Development of a Particle Flow Control Mechanism*

*Supported by DOE EERE-Patent Pending

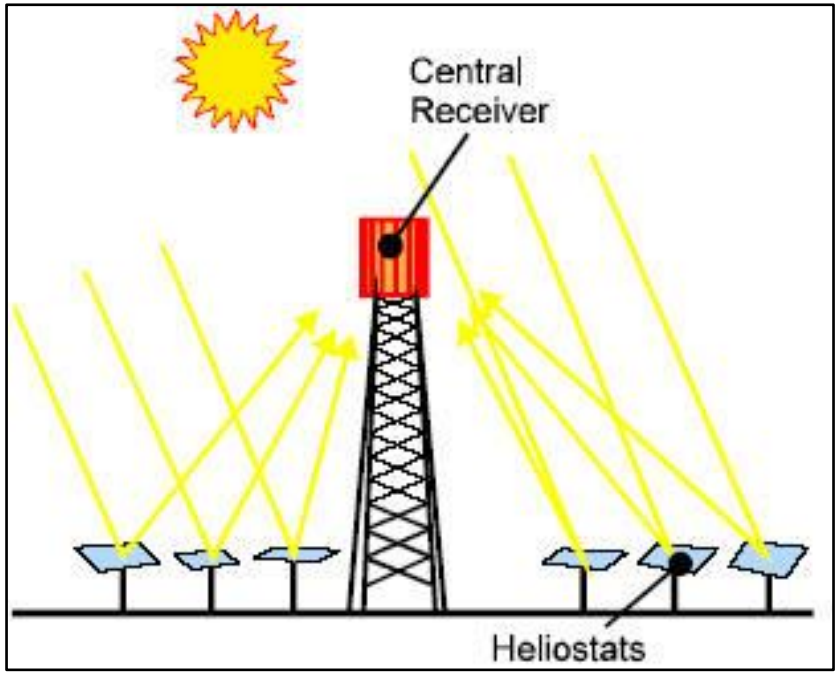
Sheharyar Malik[1], Isaac Lerner[2], Nipun Goel[2], Todd Otanicar[3], Soroor Karimi[1]

1. The University of Tulsa 2. Western Washington University 3. Boise State University

42nd Oklahoma AIAA/ASME Symposium
April 13th, 2024

Introduction

- Two main methods to utilize solar energy:
  - Photovoltaics (PV)
  - Concentrated solar power (CSP) systems[1]
- Particle-based CSP systems:[2-4]
  - Allow for much higher temperatures (>700°C)
  - Eliminate the concern for particle freezing
  - Do not involve any corrosive materials

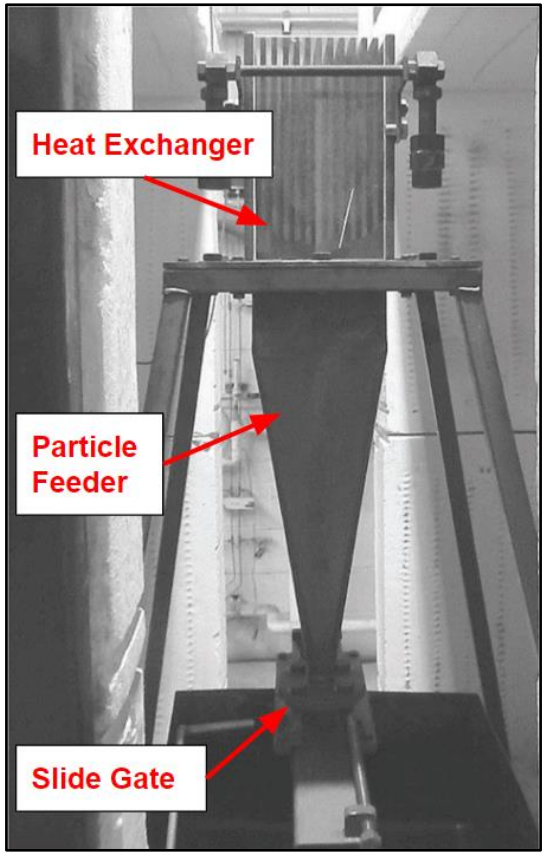


[5]

[1] "Solar Energy in the United States." Energy.Gov, https://www.energy.gov/eere/solar/solar-energyunited-states Accessed 27 Apr. 2022.
[2] "Generation 3 Concentrating Solar Power Systems (Gen3 CSP) Phase 3 Project Selection." Energy.Gov, https://www.energy.gov/eere/solar/generation-3- concentrating-solar-power-systems-gen3-csp-phase-3- project-selection. Accessed 4 April 2022.
[3] Ho, Clifford K., Kevin J. Albrecht, et al. Overview and Design Basis for the Gen 3 Particle Pilot Plant (G3P3). 2020, p. 030020, https://doi.org/10.1063/5.0029216.
[4] Ho, Clifford K., et al. "Evaluation of Alternative Designs for a High Temperature Particle-to-SCO2 Heat Exchanger." Journal of Solar Energy Engineering, vol. 141, no. 2, Jan. 2019, https://doi.org/10.1115/1.4042225.
[5] Kraemer, Susan. "How CSP Works: Tower, Trough, Fresnel or Dish." *SolarPACES*, 11 June 2018, https://www.solarpaces.org/how-csp-works/.

