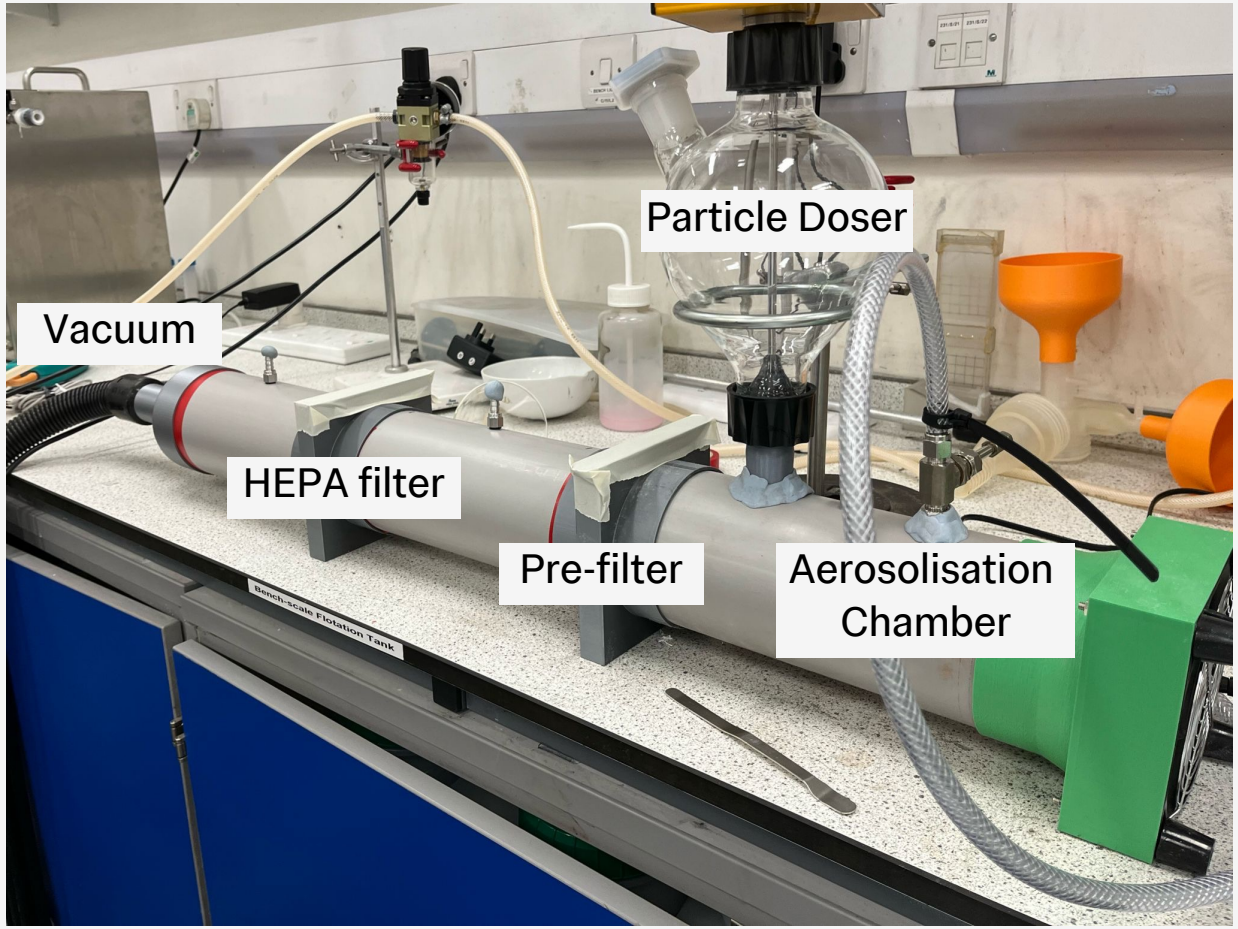
Equipment:

