Design of Fluid Flow Model for a Porous Material Bed Using Gas Cell Prototype

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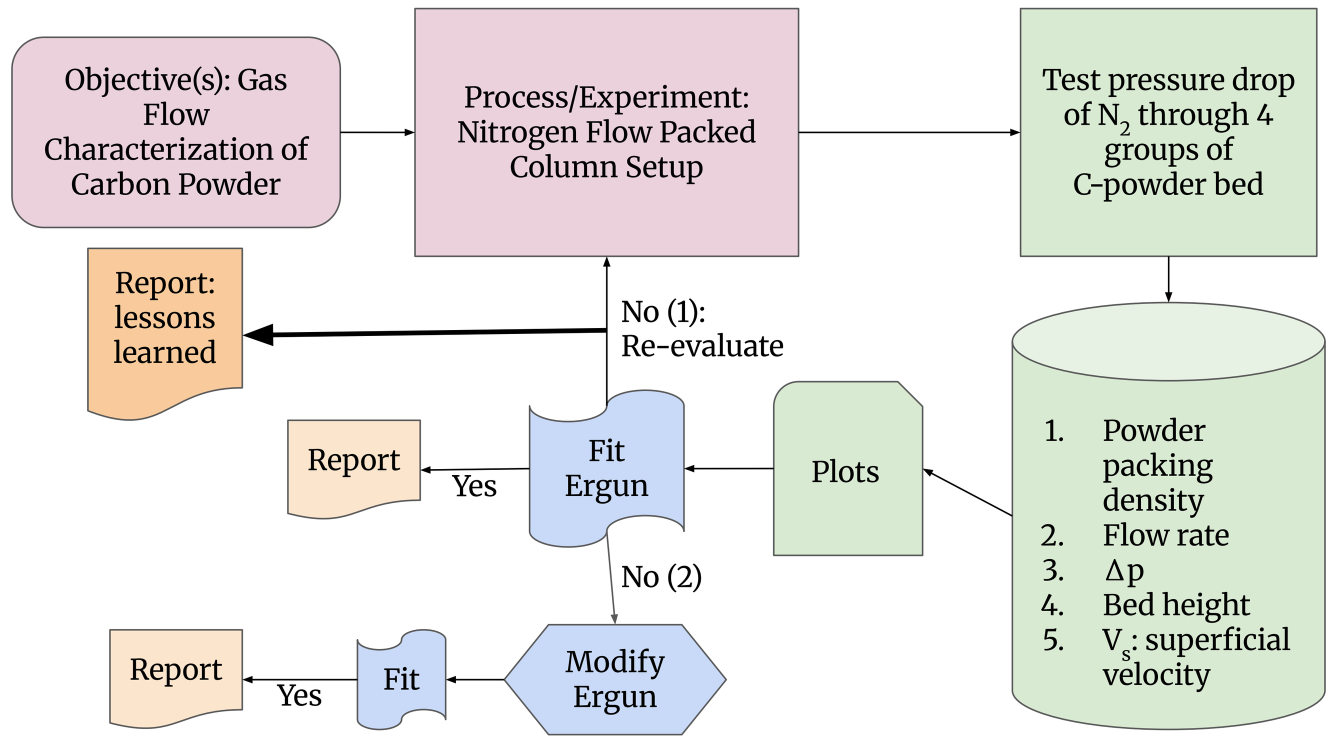
Background

The current demand for Lithium-ion batteries is predicted to increase. How can we use silicon nanoparticles to make these batteries more efficient?

