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Influence of swirling intensity on lump coal particle pickup velocity in pneumatic conveying

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ABSTRACT

Pickup velocity, defined as the airflow velocity requirement of the initial movement of solid particles, is the well-recognized minimum conveying velocity required of a pneumatic conveying system. To reduce the airflow velocity, the influence of swirling intensity on lump coal particle pickup velocity was studied via experimental measurements. The pickup velocity of lump coal particle was determined by the weight loss method and the whole process was recorded by a high-speed camera. Initially, a side inlet guide vanes swirling generator was developed and used to measure the effect of swirling airflow. The impact of the swirling intensity was discussed and regressed, considering the tangential flow rate, the total inlet airflow rate, and the measurement position. Subsequently, the pickup velocities of 5 to15 mm lump coal particles in axial and swirling flow field were separately determined. In addition, a normative gradual change of tangential flow rate was utilized to examine the pickup velocity variation with swirling intensity. Two points in particular are worth highlighting: (1) the lump coal particle pickup process is prone to rolling up from coal particle bed fore-end, rather than the locally layer-by-layer peeling off in axial flow field; and (2) the pickup velocity of lump coal particle first increases and then decreases with swirling number, and a cubic polynomial function has favorable adaptability to fit the relationship between the lump coal particle pickup velocity and swirling intensity. The fitting results show good agreement with the measurements, with the fitting errors being <3%.

1. Introduction

Pneumatic conveying is a common approach for granular material pipeline transportation because of its characteristics of eco-friendliness, simple operation, flexibility, and security. As a fundamental industrial raw material, coal plays a very important role in the national economy. Moreover, the green coal industry, including all constituent components (coal mining, coal logistics, coal processing, and so on) is an inevitable choice for the sustainable development of the fuel supply system. As an appropriate step, the pipeline transportation of coal will benefit green coal logistics for improving the public health, environmental cleanup, and operational safety advantages [1]. Thus, pneumatic conveying is widely used in coal ash transportation of thermal power plants [2, 3]. However, for some other industries, such as coking and coal gasification, coal pneumatic conveying is restricted when the specific sizes of coal particles are necessary to ensure unitization. Based on the fundamental of pneumatic conveying, problems such as high energy consumption, excessive pipe wall erosion, coal particle breakage, and the limitation of lump coal particle pneumatic conveying are mainly caused by the high airflow velocity requirement.

As the most important parameter, the airflow velocity in pneumatic conveying prominently affects the system energy efficiency and transportation performance [4]. The pickup velocity, defined as the airflow velocity requirement the initial movement of solid particles, is the well-recognized minimum conveying velocity required of a pneumatic conveying system [5, 6]. Previous studies [4, 7–10] have well studied the mechanism, the determination, and the influence factors of fine particles. The aforementioned researchers have revealed the mechanism of particle pickup and predicted the pickup velocity for different particles. A review of the efforts on the pickup velocity is given here in chronological order. Cabrejos [11] derived a pickup velocity calculation model based on experimental data and a dimensional analysis method. Thenceforth, the particle pickup investigation was widely pursued. Kalman and Rabinovich [4, 12, 13] concluded approximately 100 measurements of a 24 materials pickup experiment and defined three zones to predict particles velocities on the basis of straightforward equations between the Reynolds number and the Archimedes numbers, which were reasonably correlated to Geldart's classification groups, and then, they verified the three-zone master curve by measurement for a variety of particulate solids in gases and liquids. Dasani [14] measured

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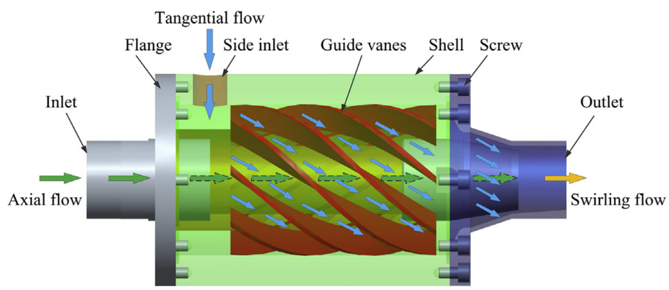

Fig. 1. Side inlet guide vanes swirling generator.

the pickup velocities of particles <450 μm in water and developed the force balance model of particles for gas phase system. Next, Goy et al. [15] measured pickup velocities for entrainments of particle mixtures between different Geldart's groups having binary particle size distributions using the weight loss method and found that the empirical correlation fails to accurately predict the pickup velocity for zones I and II particles binary mixtures. Gomes [9, 16] conducted analogous investigation and emphasized the effect of particle size and shape on the pickup velocity, over the particle size range from 20 μm to 4000 μm. Other typical investigators, such as Anantharaman and Chew [10, 17–19], were focused on pickup process of nano-scale and micron-scale particles; moreover, they derived a calculation model for Geldart B particles on the basis of forces balance between friction force and drag force, and take both the particle shape and the pipe diameter into account. Next, Soepyan [20] introduced a semi-mechanistic model based on the force and torque balance on a single particle and then quantified his model uncertainty by bootstrap method. To date, the three zones calculation method proposed by Kalman and Rabinovich is the most approved model. Their studies indicated that the pickup velocity of particle is positively correlated with particle size and density. Moreover, to meet the criterion of industry application and high cost, the lump coal particles commonly have the size of 6–25 mm. The pneumatic conveying operational process of lump coal particles should be different from the conventional dilute-phase or dense-phase pneumatic conveying as well as the pickup velocity prediction. Therefore, to generalize lump coal particle pneumatic conveying process, it is necessary to study low velocity pneumatic conveying technique on the basis of thorough comprehension the pickup process of lump coal.