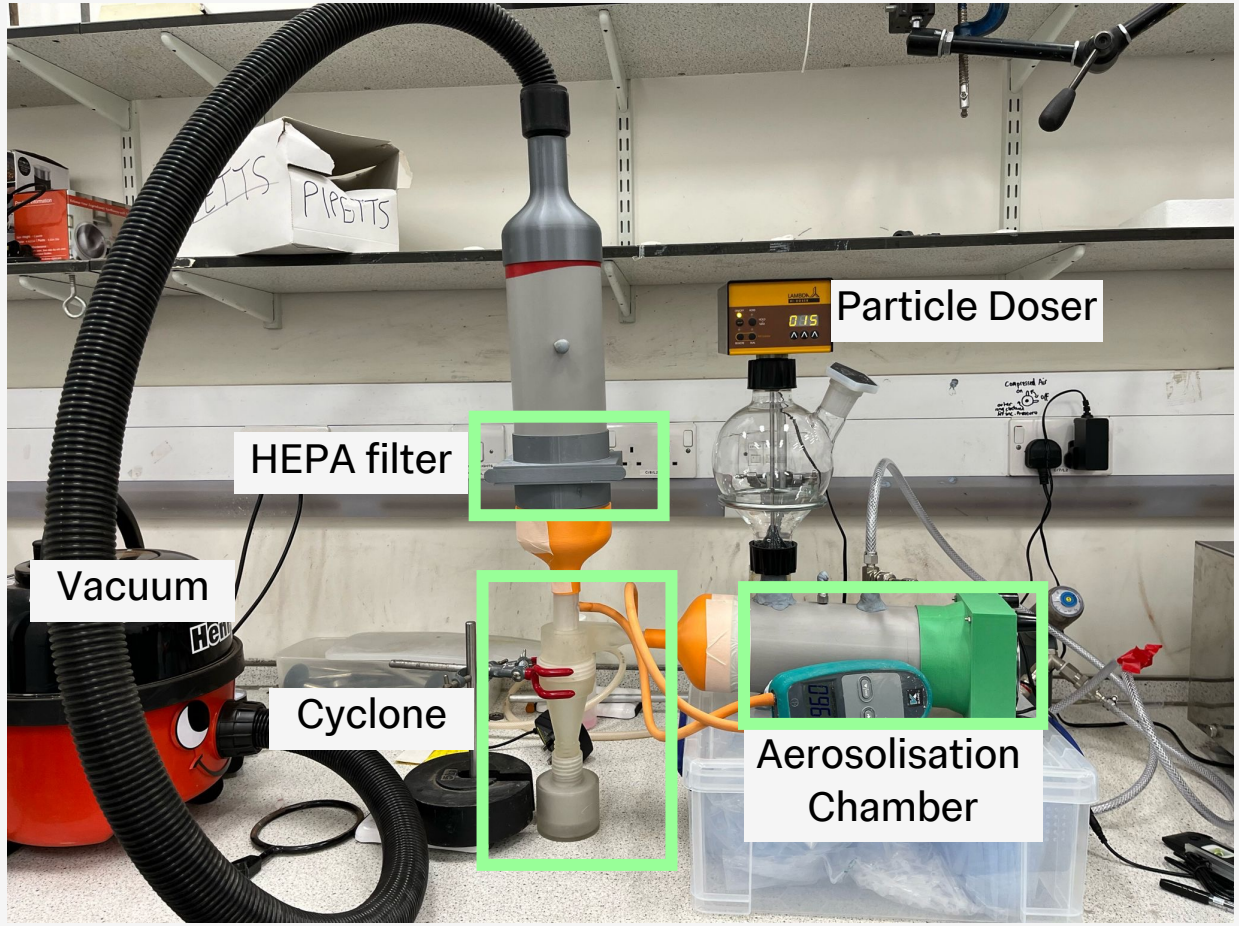
- Pipe diameter: 100 mm; no reduction in area for filter
- Cyclone diameter: 50 mm, but with reduction in inlet diameter and expansion at outlet



