Dedicated vertical wind tunnel for the study of sedimentation of non-spherical particles

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A dedicated 4-m-high vertical wind tunnel has been designed and constructed at the University of Geneva in collaboration with the Groupe de compétence en mécanique des fluides et procédés énergétiques. With its diverging test section, the tunnel is designed to study the aero-dynamical behavior of non-spherical particles with terminal velocities between 5 and 27 ms^{-1}. A particle tracking velocimetry (PTV) code is developed to calculate drag coefficient of particles in standard conditions based on the real projected area of the particles. Results of our wind tunnel and PTV code are validated by comparing drag coefficient of smooth spherical particles and cylindrical particles to existing literature. Experiments are repeatable with average relative standard deviation of 1.7%. Our preliminary experiments on the effect of particle to fluid density ratio on drag coefficient of cylindrical particles show that the drag coefficient of freely suspended particles in air is lower than those measured in water or in horizontal wind tunnels. It is found that increasing aspect ratio of cylindrical particles reduces their secondary motions and they tend to be suspended with their maximum area normal to the airflow. The use of the vertical wind tunnel in combination with the PTV code provides a reliable and precise instrument for measuring drag coefficient of freely moving particles of various shapes. Our ultimate goal is the study of sedimentation and aggregation of volcanic particles (density between 500 and 2700 kgm^{-3}) but the wind tunnel can be used in a wide range of applications. © *2013 AIP Publishing LLC*. [http://dx.doi.org/10.1063/1.4805019]

I. INTRODUCTION

Transportation of solid particles within a continuum fluid is common in a wide range of phenomena. Dispersal of volcanic particles,[1] sedimentation and erosion in river channels,[2] deposition of solid carbon dioxide hydrate in ocean,[3] particle transport in fluidized beds,[4] and deposition of airborne particles in indoor environments[5] are just a few examples. These phenomena are associated with various types of fluids, process speed and particle shape, size, and density. Forces and torques, which fluids exert on the particles, represent some of the most important aspects that characterize the interaction between fluids and particles.

Many natural and industrial processes involve transportation of particles either in high particle to fluid density ratios or high particle Reynolds numbers, which include many processes where solid particles are transported in gases. Drag coefficient has typically been measured of large fixed particles in horizontal wind tunnels[6–9] or of particles freely falling in liquids.[2,3,10–17] However, the measurements of the drag coefficient strongly depend on the nature of particle secondary motions, which are different for different density ratios.[2,3,10,12–24]

Besides, it is found that the drag coefficient of particles of any shape at intermediate Reynolds numbers ($1 < \mathrm{Re} < 10^4$) is related to values of their drag coefficient at very low ($\mathrm{Re} \ll 1$) and at very high Reynolds numbers ($10^4 < \mathrm{Re} < 10^5$).[25,26] Therefore, characterization of drag coefficient of particles at both high Reynolds number and high density ratios can be used either directly or to be used for estimating particle drag coefficient at intermediate Reynolds numbers. A dedicated vertical wind tunnel has been built at the University of Geneva in collaboration with the Groupe de compétence en mécanique des fluides et procédés énergétiques (CMEFE) from the University of Applied Sciences Western Switzerland in Geneva (HES-SO//hepia) (Fig. 1) in order to characterize drag coefficient of volcanic particle (i.e., highly irregular particles of various shapes, sizes, densities, and porosities). In Sec. II we first discuss fundamental aspects of forces exerted on the particle when it is freely transported in a fluid and the relationship with the particle orientation. This is followed by the methods available in the literature for the measurements of drag coefficient of particles. Advantages and disadvantages of these methods are discussed along with our motivation of building a vertical wind tunnel. Design parameters of our wind tunnel components are then presented and discussed. Our particle tracking code (PTV) developed to extract the results from the experiments with the wind tunnel is described. Finally, error estimation on our measuring method and the validation of our measurements of some spherical and cylindrical particles is presented.

II. DRAG COEFFICIENT

Particle transportation, in most cases, is associated with a fluid flow, with a fall due to gravity, with rising due to buoyancy, or with various combinations of these processes. Particles of arbitrary shapes when transported in a fluid experience forces and momentum on all three coordinate axes.[27]

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