

Pickup (critical) velocity of particles

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Abstract

This work presents experimental results on pickup velocity (critical velocity) measurements for a variety of particulate solids. The present experiments together with previously published experiments of a number of researchers encompass about 100 measurements of 24 materials for a wide range of particle sizes, shapes and densities. Based on the experimental results, three zones are defined by establishing simple relationships between the Reynolds and Archimedes numbers. The empirical relationships were further modified by taking into account the pipe diameter and particle shape (sphericity). The three-zone model was shown to reasonably correlate to Geldart's classification groups.

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1. Introduction

Operation of a pneumatic conveying system is influenced by many parameters [1,2]. The operating air velocity influences the system performance and its economic efficiency to the largest extent. Conveying velocities above what is necessary can lead to wasted energy, particle attrition [3], and pipe erosion. Prediction of the minimum conveying velocity requires understanding of the saltation and pickup mechanisms. Pickup of particles differs from their saltation in relation to the initial position of the particles. For pickup mechanism particles initially lie at rest on the bottom of the pipe whereas for saltation, particles are initially suspended. Pickup velocity has been defined as the fluid velocity required to initiate sliding, rolling and suspension of particles [4]. However, the most general definition is as follows: The velocity required to resuspend (blowing away) a particle initially at rest on the bottom of pipe is the pickup velocity.

The pickup velocity is relevant in other wide range of applications. For example, some pharmaceutical areas are focused on dry powder inhalers for drug delivery [5], the movement of sand dunes and soil deposition in river and ocean flows.

Several studies have dealt with the phenomenon of particle pickup velocity. For transport of single particle in a gas stream, it is possible to generalize that the pickup velocity is up to 2–2.5 higher than the saltation velocity [1,6]. Cabrejos and Klinzing [2,7,8] conducted experiments with various materials and developed a theoretical model based on force balance leading to sliding, as well as an empirical correlation for particles larger than 100 μm [2]. Hayden et al. [5] developed a similar force balance, but assumed that the vertical force balance leads to particle entrainment for fine powders. Hubert and Kalman presented new methods for measuring saltation [9] and pickup velocities [10], comparing velocities measured in a layer of particles and in heaps [10].

In this paper we investigate the pickup mechanism in a layer of particles. Experiments conducted are combined with previous experiments [2,5,7,8] to cover a wide range of particle properties. It was found that the range of pickup velocities can be divided into three zones of behavior that can be described accurately by developing simple relations between the Reynolds and Archimedes numbers.

2. Experimental

Cabrejos and Klinzing [2,7,8] and Hayden et al. [5] conducted experiments in a circular pipe. A section of the

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pipeline was filled to a certain height by a layer of particles. Then, a constant airflow rate was applied through the pipeline. The layer of particles was eroded due to entrainment of particles to the air stream while the average velocity is higher than the pickup velocity. While the layer of particles was eroded, the average air velocity above the layer was decreased (the cross-sectional area for the air flow increased). The air was supplied until the height of the layer was observed to become steady. At this point, the air velocity was calculated by dividing the volumetric airflow rate to the free cross-sectional area of the pipe (above the particle layer). However, these types of experiments can lead to some slight errors due to non-constant erosion along the particle layer.

Our experiments were conducted by using a rectangular wind tunnel [10]. The experimental setup is depicted in Fig. 1a. The main part of the setup is a Plexiglas wind tunnel, which consists of 10 square ducts. Each duct is 0.6 m long and its internal dimensions are 0.1×0.1 m. A compressor was used as the source of air. The average gas velocity was measured by a mass flow meter for flow rates below 2500 l/min (accuracy of $\pm 0.1\%$) and by a thin-plate orifice (estimated accuracy of $\pm 3\%$) for higher flow rates. Particulate solids were separated from gas and collected in a cyclone at the exit from the wind tunnel. For fine particles, the cyclone could be equipped with a sleeve filter on the top. The layer of particles was created by filling a rectangular shallow bath attached to the bottom of the wind tunnel (Fig. 1b). The top surface of the particle layer matched the bottom surface

of the tunnel. The height of the wind tunnel was sometimes reduced to increase the air velocity, as shown in Fig. 1c.