Background

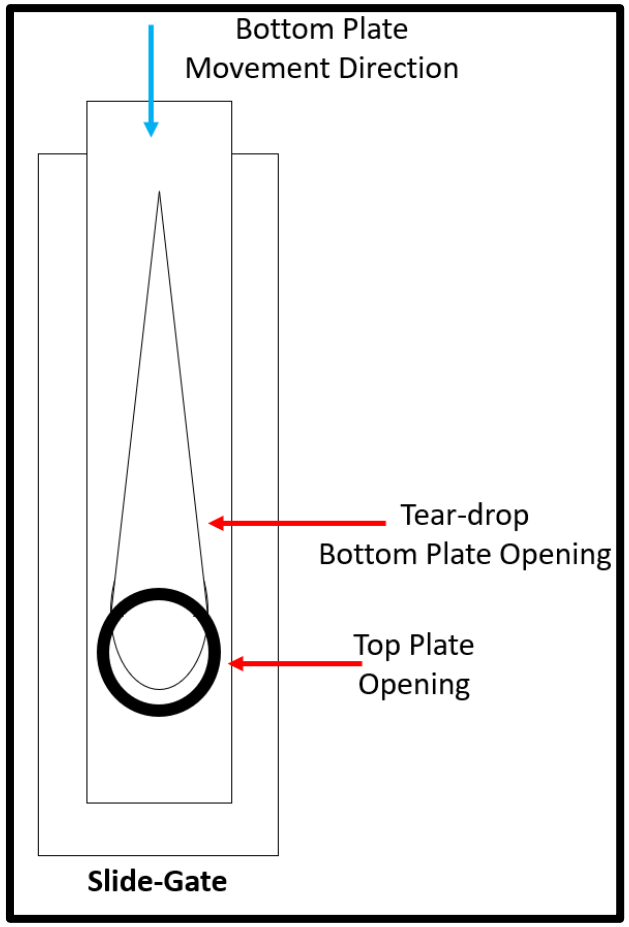
- A study showed that the **flow rate decreased** by 25% **during high-temperature tests** compared to the ambient temperature tests.[1]
- The study stated that they achieved a **sensitivity of 0.354 g/s-mm** with the current slide-gate mechanism in place.[1]
- Sensitivity is defined as mass flow rate divided by distance moved.



[1] Albrecht, Kevin J., and Clifford K. Ho. High-Temperature Flow Testing and Heat Transfer for a Moving PackedBed Particle/SCO2 Heat Exchanger. 2018, p. 040003

Slide-Gate Challenges

- The slide functions by linearly actuating a plate across a tear drop shaped opening.
- The key issues with the slide-gate include:
  - Operational difficulty due to the pressure exerted by the particle mass
  - Lodging of particles between the moving parts
  - Particle leakage
  - Withering and rounding of edges due to erosion



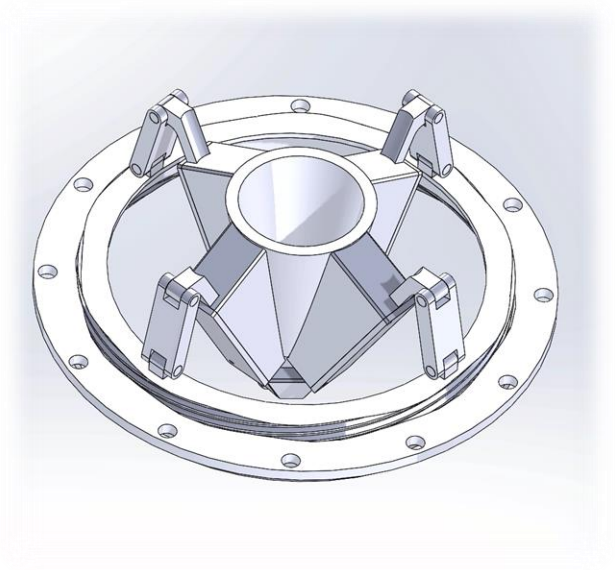
Particle Flow Control Apparatus

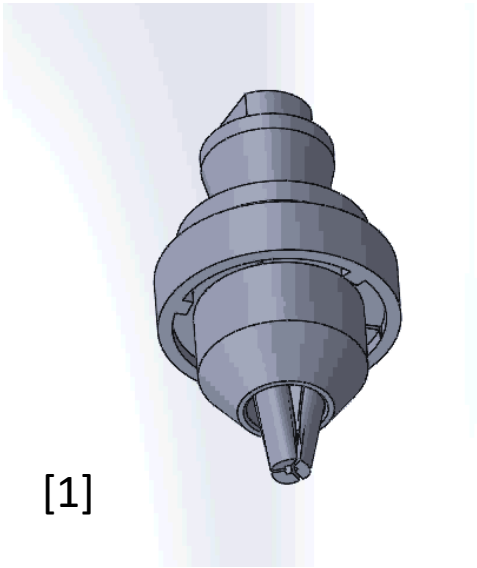
Objective

To design, fabricate, model, and test a new particle flow control apparatus for the particle-sCO_2 heat exchanger in a CSP system for both room and at operating temperatures, that mitigates or eliminates the shortcomings of the slide-gate.

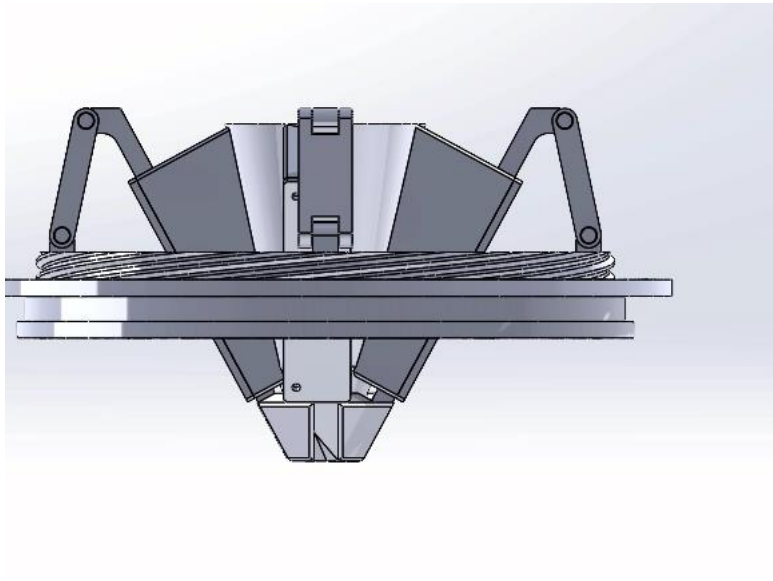
Design Approach

- The flow control device was inspired by a chuck mechanism seen in a drill where a rotation of the sleeve elicits movement of jaws both vertically and horizontally.