- Traditional Li-ion batteries use graphite anodes, which are low-cost and stable but have low capacity and slow recharge rates[1]
- Group 14 aims to replace graphite with silicon, which offers higher energy density and faster charging, but suffers from structural instability due to volume expansion
- Their solution is a silicon-carbon (Si-C) composite anode, created by depositing silicon nanoparticles onto a porous carbon structure to enhance stability

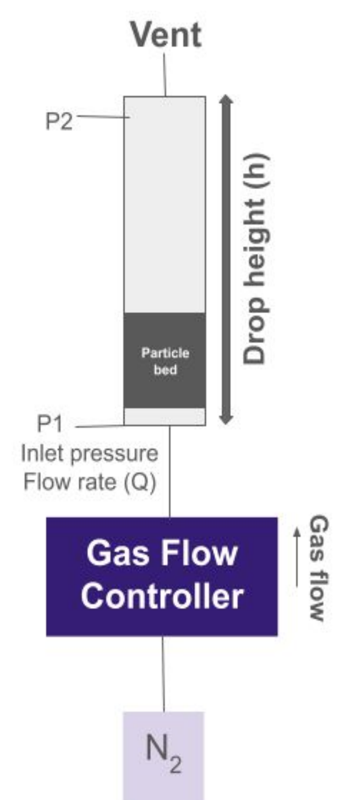
Introduction

- Goal of experiments was to measure the different pressure drop characteristics of powder samples provided by G14
- An experimental set up consisting of a mass flow controller/pressure sensor attached to cylindrical vessel where the packed bed would be tested
- Nitrogen gas was flown through the packed bed allowing for determination of pressure drop by subtracting pressure before the bed to the exit pressure (assumed to be atmospheric)
- The pressure data was analyzed, comparing the different powder samples across varying bed heights, flow rates, and packed densities to find trends supporting an approach to modify the ergun equation to model the gas flow behavior



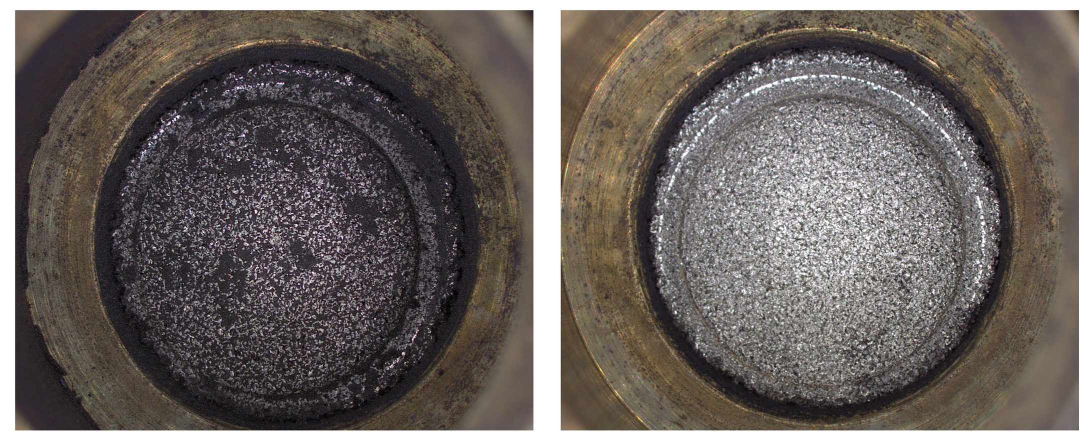
A flow chart outlining the design process of the experimentation

Experimental Design



Apparatus

The gas flow controller inlet is connected to the nitrogen tank and the outlet to the inlet of the packed bed column. The inlet of the packed bed is connected to pressure gauge 1 (P1) and the outlet to pressure gauge 2 (P2), the end of the tube will be connected to ambient pressure (vent). The carbon particle bed will be placed inside a cylindrical gas column where the height of the packed beds will be varied and the gas flow rate will be increased in small intervals.