Dust Removal

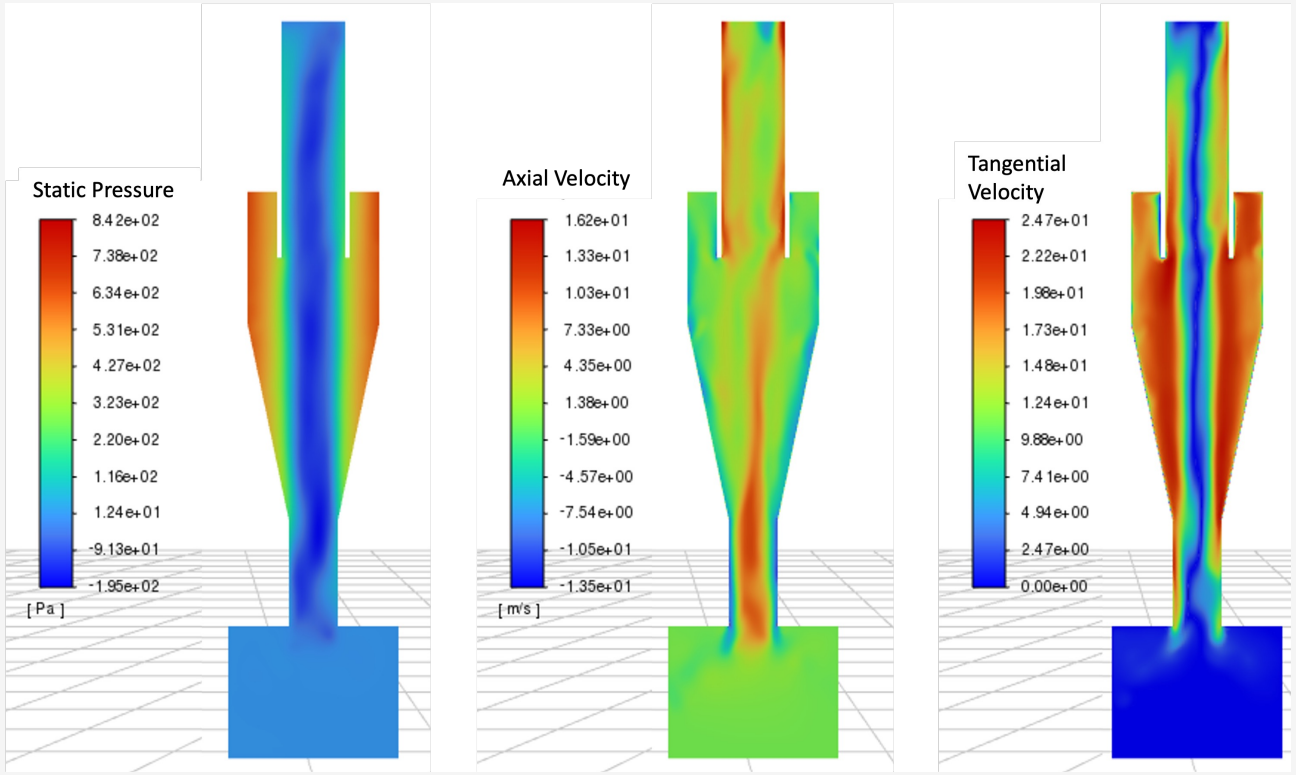
Experimental Set-up

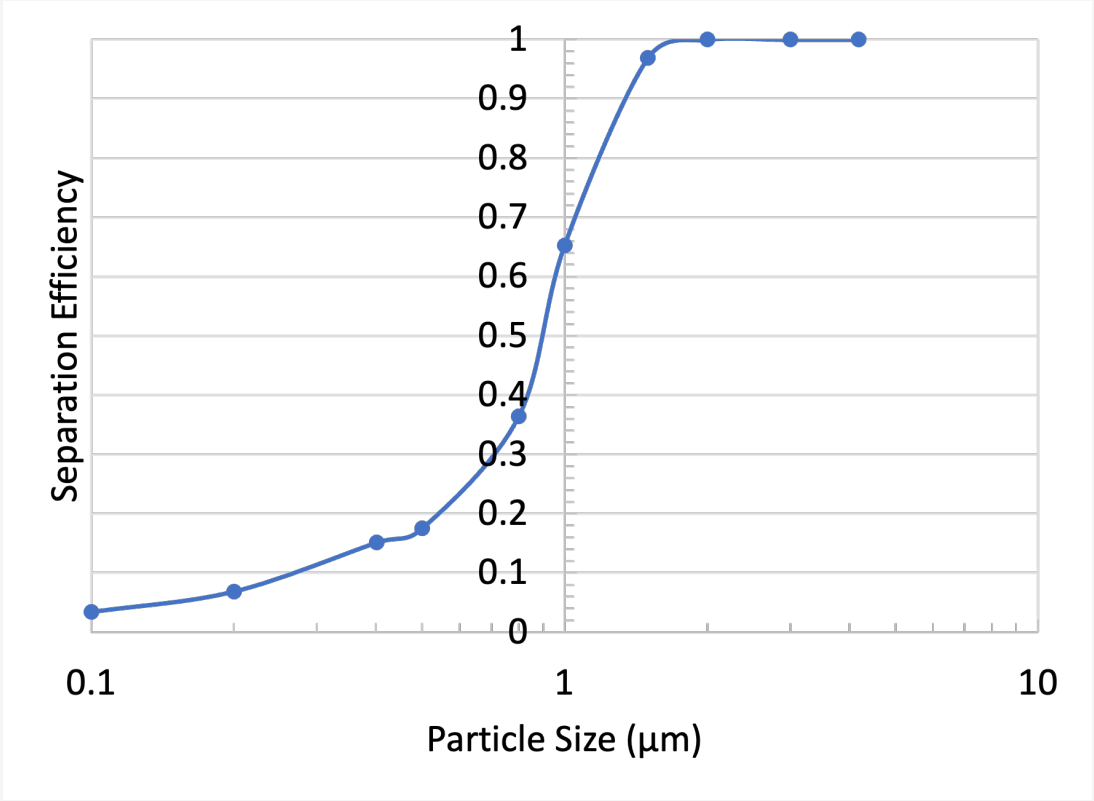




Numerical Modelling

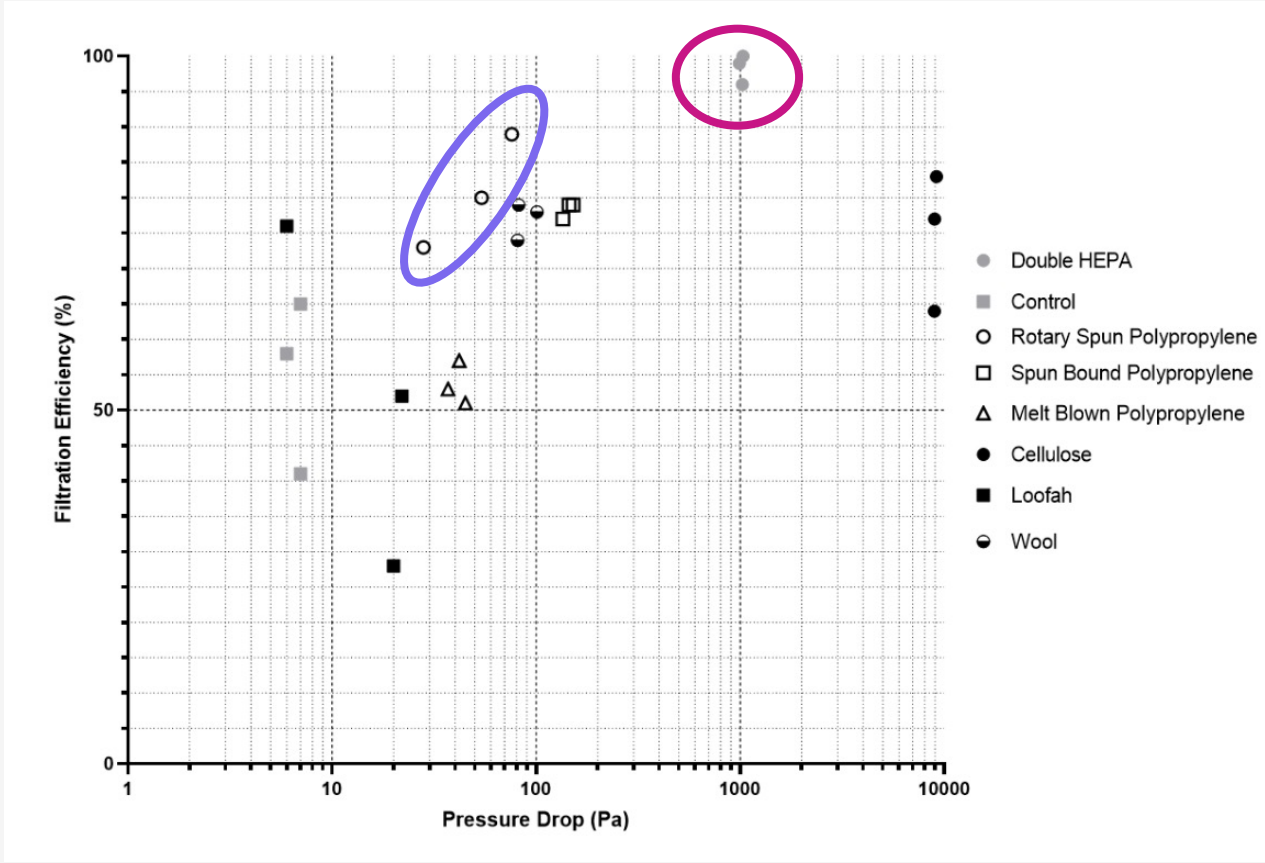
Gas Cyclone

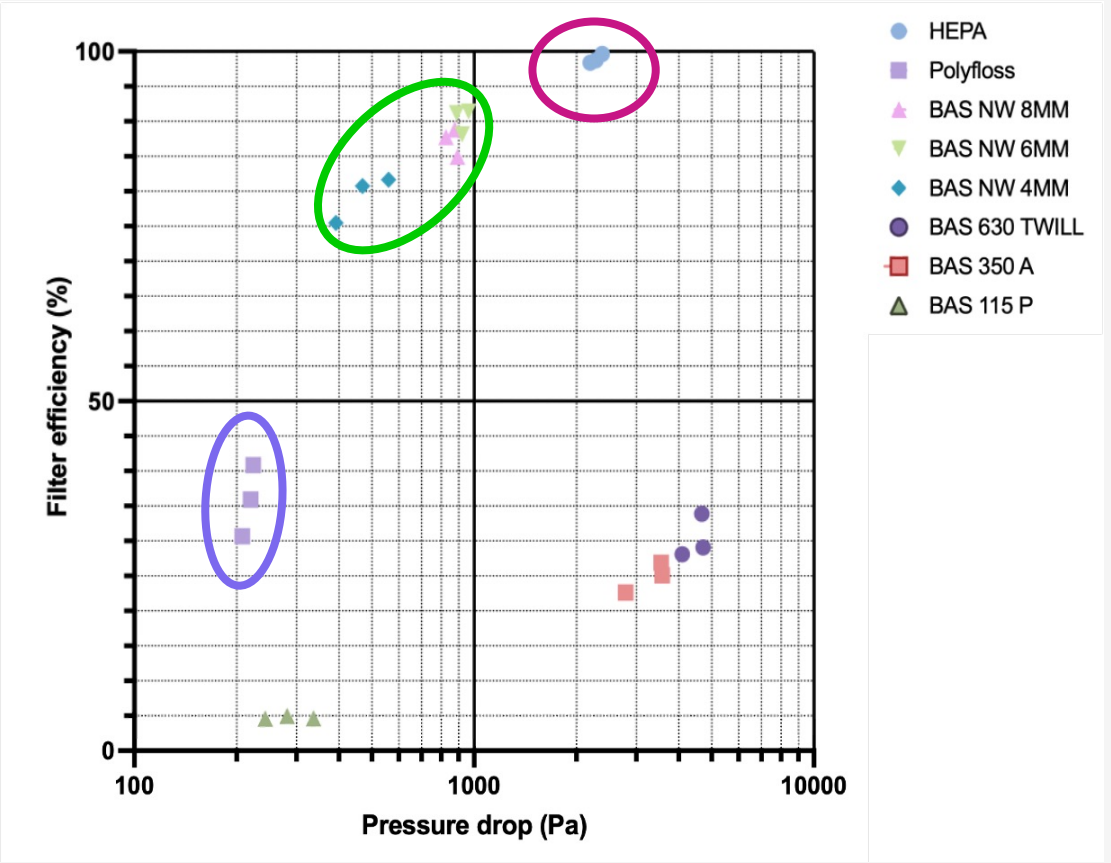




Dust Removal

Filter Performance vs Pressure Drop



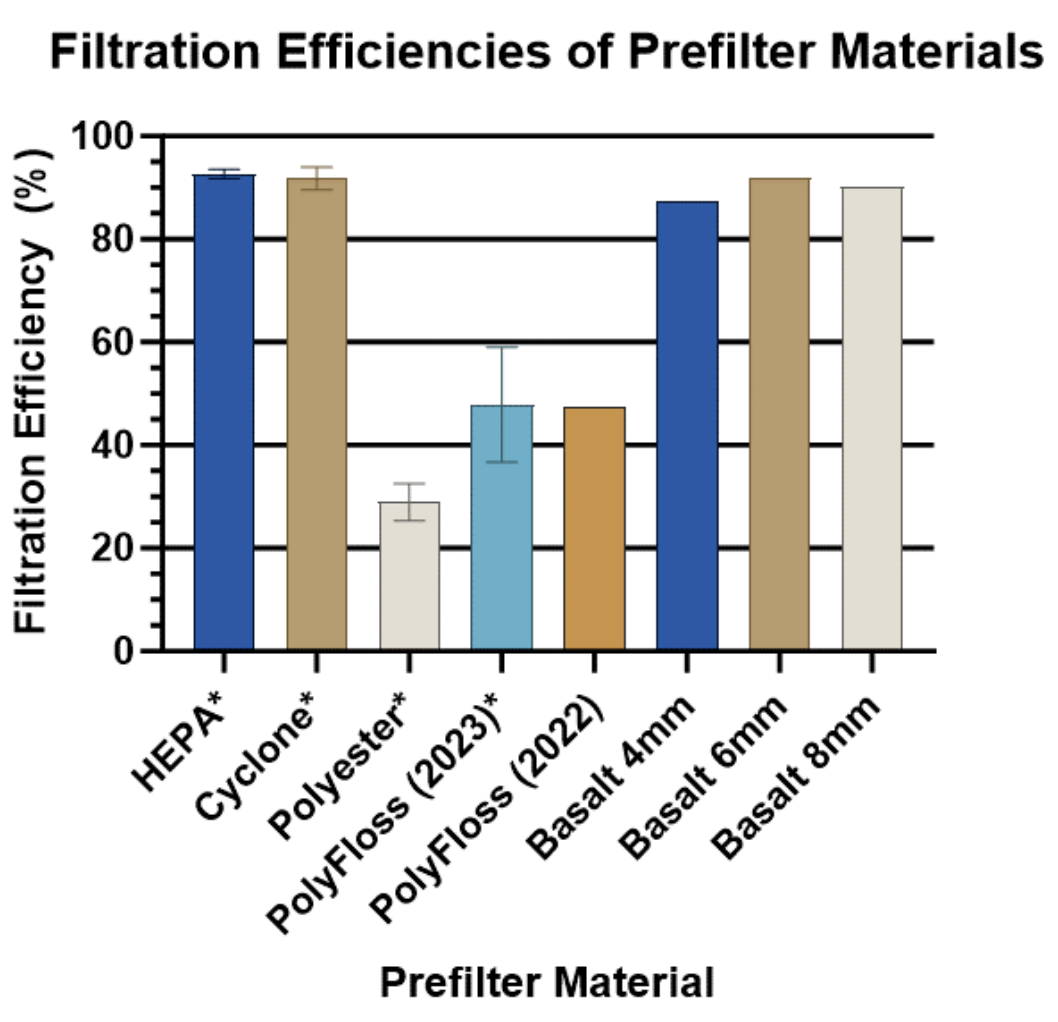


$$Filtration\ Efficiency = \frac{\Delta m_{prefilter}}{\Delta \mathrm{m_{prefilter}} + \Delta m_{HEPA}} \cdot 100$$

Dust Removal

Filters vs Cyclones

- Cyclone filtration efficiency (91.8%) comparable to the measured HEPA filter efficiency (92.6%) → differences are statistically insignificant
- Spun polymer filters (polyester, PolyFloss) performed poorly, with efficiencies below 50%.
- Basalt fibre filters demonstrated robust performance, achieving filtration efficiencies up to 91.9%



Conclusions

Conclusions

- Dust handling and mitigation strategies will be critical for both ISRU and lunar habitat design
- The Electrostatic Travelling Wave method can be used to remove dust from surfaces, such as solar panels, thermal radiators, airlocks, and ductwork
- Needlefelted pre-filters produced from melt-spun regolith present a recyclable option for filtration that provide high levels of particle capture and retention with low pressure drops
- Gas cyclones similarly offer high levels of dust removal, with the added benefit of long service life and have no consumable components requiring replenishment from Earth

Acknowledgements

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Thank you

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