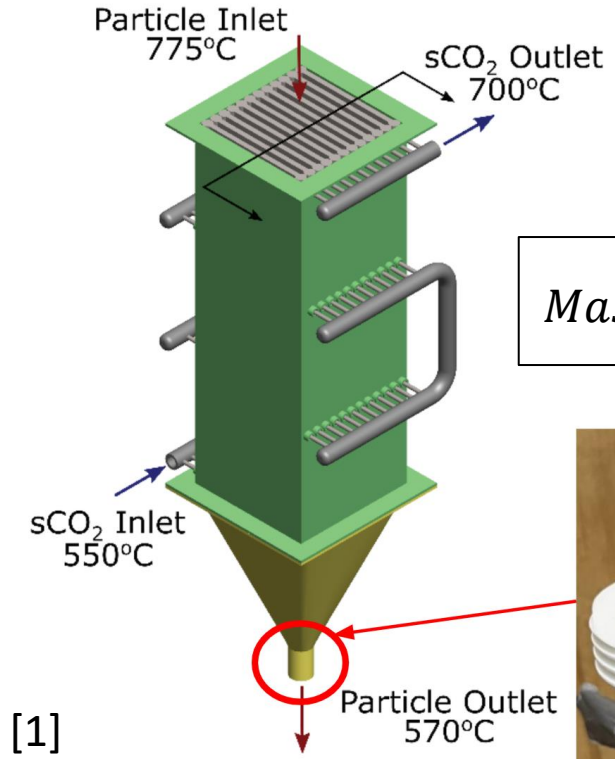
[1]



[1] *Keyless Drill Chuck | 3D CAD Model Library | GrabCAD*. https://grabcad.com/library/keyless-drill-chuck-1. Accessed 27 Mar. 2023.

Experimental Approach

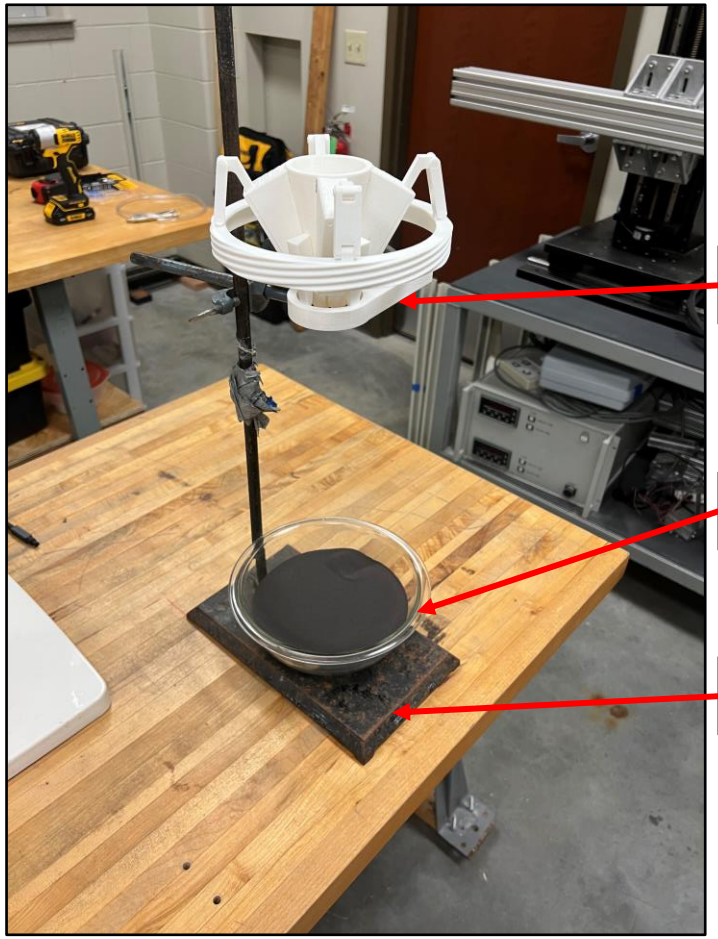
- 3D printed prototypes
- Particles – HSP 40/70 ceramic particles
- At each jaw setting, tests were performed at room temperature
- Mass flow rate measured
- Jaw movement measured

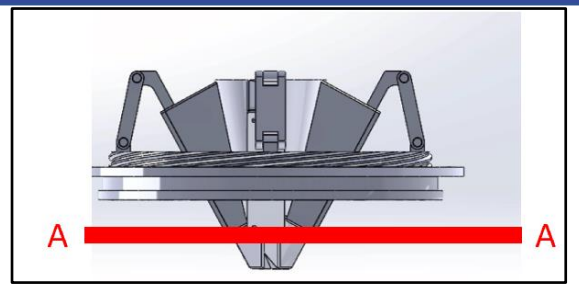


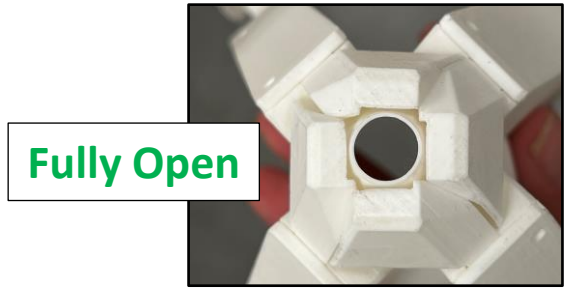
$$Mass\ Flow\ Rate = \frac{Mass}{Time}$$

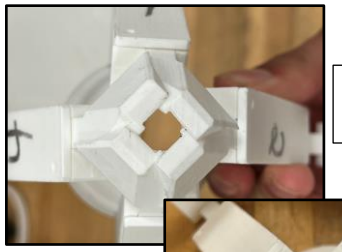
[1] Albrecht, Kevin J., and Clifford K. Ho. High-Temperature Flow Testing and Heat Transfer for a Moving PackedBed Particle/SCO2 Heat Exchanger. 2018, p. 040003

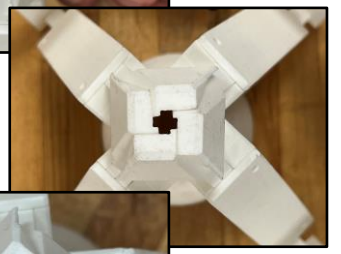
3D Printed Model Experimental Test Setup

