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Experimental study on velocity field between two adjacent blades and gas–solid separation of a turbo air classifier

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ABSTRACT

The velocity field between two adjacent blades in a turbo air classifier was measured using the particle image velocimetry (PIV) technique equipped with a self-developed synchronizer. It was found that vortex swirling flow existed between the two blades or in the annular region between the impeller and the side wall. Under a given condition, the swirling intensity was higher while the swirling zone was smaller in the horizontal plane of the upper stream. As the impeller rotational speed S increased, the swirling became more intensive and the vortex center moved toward the side wall; when total air flow rate Q increased, the swirling intensity increased but the swirling center barely changed. The performance experiments showed that the overall classification efficiency η increased with S firstly and then decreased with the further increase of S. Correspondingly, non-monotonic variation trend was found for the cut size of the passing through particles d_{50}. At a higher inlet solid concentration C_s, the dependence of d_{50} on S was more profound. d_{50} decreased significantly with the increasing C_s when C_s was smaller than a critical value and then barely changed when C_s kept increasing. For the tested turbo air classifier, when $Q = 750\ \mathrm{m^3 \cdot h^{-1}}$, the minimum d_{50} was ~32 μm, occurring at the condition of $C_s \approx 0.08\ \mathrm{kg \cdot m^{-3}}$ and $S \approx 120$ rpm. The classification performance could be well explained by the velocity field near the entrance of the impeller and particle aggregation in the classifier.

1. Introduction

A turbo air classifier is widely used for solid–gas separation and particle size selection in various industries, including pharmaceutical, food, coal, cement, and power generation [1–6]. Its classification performance is generally evaluated by the overall classification efficiency η and the cut size d_{50}. By definition, η is the mass fraction of the particle discharged from the bottom of the classifier to the input particles and d_{50} corresponds to the particle size with 50% possibility to pass through the classifier [1]. Differing from a regular cyclone, the turbo air classifier has a rotary impeller or disk installed inside to improve the classification performance. For a pulverized coal-fired power plant, the performance of the turbo air classifier directly affects the output and economic operation of the grinding equipment, playing an important role in the boiler efficiency and power generation efficiency [6–10].

In order to reveal the classification mechanisms and control the cut size of the product, a number of researches have been conducted on the gas–solid two-phase flow field in the turbo air classifier. The numerical simulations via CFD modeling [7–14] revealed that the performance of an air classifier is strongly influenced by the classifier configuration, structural of blades, and operating parameters. Some researchers [e.g., 4,15–17] theoretically analyzed the performance of the classifier and presented some correlations to predict η and d_{50}. In the meantime, several experimental studies have been also conducted on the air classifiers, but mostly on the influencing factors of classification efficiency and the cut size [e.g., 6,18–20]. The studies with detailed measurements of the inside flow field are scarce. Guo et al. [20] employed laser Doppler velocimetry (LDV) to measure the velocity field in the annular region and found that the axial and tangential velocity distributions in this region are greatly influenced by the structure of the bottom plates but insensitive to that of the rotor cage. The increase of the tangential velocity resulted in a narrower size distribution of the escaped particles. However, no study has been conducted on the measurement of the flow field characteristics between two adjacent blades of the rotatory impeller, although these studies are desired to further understand the classification process and validate the CFD modeling.

In this paper, a laboratory-scaled turbo air classifier was established to mimic the commercially used pulverized coal mill. The flow velocity

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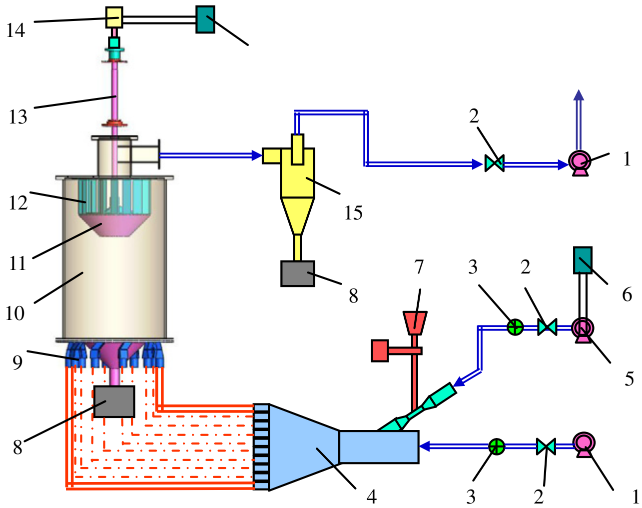

Fig. 1. Schematic of the experimental system of a turbo air classifier.