By using a high-speed video camera we were able to observe the pickup movement (see Fig. 2). At $t=0$, the particles were at rest. When particles were picked up from the layer of particles, it was possible to observe and distinguish three stages. Initially, the particles started rolling along the layer of the particles ($t=280$ and 354 ms). Since the surface of this layer is rough, in the second stage the particles started to bounce due to collisions with other particles in the layer ($t=370$, 392 and 396 ms). In the third stage, the newly entrained particles collided with the particles already carried with the air ($t=442$, 460 and 486 ms).

Since defining the pickup velocity by visual observations could lead to significant errors, we preferred to measure the pickup velocity by a qualitative manner, although this requires some degree of extrapolation. Plotting the amount of entrained particles (weight reduction of the layer) as a function of operating gas velocity made it possible to determine the pickup velocity. The pickup velocity was determined at the intersection of the extrapolated curve passing through the measured points and abscissa (Fig. 3). In this way, we overcome the problem of identifying the first particle that was picked up. The identification of the pickup of the first particle is acquired by quantitative measurement rather than visual observation, although it is based on extrapolation of an experimental curve. In order to obtain the curve we measured the layer weight loss as a function of the air

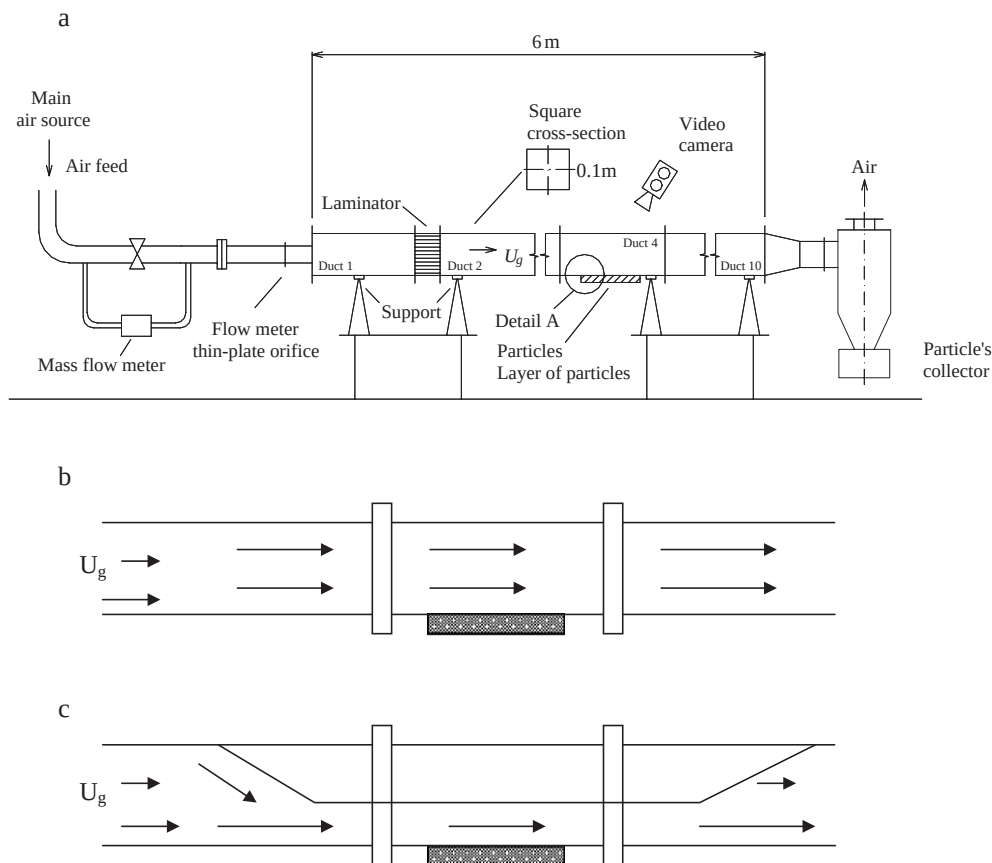


Fig. 1. Scheme of the experimental setup.

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