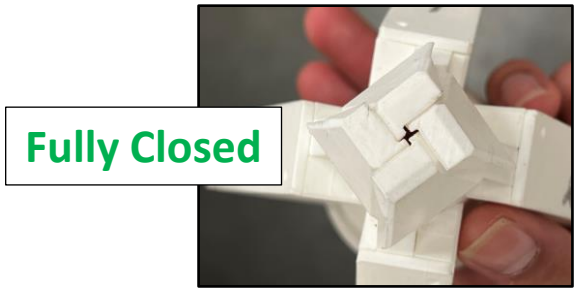


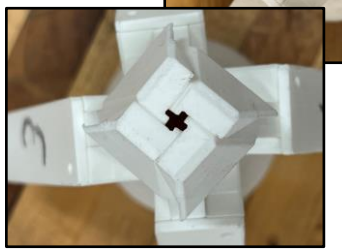






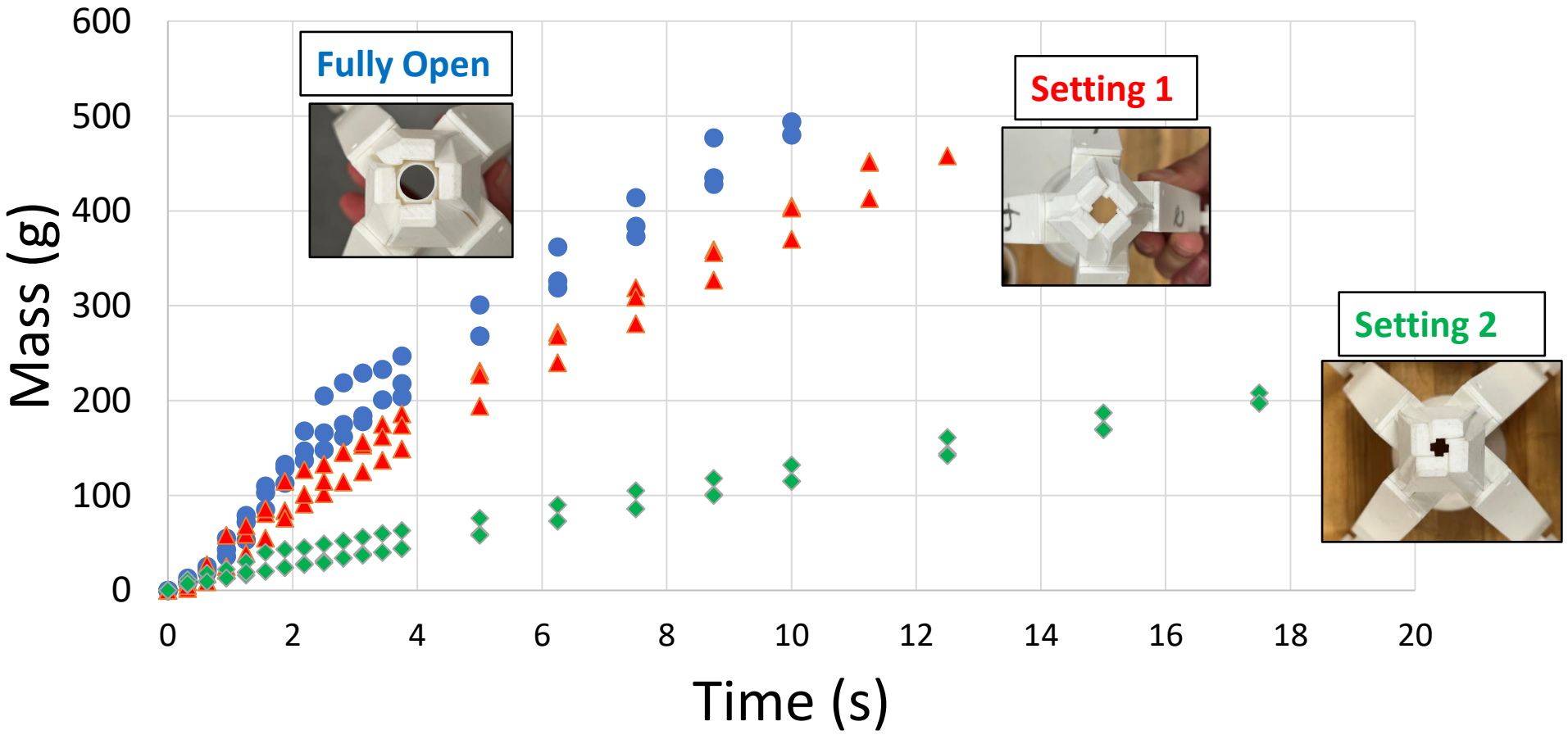






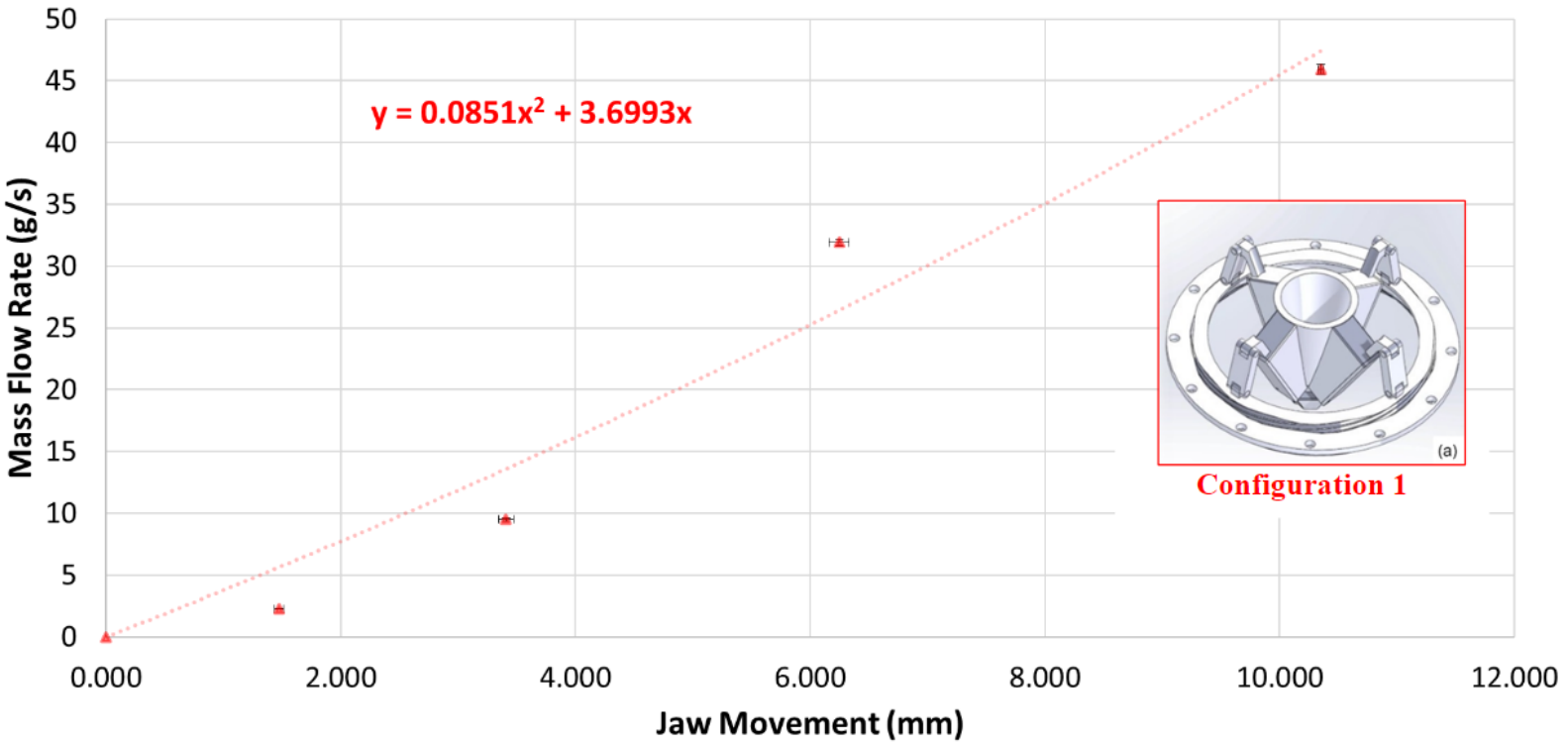
Particle Flow Control Apparatus