Diffuser before and after cleaning

Procedure

- Checking for kinks in the tubing
- Tapping in between changing flow rates
- Repeated trials to account for variation
- Cleaning diffusers in between changing flow rates

Ergun Equation

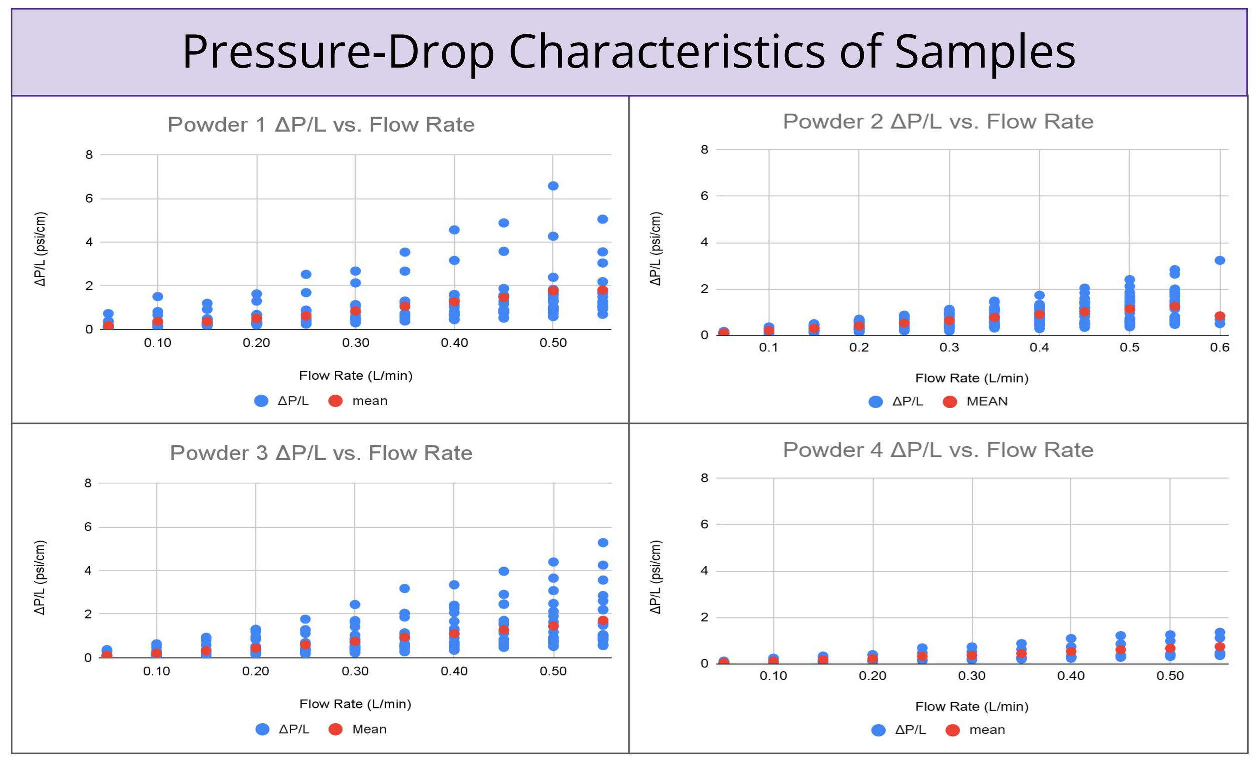
The Ergun equation shows how pressure drop depends on several variables across a packed bed in the laminar region.

$$\Delta p = \frac{150\mu L}{D_p{}^2}\frac{(1-\epsilon)^2}{\epsilon^3}v_s + \frac{1.75L\rho}{D_p}\frac{(1-\epsilon)}{\epsilon^3}v_s|v_s|$$