Many studies have examined optimized flow regimes for pneumatic conveying such as swirling flow [21, 22], spiral pipe flow [23, 24], and oscillating flow [25, 26]. The aforementioned studies indicated that the optimized airflow regime could reduce the particle conveying velocity and improve the conveying performance. In particular, the swirling flow can reduce the minimum conveying velocity, the particle breakage, and the possibility of particle deposition and blockage in pipes. However, because of the unsteady and complicated properties of swirling flow pneumatic conveying, a thorough understanding of gas-solid two-phase conveying behaviors is very acutely lacking for swirling flow pneumatic conveying operation and optimization as well as the proper swirling generation technique. Li and Tomita [21, 22, 27, 28] comprehensively studied a swirling flow pneumatic conveying system for three plastics pellets with mean diameters of 1.7, 3.1, and 4.3 mm. Their works indicate that the pressure loss, energy consumption, and the minimum conveying velocity of swirling flow pneumatic conveying system are remarkably lower than that of an axial airflow system. Subsequently, Bilirgen [29] numerically and experimentally studied the rope dispersion characteristics of particles in a pipe with different structures, including nozzles, air jet injection, and swirl vanes, and found the rope dispersion rate of solid particle in all directions were significantly lower than that of simple pipe, for which the secondary velocities of airflow are absent. Fokeer [23, 24] experimentally and numerically examined the axial, radial and tangential velocity distributions of a three-lobed pipe swirling flow field and found the variation and decay law of the swirling flow. Rinoshika [25, 26] proposed an oscillating flow pneumatic conveying by built-in soft fins, similar to the swirling flow, and found that the air velocity with minimum pressure drop, the pressure drop, and the additional pressure drop, as well as the power consumption coefficient, can be largely reduced compared to the simple axial flow pneumatic conveying. Recently, Zhou [30] studied the flow regime and particle movement of three types of swirling generators using the computational fluid dynamics and discrete element method (CFD-DEM) coupling simulation method and found a positive correlation between the particle dispersion and the swirling intensity; it also shows that the internal spiral vanes swirling generator is of good applicability for lump coal particle pneumatic conveying. Subsequently, Zhou [31, 32] examined the influence of swirling intensity and particle shape on the lump coal particle breakage and pipe wall erosion; the results showed that the particle breakage and pipe erosion rate were significantly decreased with swirling intensity. However, the influence of the swirling intensity on the lump coal particle pickup process has not been conducted yet.

In the present work, a side inlet guide vanes swirling generator was developed and measured for lump coal particle pickup in pneumatic conveying on the basis of prior study [30]. Next, the pickup velocities of lump coal particles in axial and swirling flow field with different size and swirling intensity are measured using the weight loss method. The pickup process and the pickup phenomenon in different flow fields are discussed, and the pickup velocity variations based on the coal particle size and swirling intensity are also examined.

2. Methodologies

2.1. Swirling generator development and measurement

Previous work [30] showed that the internal spiral vanes swirling generator has excellent comprehensive performance, whereas it has

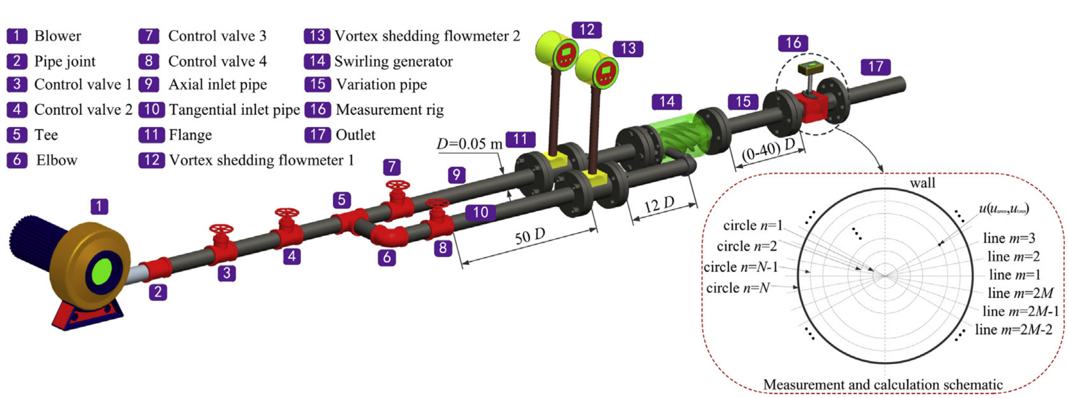

Fig. 2. Measurement system of the swirling intensity.