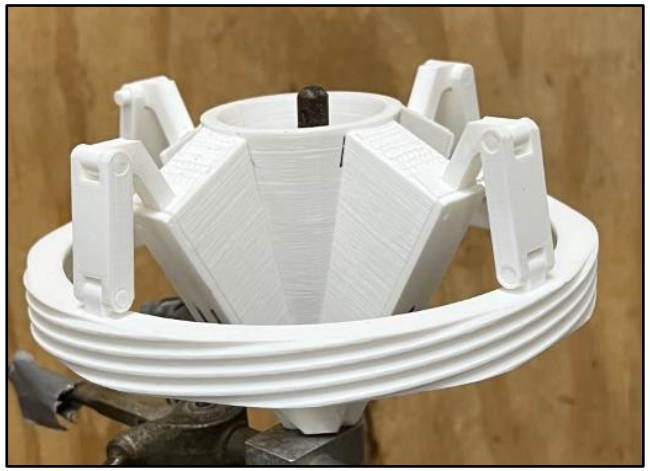
Results: Steady-State Flow Testing



Particle Flow Control Apparatus

Results: Design Sensitivity

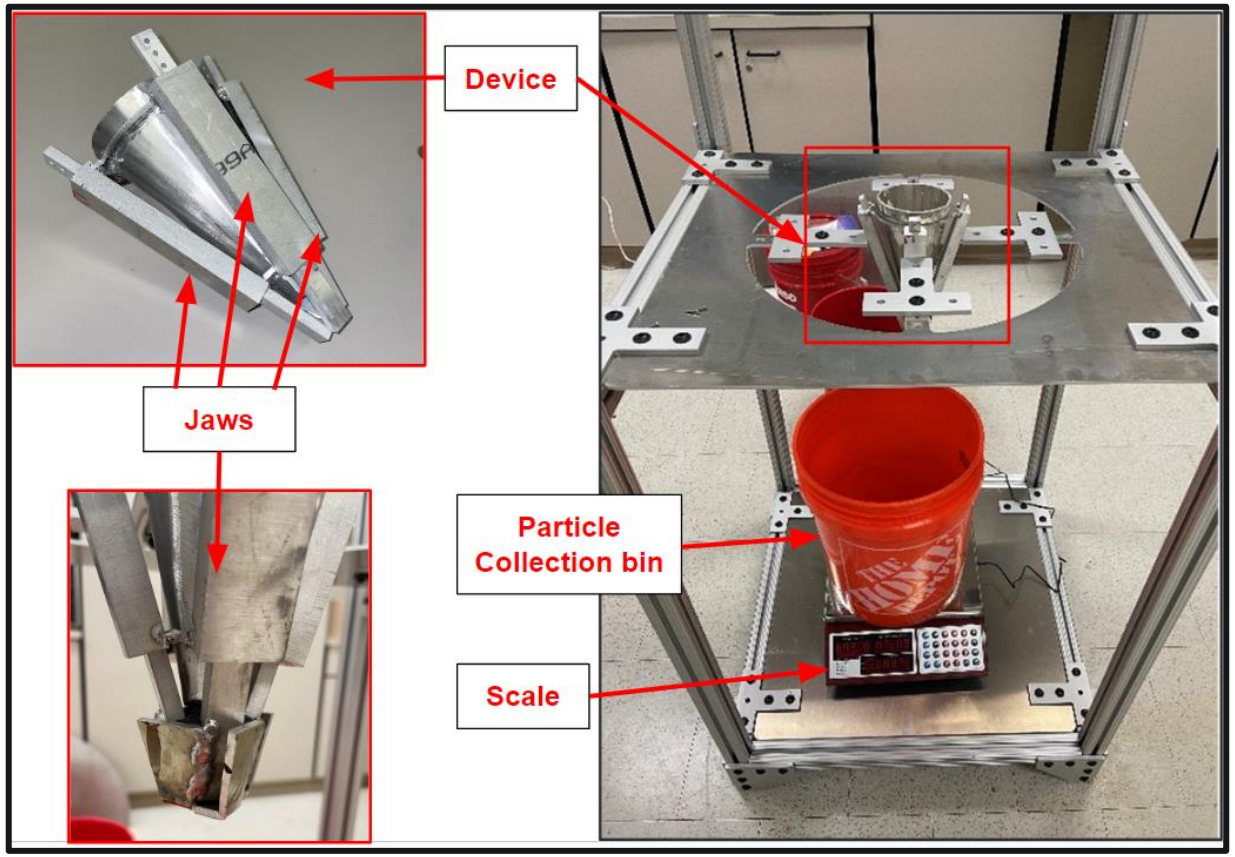


