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Effects of fine particle outlet on performance and flow field of a centrifugal air classifier

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ABSTRACT

A fine particle outlet was designed and introduced to a centrifugal air classifier to improve its classification performance. Effects of the inserted depth and diameter of fine particle outlet were investigated experimentally and numerically. The turbulent airflow was modeled using the Reynolds Stress Model. The calculated pressure drop of the classifier agrees well with the experimental date. The experimental results indicate that the insertion of fine particle outlet significantly enhanced the particle classification efficiency. Optimal particle classification can be achieved when the fine particle outlet inserted depth ratio is 0.5. Increasing the fine particle outlet diameter decreases both the tangential velocity and the turbulent intensity, thereby increasing the cut size. Both too large and too small fine particle outlet diameters lead to poor classification performance. Moreover, the fine particle outlet diameter has a more significant effect on pressure drop compared to the insertion of fine particle outlet. The obtained results can provide a guideline for design of the centrifugal classifier.

1. Introduction

Size classification is an important unit in various industries such as mineral processes, chemical, cement, power generation, agriculture, food and resources recycling (Karunakumari et al., 2005; Johansson and Evertsson, 2014; Cepuritis et al., 2015; Altun and Benzer, 2014; Ferrari et al., 2009; Lanzerstorfer, 2015). To date, both dynamic turbo- and static air classifiers are widely used for dry classification. The turbo air classifier usually works with turbine, which mainly generates a forced vortex for classifying the materials (Eswaraiah et al., 2008a, 2008b). It is well known that both capital cost and operational energy consumption of turbo air classifier are much higher than that of static air classifier (Li et al., 2015). In additional, the static air classifier is more applicable for harsh environment such as high temperature. The improvement for the classification efficiency of the static air classifier is worth studying (Li et al., 2015; Wang et al., 2001; Lai et al., 2009). Fig. 1 shows a typical static centrifugal air classifier, which mainly employs centrifugal force and air drag force to separate particles at cut points from ten microns to hundred microns (Johansson and Evertsson, 2014; Shapiro and Galperin, 2005).

Seeking to improve the classification efficiency of the centrifugal air classifier, Johansson and Evertsson (2014) studied the flow field inside the classifier using computational fluid dynamics (CFD). The results showed that a Rankin vortex exists in the classifying chamber and secondary recirculation flows appear near the fine particle outlet (exit hole). They also found that fine particles were more easily influenced with the variation of fine particle outlet diameter. Decreasing the fine particle outlet diameter may decrease the cut size (Cepuritis et al., 2015). Johansson and Evertsson (2012) further showed that the performance of centrifugal air classifier is highly associated with the operating parameters (including primary air velocity v_p and secondary air velocity v_s). Although the effects of fine particle outlet and operating parameters on classification performance have been mentioned, a comprehensive study has not been found in the literature.

The objective of this research is to improve the static centrifugal air classifier performance by optimizing the inserted depth and diameter of fine particle outlet and the corresponding operating parameters. To understand the classification behavior of the classifiers, the air velocity distribution and the turbulence level were investigated using the CFD method. The findings from this study should be useful for a bet-

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Nomenclature

d	Diameter of fine particle outlet (mm)
d_{25}	Diameter at 25% penetration (μm)
d_{50}	Diameter at 50% penetration, cut size (μm)
d_{75}	Diameter at 75% penetration (μm)
De	Equivalent diameter of classifying chamber (mm)
h	Inserted depth of fine particle outlet (mm)
K	Classification sharpness index (dimensionless)
v_p	Primary air velocity (m/s)
v_s	Secondary air velocity (m/s)
W	Width of classifying chamber (mm)
ΔP	Pressure drop (Pa)

ter understanding of the effects of fine particle outlet and operating parameters.

2. Particle classification experiments

2.1. *Classification principle of the centrifugal air classifier*

The centrifugal air classifier works mainly based on the centrifugal separation mechanism. As shown in Fig. 1, air-particle flow enters into the classifier through a pre-separation channel (1). When passing the guiding vane (2) most particles travel along the inside path, while the airflow travels along the outside path. As the particles reach the end of the guiding vane (3), the airflow crosses the particle stream and starts the classification process. Fine particles will follow with the airflow entering the fine particle outlet (4) under the action of air drag force. Coarse particles with large centrifugal force are thrown out and fall down along the wall. In actual operations, due to various stochastic factors (particle agglomeration and collisions, air turbulence, etc) some fine particles are difficult to be separated from the coarse fraction. To improve the particle classification precision, recirculation of the fine particles is created by controlling the secondary air stream.

