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Investigation on dust collection and particle classification performance of cyclones by airflow control for design of cyclones

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ABSTRACT

We investigated the design of relatively large cyclones with large amounts of airflow containing dust that are used in actual dust collection plants. In order to obtain basic data on the design of conical cyclones with a Reynolds number of approximately 8.9×10^5, we compared the fluid analysis results with the experimental results on dust collection and particle classification performance for conical cyclones to which apex cones and stabilizers were attached. Then, we elucidated the relationship between the flow conditions inside the conical cyclone with a Reynolds number of 8.9×10^5 and dust collection and particle classification performance.

1. Introduction

The separation and collection of particles at dust collection plants using pneumatic conveying generally involve the installation of a receiver tank (settling tank) for the conveying process where particles with relatively large diameters and high densities are separated and collected via the gravitational force that acts on them. Particles with smaller diameters and lower densities, which cannot be separated and collected easily with a receiver tank (for cases where Stokes' law applies to the aerodynamic force acting on particles), are partially separated and collected by the cyclone in the subsequent process, by utilizing the centrifugal force acting on the particles. However, the particles that cannot be collected by the cyclone are separated and collected using a filter in the following process. Subsequently, the airflow is usually guided into a suction machine (blower) installed at the very end of the conveying line and then discharged into the atmosphere. In order to reduce the load on the filter during such dust collection processes, it is necessary to improve the dust collection and particle classification performance of cyclones.

Particle separation in a cyclone is based on the principle wherein particles are accumulated in a dust collection section after being separated outward by the centrifugal force originating from a swirling flow and trickling into the dust collection section along the cyclone wall surface. The swirling flow inside the cyclone is a combination of a free vortex and forced vortex (hereinafter referred to as the Rankin vortex). This combined vortex also has descending and ascending flows, causing a downward reverse flow at times as negative pressure occurs around the central region. Therefore, it is known as an unsteady flow because the inclination angle of the flow to the tangential direction changes constantly owing to the eccentricity of the swirling flow center and the shape center [1,2].

Thus, in order to design a cyclone with high particle classification performance, it is necessary to have an appropriate design that takes the unsteady flow into consideration. However, it is not practical to create a prototype in advance and take measurements using a Pitot tube current meter, hot-wire anemometer, or particle image velocity (PIV) for the estimation of the flow field inside a cyclone during design, from the standpoint of the time and cost required for the measurements and prototyping.

However, the high processing speeds and decreased prices of computers in recent years have made it possible to apply the analysis of the fluid dynamic phenomenon by computational fluid dynamics (CFD) to engineering as well.

Using CFD, Yoshida et al. [3–6] calculated the flow inside cyclones and the particle trajectory in a three-dimensional simulation by the direct method. They discussed the particle classification and dust collection performance of the cyclones by comparing the results of dust collection and classification experiments.

With regard to the prediction of unsteady flow fields inside cyclones, further progress in CFD, especially in recent years, allowed Akiyama

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Abbreviations: CFD, computational fluid dynamics; LES, large eddy simulation; PIV, particle image velocity; SGS, sub-grid scale; WALE, wall-adapting local eddy-viscosity; SST, shear-stress transport.

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et al. [7,8] to confirm the feasibility of reproducing the unsteady flow inside cyclones based on the comparison between the experimental values in the flow field and the analysis results obtained by employing CFD with large eddy simulation (LES), which targets a compact cyclone (Reynolds number of approximately 3×10^4 to 4×10^4) with a low flow rate at its inlet. Additionally, they discussed the dust collection and particle classification performance by comparing dust collection and particle classification experiment results.

We clarified the validity of the analysis conditions (e.g., the mesh and Courant number) by comparing the CFD calculation results obtained by employing LES with the experiment results for the flow fields inside a relatively large cyclone (Reynolds number of approximately 8.9×10^5) with large amounts of airflow containing dust, which is used in actual dust collection plants; we also considered a design target for this study. Then, we reported that the distinctive flow inside the cyclone [1,2] can be reproduced in a conical cyclone [9].