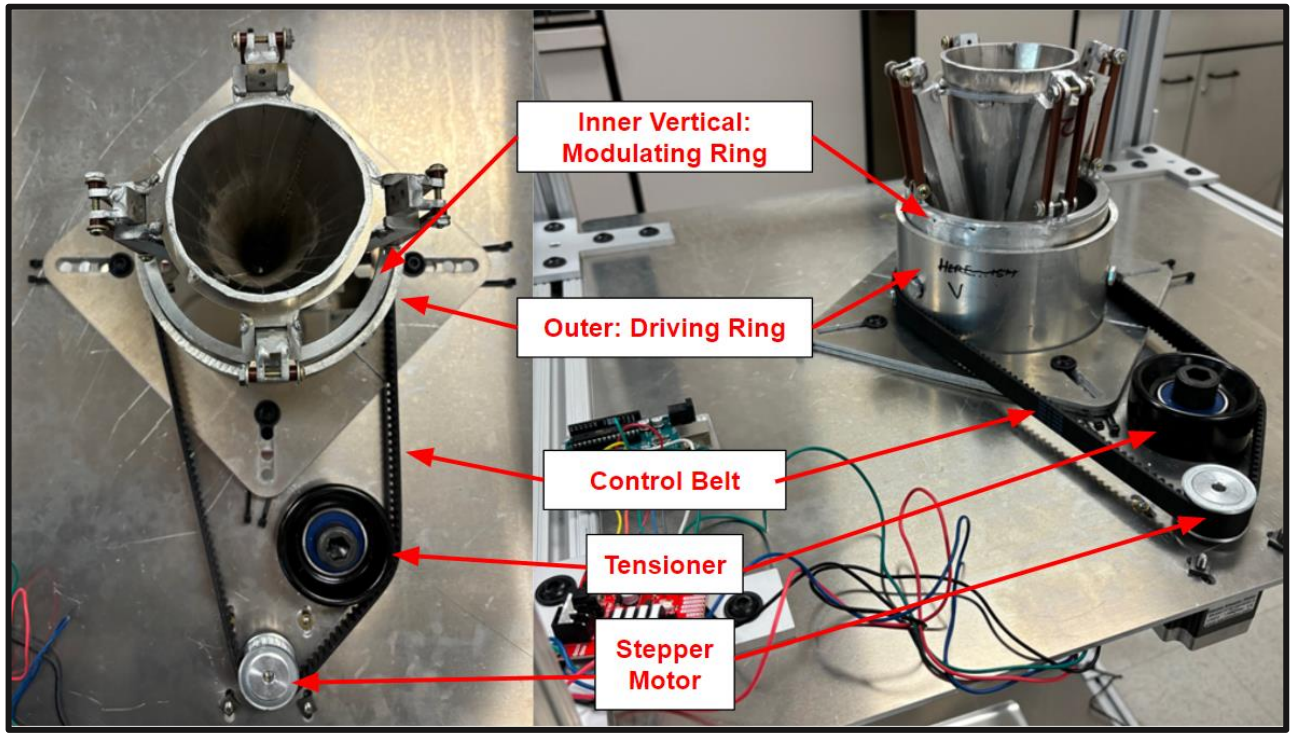


Jaw Setting (mm)	Avg. Mass Flow Rate (g/s)	St. Dev %	Uncertainty %
Setting 1 – 6.25mm	31.93	1.54	4.87
Setting 2 – 3.409mm	9.53	2.86	2.40
Setting 3 – 1.475mm	2.27	3.02	2.22