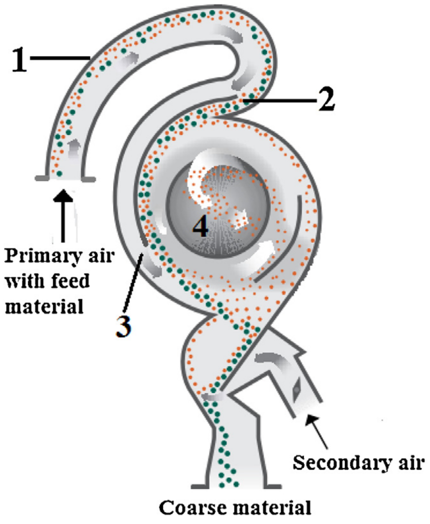

Fig. 1 – Principle of the centrifugal air classifier (Johansson and Evertsson, 2014).

Table 1 – Experimental conditions in the present study.

Fine particle outlet inserted depth ratio (d/De = 0.5) 2 h/W					Fine particle outlet diameter ratio (2 h/W = 0.5) d/De				
0.17	0.33	0.5	0.67	0.83	0.25	0.3	0.37	0.5	0.58

2.2. *Experimental setup*

A schematic of the centrifugal air classifier with its characteristic dimensions is shown in Fig. 2. The traditional air classifier is the industrial simplified structure, whose inserted depth of the fine particle outlet is zero (2 h/W = 0). The modified air classifiers are characterized by different inserted depths and diameters of the fine particle outlet. Details on the variations of the fine particle outlet are listed in Table 1.

2.3. *Experimental methodology*

The experimental system for the centrifugal air classifier is shown in Fig. 3. The primary and secondary air velocities were measured using pitot tubes (M1, M2), respectively. The air flow rates were regulated by valve 1 and 2. The pressure drop between the feed inlet and the air outlet of the classifier was measured by an inclined tube manometer (M3). The feed material has actual density of 1500 kg/m^3, with particle diameter ranging from 1 to 250 μm and a volume median diameter of 64 μm. Materials were fed at a concentration of 0.25 kg/m^3.

After each test, coarse and fine powders (including superfine powder) were weighted separately for the purpose of mass balance. Coarse powder samples were analyzed using a BT-9300S laser particle sizer. Then the partial classification efficiency (also known as grade efficiency) of the classifier can be calculated (Karunakumari et al., 2005; Cepuritis et al., 2015). The characteristic particle sizes d_{25}, d_{50}, d_{75} were taken from the grade efficiency curves, and the classification sharpness index K was calculated according to the formula $K = d_{75}/d_{25}$. The cut size d_{50} means that the forces equally affect the particles; hence, they have 50% probability either to coarse fraction or fines. The sharpness index K has a value of unity for a perfect classification process. The steeper the grade efficiency curve is, the better the classification precision will be (Eswaraiah et al., 2008a, 2008b, 2012; Guizani et al., 2014; Yu et al., 2013; Wang et al., 1999; Feng et al., 2008). For the classifiers in this study, smaller K and d_{50} value indicates better particle classification performance. Besides, the pressure drop which is crucial for the economic viability of a classification (Guizani et al., 2014; Nied, 2004) was used to evaluate the classifier performance.

3. Experimental results and discussion

3.1. *Effects of the inserted depth of fine particle outlet*

Discussion of the results obtained under the inserted depth of fine particle outlet was to start with before moving on the description of the impacts of the diameter of fine particle outlet. The particle size distribution of the classification results is shown in Fig. 4. For the collected coarse powder, the particles with differential frequencies larger than 1.25% range from 24.7 μm to 245 μm by using traditional air classifier (2 h/W = 0). However, in the case of 2 h/W = 0.5, the particles with differ-