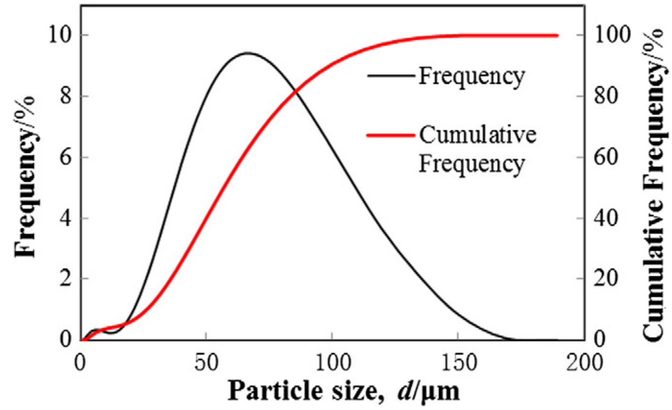

Fig. 3. Raw material particle size distributions.

fields between two adjacent blades of the rotary impeller were measured at three vertical levels and different impeller rotational speeds, using the particle image velocimetry (PIV) technique. In addition, the classification efficiency of the model classifier was measured under various impeller rotational speeds and particle loadings. According to flow field and classification efficiency measurement, the mechanisms of gas–solid separation in the turbo air classifier were discussed.

2. Experimental

2.1. Experimental system

The experimental apparatus of the turbo air classifier is shown in Fig. 1. It consisted of main body of the classifier, a particle feeding system, an air supply system, a particle collection system, a rotational speed control system, and a measurement system.

The main body of the classifier consisted of a house, an impeller, a guide cone, and a set of inlet nozzles. The house was a cylindrical chamber with the dimension of ϕ 550 mm × 900 mm. Its top cover was a flat ring with a center opening connected with an exhaust pipe. Both the house and the top cover were made of transparent Plexiglas for the convenience of optical access and visual observation. The bottom of the house was a hopper installed on a flat ring. Around the ring, 10 air inlet nozzles were mounted uniformly. The nozzles were installed with an incline angle of 45° to keep the gas–solid flow in the house swirling in counterclockwise orientation.

The impeller, as shown in Fig. 2, was a cylindrical vane of ϕ 400 mm × 200 mm, with 16 blades evenly mounted on its outer rings. Each blade was of 2 mm in thickness, 50 mm in width, and 200 mm in length and installed with an angle of 45°. The impeller was mounted close to the top cover of the house, and between them, effective sealing was realized with a soft brush adhered to the top edge of each blade. Underneath the impeller, there was a static, enclosed guide cone. The impeller was driven by a motor whose rotational speed was adjusted by a frequency converter. The rotational orientation of the impeller was against the upward-swirling main gas flow.

Particles were carried by high-pressure air flow supplied by a Roots blower and then mixed into the main air stream supplied by a blower in a Venturi-type injector. To keep the feeding smoothly, the exit of feeding pipe was extended to the middle of the throat of the injector. The solid mass flow rate was adjusted by the rotary speed of the screw feeder and pre-calibrated before the experiments. The flow rates of both air streams were measured and controlled separately. The particle-laden flow was evenly divided into 10 routes through an air distributor. Each route was separately connected with an inlet nozzle mounted on the bottom of the house.

2.2. Classification performance measurement

Spherical glass beads were used as the solid particles in the classification performance experiments. Their bulk density was ~1200 kg·m^{-3}. The size distributions of the particles measured by a Malvern size analyzer are given in Fig. 3, and the averaged size of the particles was ~63 μm.

Experiments were carried out when the system was operated in a steady state with balanced ventilation. Since the collection efficiency of the cyclone in the exhaust line was ~99% as measured before experiment, the fine particles passing through the classifier were regarded to be fully captured. Just before the measurement, the coarse particles

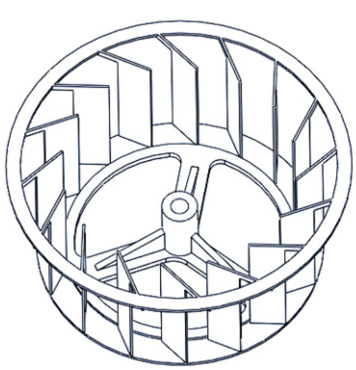

Fig. 2. The configuration of the impeller.

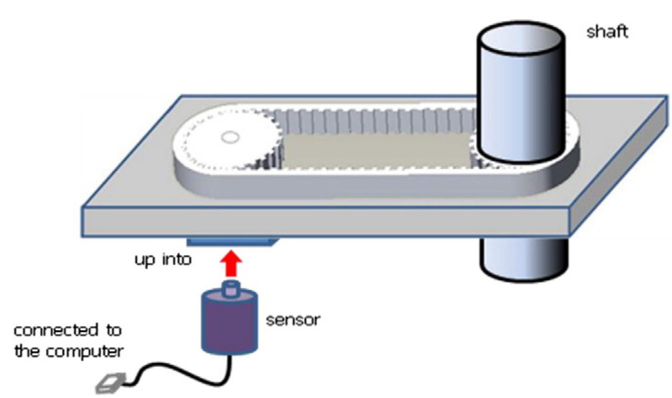

Fig. 4. The schematic of synchronizer.