A study of sedimentation and aggregation of volcanic particles based on experiments carried out with a vertical wind tunnel

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I. Introduction

Motivation

Dispersal and accumulation of volcanic particles (tephra) can result in various hazards, such as threat to aviation, damage to vegetation and crops, collapse of buildings, health problems. An accurate parameterization of particle sedimentation processes is needed in order to forecast both ash concentration in the atmosphere and ground accumulation.

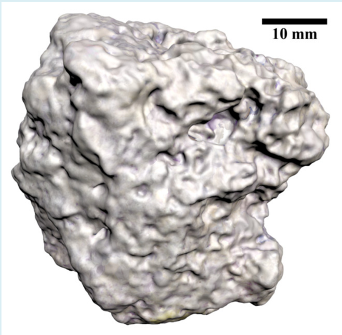
The problem

Volcanic particles are typically highly irregular and porous. Existing parameterizations of associated settling velocity either approximate shape as spheres or require specific morphological descriptions which are complex to quantify, e.g. particle surface area. Another critical issue that still needs to be investigated in detail is particle aggregation. Aggregation of volcanic particles is a fundamental process which typically occurs in ash-rich volcanic eruptions for particles with diameters less than about 100 µm and results into premature fallout of fine ashes.

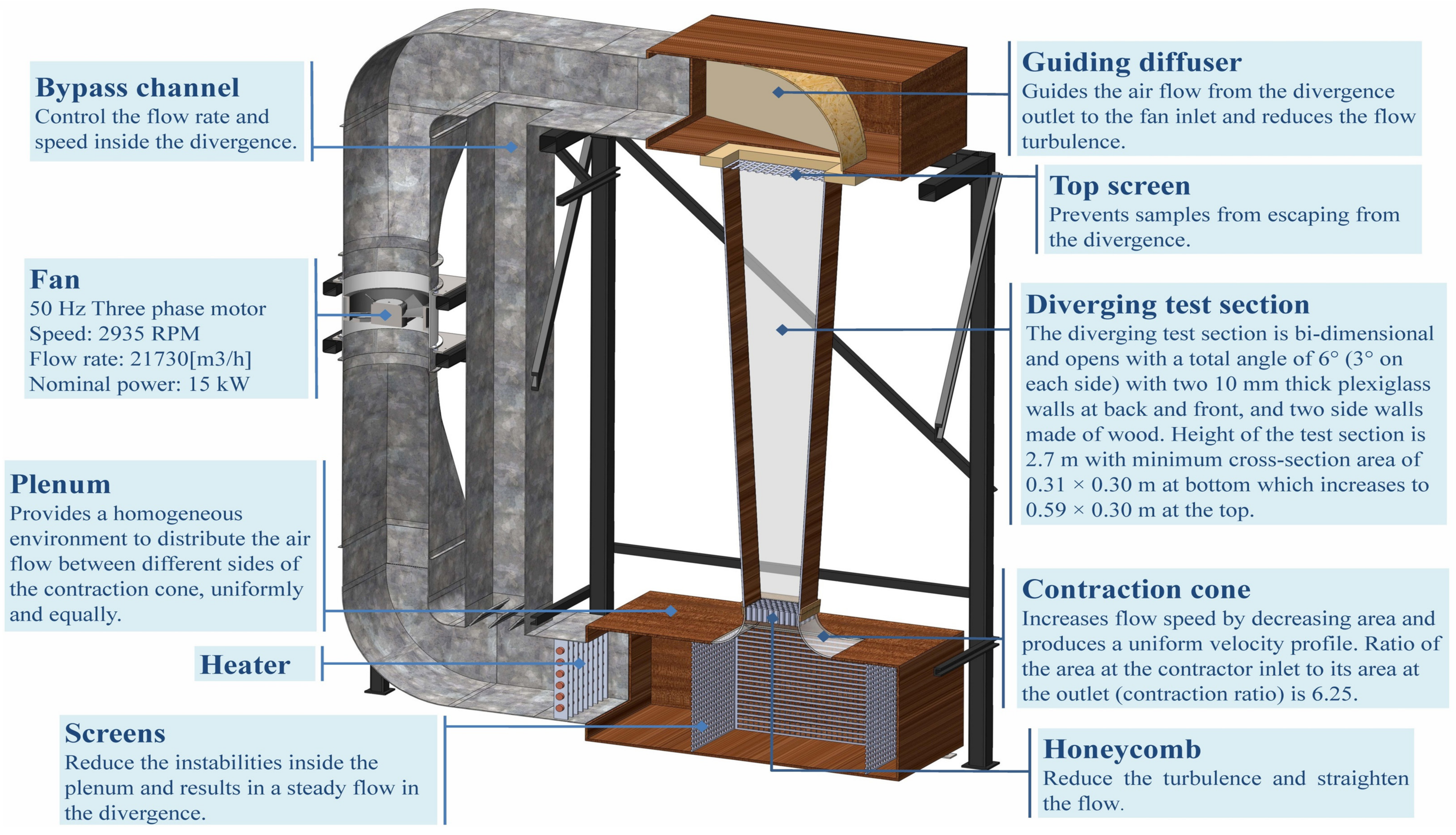
Objectives

I. Study the effect of shape and porosity on the terminal velocity of volcanic particles.
II. Find an easy to measure shape descriptor correlated to particle terminal velocity.
III. Benchmark existing parameterization of particle terminal velocity for a wide range of Reynolds number.
IV. Investigate mechanisms of particle aggregation in both dry and wet conditions.

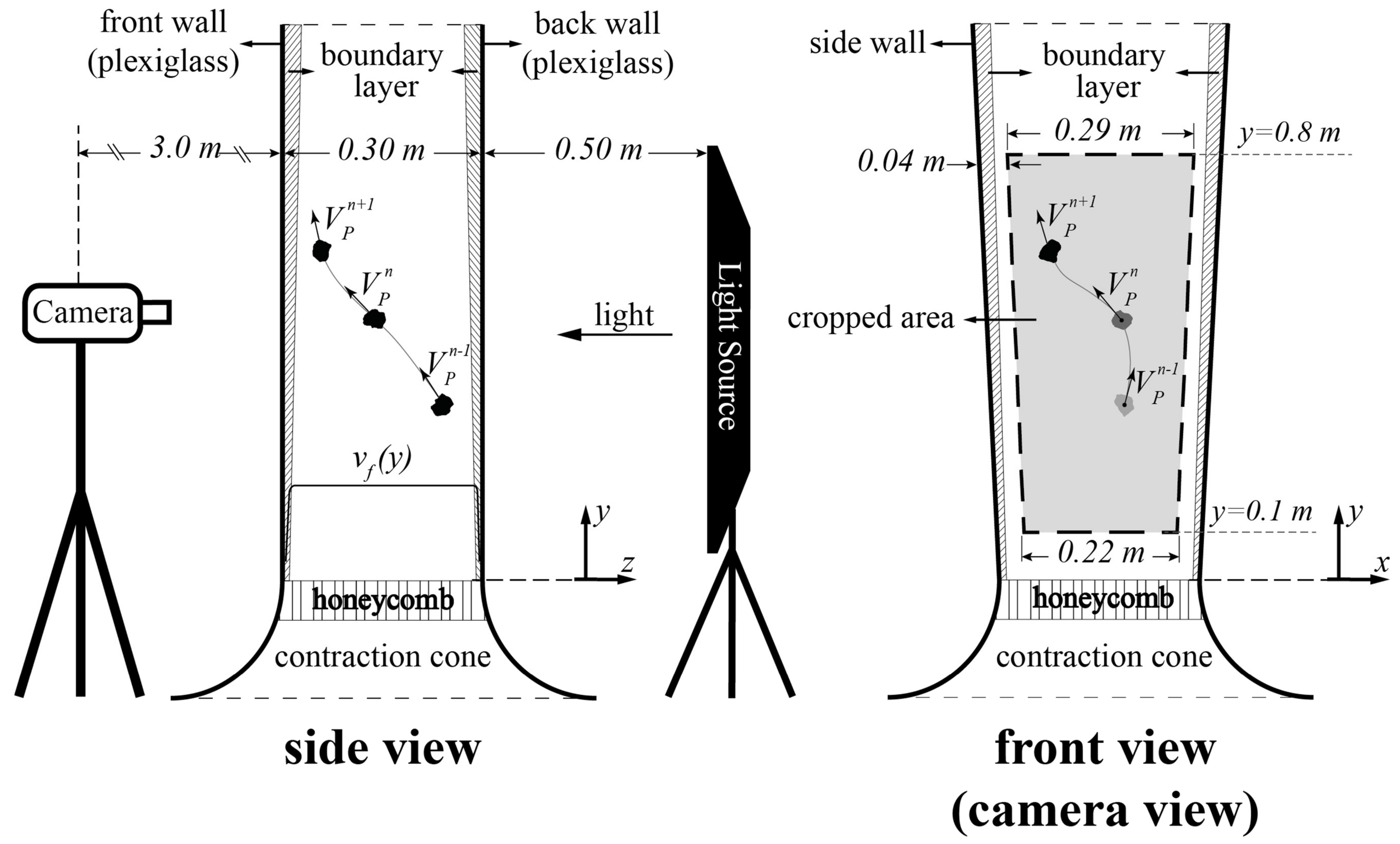
Volcanic particles are typically irregular and porous. This figure represents a 3D model of a volcanic particle obtained by a 3D-scanner.