Particle Flow Control Apparatus

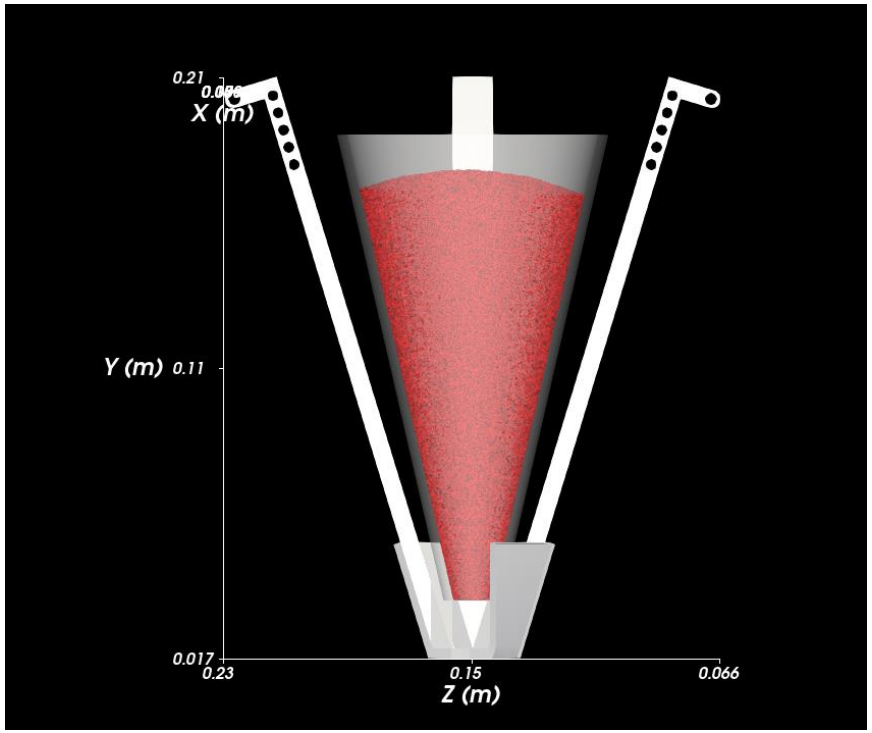
Room Temperature Test Apparatus

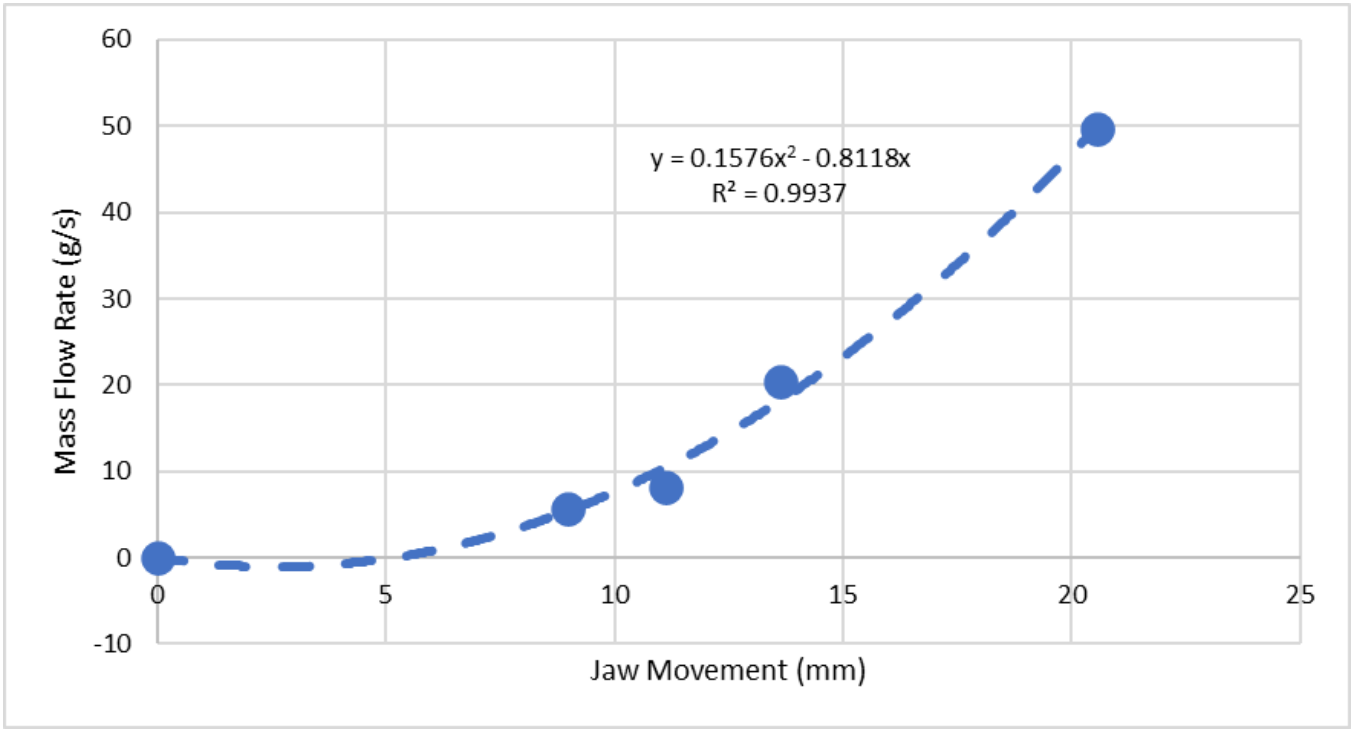




Particle Flow Control Apparatus

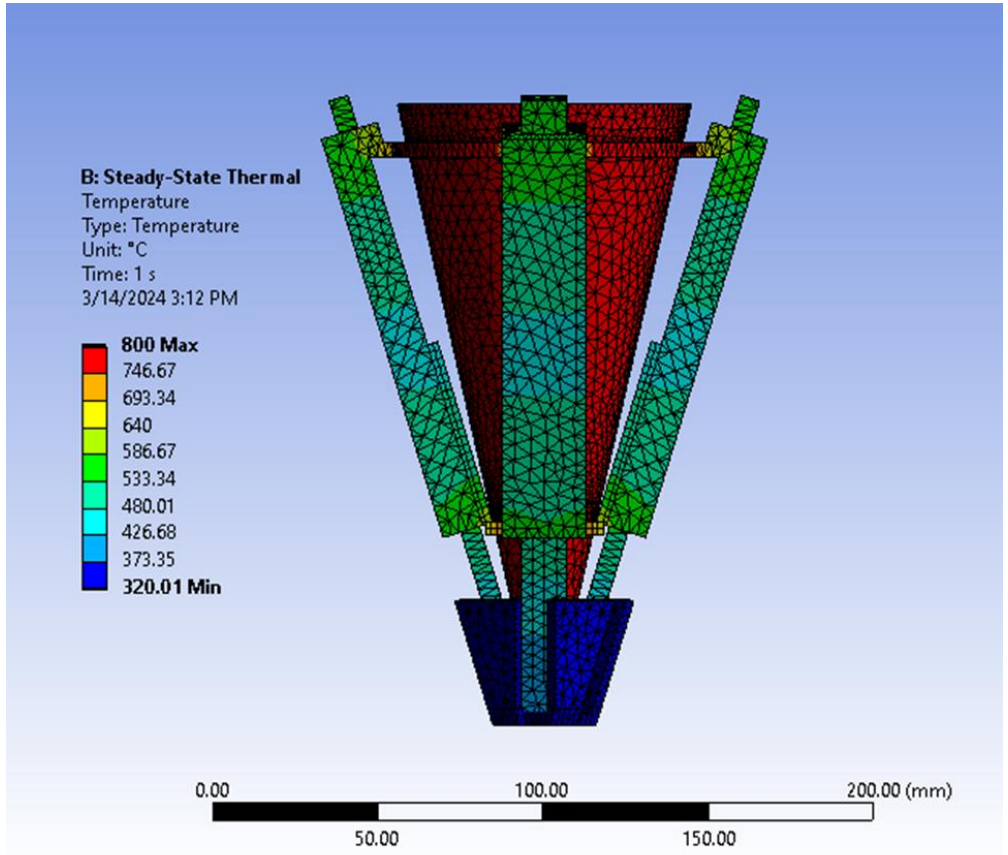
Room Temperature Simulations

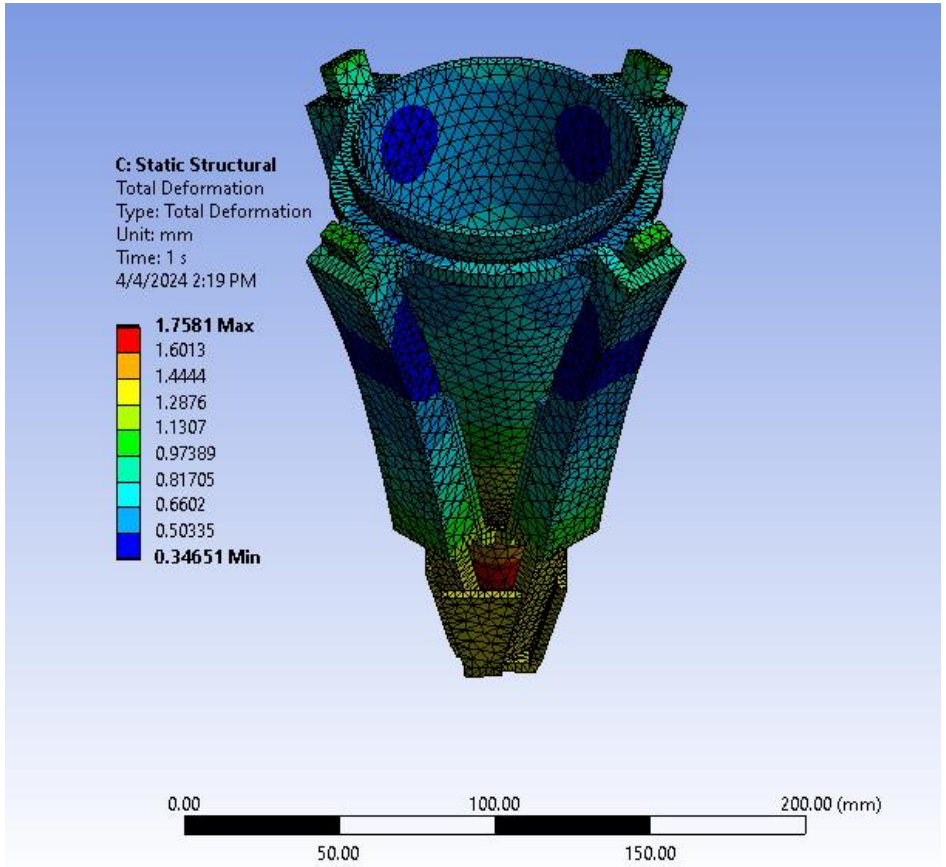




Particle Flow Control Apparatus

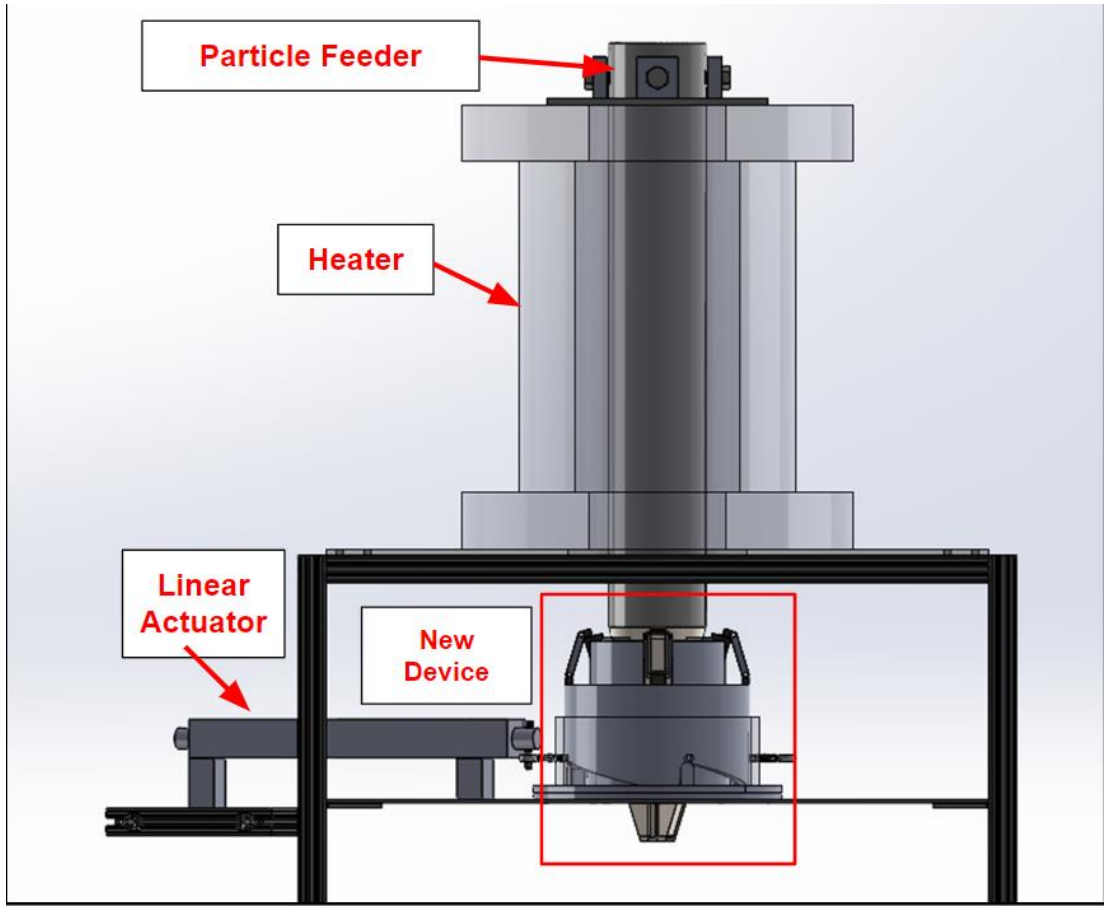
High Temperature Simulations

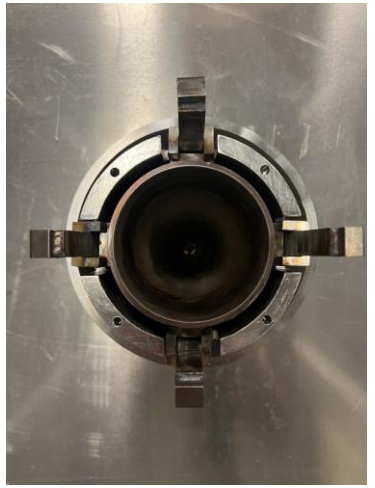




Particle Flow Control Apparatus

High Temperature Test Apparatus





Particle Flow Control Apparatus

Summary and Conclusions

- Designed, 3D printed, and tested a new particle flow control device, and obtained its sensitivity curve.
- Created a room-temperature experimental testing apparatus.
- Performed room temperature particle flow simulations and found a theoretical sensitivity curve.
- Currently developing a high-temperature experimental testing apparatus.
- Performed thermal and structural analysis on the model at high-temperatures.

Future Work

- Obtain sensitivity curve for room temperature model and compare it to the theoretical curve.
- Finish building the high temperature experimental facility.
- Automate the actuation of the device using a linear actuator.
- Validate high temperature results with particle flow simulations.

Acknowledgments

I would like to thank:

- My advisors: Nipun Goel, Todd Otanicar, and Soroor Karimi
- Isaac Lerner and Maura Wahl for their assistance on this project
- The Department of Mechanical Engineering at the University of Tulsa for the use of their facilities
- The Department of Energy for their support and funding

Thank you for your time!
Questions?

Email: sam5550@utulsa.edu