The purpose of this paper is to report the useful knowledge gained by conducting an investigation on the relationship between the flow conditions inside a cyclone and the dust collection and particle classification performance of the cyclone. This task was carried out by conducting dust collection and particle classification experiments, implementing LES analyses for cases when using an apex cone and a stabilizer [6,8]—a structure and configuration intended to improve dust collection and particle classification performance reported in the past studies on conical and cylindrical cyclones—and performing comparative analyses on the obtained results. The investigation aimed to gather basic data on the design of relatively large conical cyclones (Reynolds number of approximately 8.9×10^5) with large amounts of airflow containing dust, which are used in actual dust collection plants.

2. Dust collection and particle classification experiments

2.1. Experiment device

Fig. 1 shows a schematic diagram of the experiment device. While air is allowed to flow into the cyclone by maintaining the average flow rate at the inlet of the cyclone ① constant with an inverter driven suction blower ②, a constant amount of powder is supplied by the feeder ⑦ from the cyclone inlet.

Before supplying the powder, the average flow rate at the inlet of the cyclone U_{in} is defined by the following equation, based on values measured using a vortex flow meter ③, a pressure gauge ④, a thermometer ⑤ installed in the downstream side of the cyclone and a barometer and pressure gauge ⑥ installed in the upstream side from the inlet of the cyclone.

$$U_{in} = \frac{p_f T_a Q}{p_a T_f A_{in}} \tag{1}$$

where p_f is the static pressure in the vortex flow meter section, p_a is the atmospheric pressure, T_a is the atmospheric temperature, T_f is the temperature of the vortex flow meter section, Q is the volumetric flow rate measured using a vortex flow meter, and A_{in} is the cross-sectional area of the pipe at the inlet of the cyclone.

2.2. Trial cyclones

Fig. 2 shows four types of conical cyclones.

The origin of the coordinate system was set at the center of the bottom surface of the cyclone. The central axis of the cyclone was defined as the y-axis, and the direction of flow into the cyclone was defined as the z-axis.

Type-A cyclone is a standard conical cyclone comprising a cylindrical section with an internal diameter D of 385 mm, a conical section, and a dust collection section.

Type-B cyclone inhibits the re-scattering of particles that enter the dust collection section by reducing the airflow rate inside the dust collection section.

Therefore, an apex cone was installed at the inlet of the dust collection section of a Type-A cyclone [6].

For Type-C and Type-D cyclones, a core bar with a circular cross section (hereinafter referred to as the stabilizer) was installed at the central axis of the Type-A and Type-B cyclones in order to confirm the dust collection and particle classification performance when inhibiting the eccentricity of the swirling flow center and the shape center in Type-A and Type-B cyclones [8].

2.3. Experiment method

The dust collection and particle classification experiments of the cyclones were performed at an average flow rate of $U_{in} = 35$ m/s at

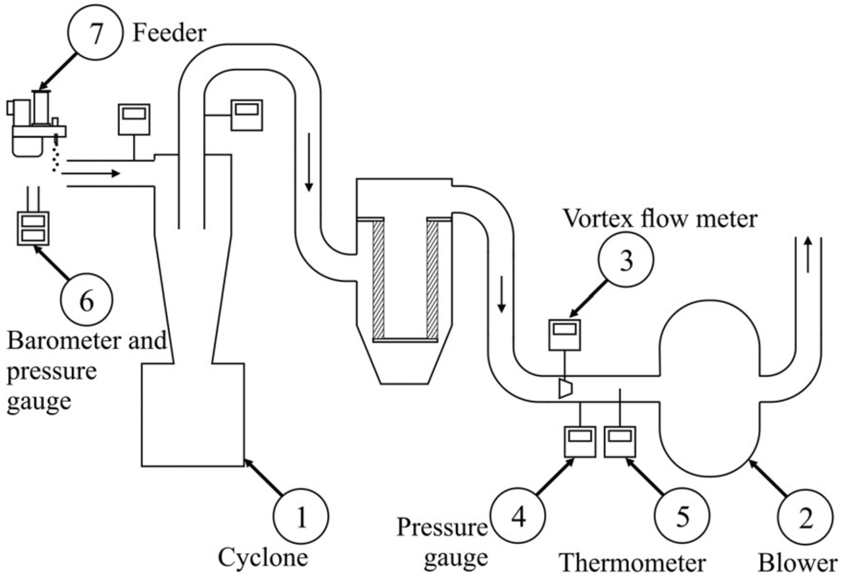

Fig. 1. Experiment device.