II. Vertical wind tunnel



III. Experimental setup



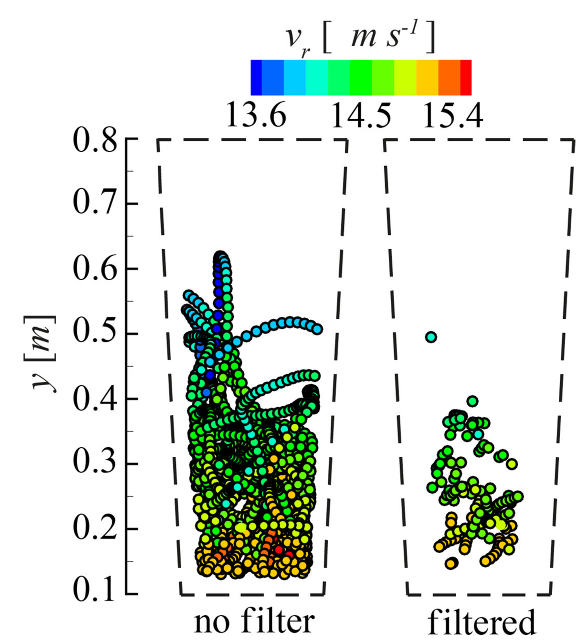
- $V_P (= u_P\,\boldsymbol{i} + v_P\,\boldsymbol{j} + w_P\,\boldsymbol{k})$ is the particle absolute velocity, v_f is air velocity and n denotes the time frame.

IV. Particle Tracking Velocimetry (PTV) code

PTV code. Calculates various aerodynamical parameters (e.g. drag coefficient, relative velocity) of the suspended particle in the test section by analyzing videos recorded with a high speed camera, particle geophysical properties and data logged by temperature, pressure and humidity sensors.

Filters. Applied to exclude frames where

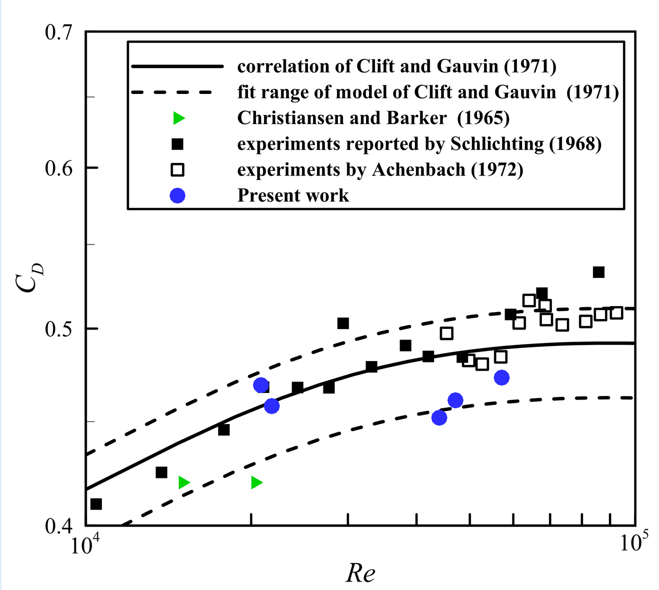
1. Particle relative acceleration was greater than 0.05 g, in order to measure particle relative velocity in standard conditions.
2. Particle was near (distance between particle centroid and walls < 4 cm) walls of the test section, in order to eliminate effects of wall on particle suspension.