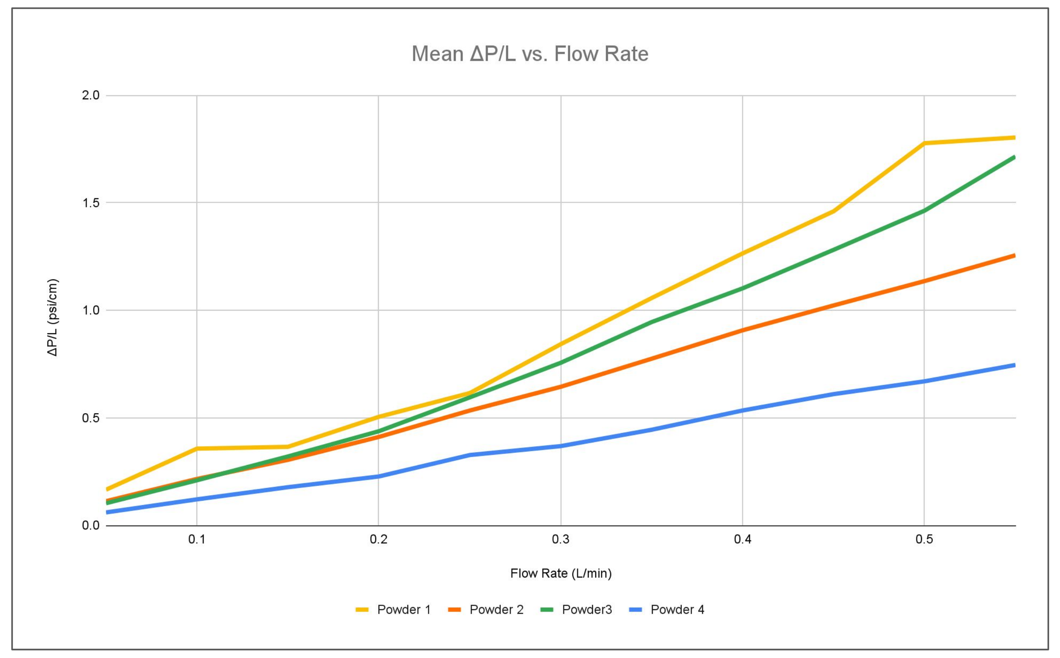
Δp: pressure drop across bed
L: is the length of the packed bed
D_p: spherical diameter
v_s: is the superficial velocity
ρ: fluid density
ε: void fraction of bed
μ: fluid dynamic viscosity

Results

Pressure drop data across all powders showed increasing variability with higher flow rates. Contrary to the hypothesis that particle porosity would reduce pressure drop, experimental values exceeded Ergun predictions, likely due to flow restriction, clogging, and inconsistent bed packing - leading to tunneling, fluidization, and blow out at even low flow rates.



Data spread was largely independent of powder density, suggesting system error over material influence. However, average pressure drop tended to increase with bed density, indicating that packing structure may play a larger role than powder density in flow resistance, an effect not fully captured by the Ergun model.



$$\rho_{bed,\ pow.\ 1} > \rho_{bed,\ pow.\ 3} > \rho_{bed,\ pow.\ 2} > \rho_{bed,\ pow.\ 4}$$

Attempts to isolate powder property effects at similar bed densities were restricted by limited data. Future work should prioritize improved calibration and standardized packing to reduce variability and support meaningful model adjustments.

Discussion/Conclusion

Our experimental data revealed:

- Minor links found between powder properties and flow rate
- Setup effects must be minimized before using the modified Ergun Equation
- Data showed significant deviation and scatter from Ergun predictions
- Deviations likely due to flow restrictions, unsteady flow, and uneven bed packing

Future Work

This experiment should continue with minor modifications to increase certainty in results:

- New pressure transducers with calibration certificates should be used
- A standardized method of packing should be determined
  - Instead of manually tapping, use an auto-tapper
- The pressure characteristics of powders should be compared at similar bed packing densities
- Powders with varying characteristics should be included to help isolate responses to important variables
- Determine the correct coefficient that can be implemented into the Ergun Equation for modification
  - With accurate data, the modified equation should be able to be adjusted to fit

Acknowledgements

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Works Cited

[1] "Our Technology." Group14, 10 Mar. 2025, group14.technology/our-technology/. Accessed 10 Mar. 2025.