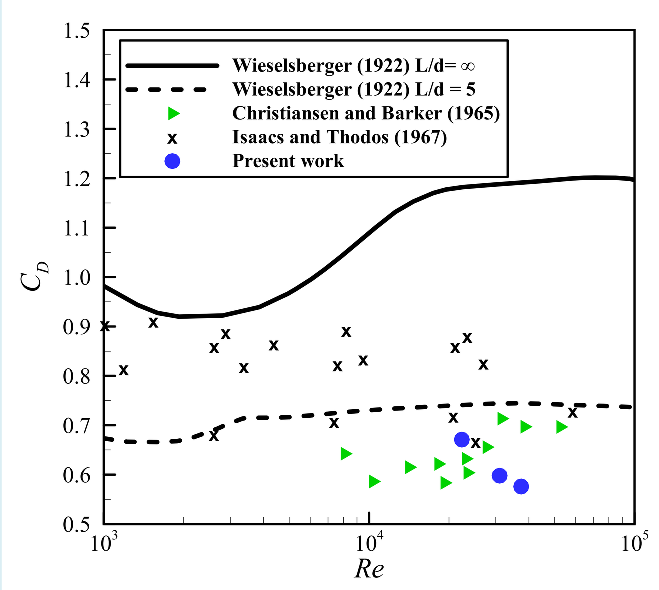
Relative velocity, v_r (= v_f - v_P), of a spherical particle with diameter of 62 mm and mass of 18.2 gr.

V. Validation

Our measurements on the drag coefficient, C_D, of spherical and cylindrical particles are in close agreement with previous studies (Re is particle Reynolds number).



Spherical particles

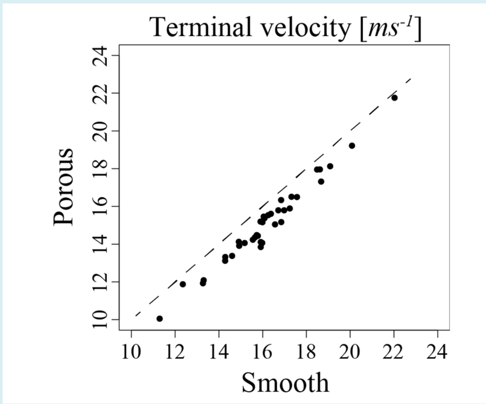


Cylindrical particles

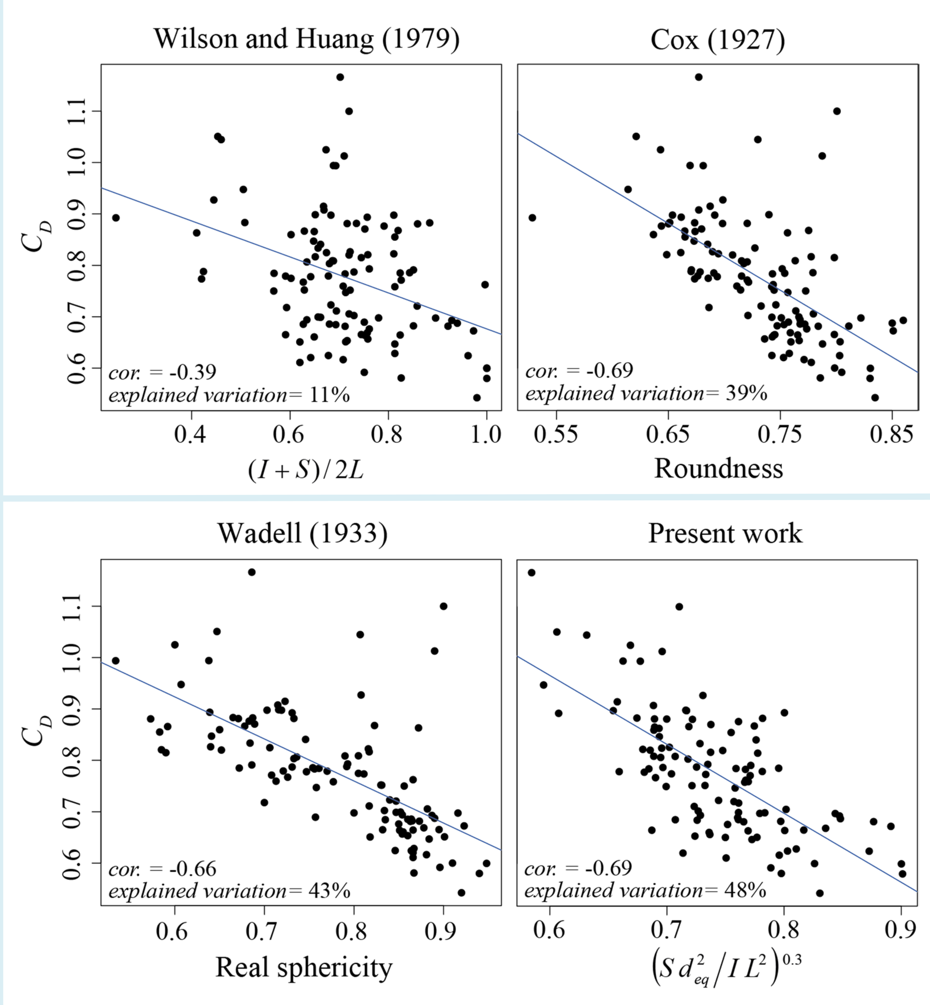
VI. Results

Effect of porosity

Terminal velocity of volcanic particles are measured with and without Parafilm wrap. Parafilm wrap covers the particle pores and create a smooth surface on the particle without significant change in the particle mass. Average difference between measured terminal velocities of particles with and without Parafilm wrap is 7.3 %.



Benchmarking shape factors



Particle equivalent diameter
d_{eq} is the diameter of a sphere having the same volume as the particle.

Particle form
L is the particle longest dimension.
I is longest dimension of the particle perpendicular to L.
S is particle dimension perpendicular to both L and I.

Roundness
Measured by image processing on particle projection images and is equal to **4π (area) / (perimeter)²**.

Real sphericity
Measured by a 3D-scanner and is equal to ***π*** $\boldsymbol{d_{eq}^2}$ ***/ (particle surface area)***

Benchmarking models

Model	Estimated terminal velocity error %		
	Min	Max	Mean
Clift and Guavin (1971)	8.1	60.3	29.8
Wilson and Huang (1979)	3.4	40.0	28.3
Haider and Levenspiel (1989)	4.0	46.0	27.0
Ganser (1993)	1.5	46.3	27.1

VII. Conclusions

- The wind tunnel performance and its calibration along with the PTV code can be used to produce reliable and accurate measurement on the drag coefficient of particles of various shapes.
- Velocities between 5 and 27 ms^{-1} can be obtained, which correspond to settling velocities of typical volcanic particles with diameters between 10 and 40 mm (density between 500 kgm^{-3} and 2700 kgm^{-3}).
- Unlike spherical particles, effect of porosity on terminal velocity of non-spherical particle is almost negligible.
- A new easy to calculate shape factor is defined which has the highest correlation with the particle drag coefficient.
- Terminal velocity of non-spherical particles can be explained better with a range of velocities instead of a single value.
- In case of non-spherical particles, estimation of all models on particle terminal velocity have about 30% error.