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Collection and charging characteristics of particles in an electrostatic precipitator with a wet membrane collecting electrode

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ABSTRACT

Electrostatic precipitator (ESP) with a wet membrane collecting electrodes plays an important role in the flue gas cleaning process. In this work, a lab scale ESP model, with a wet membrane collecting electrode, was constructed and investigated. The collection and charging characteristics of particles in the ESP model were studied. In addition, the discharge characteristics and electric power consumption of ESP were also presented. The mechanisms causing higher collection efficiency of this wet membrane-based ESP in the aspect of electrical characteristics were discussed in detail. Compared with the ESP with dry metal collecting electrode, results show that the discharge current of the ESP with wet membranes collecting electrode was higher for the same conditions. The wet membranes electrode had a better effect on the charging process of particles, especially for particles smaller than 1 μm in diameter. The collection efficiency of this ESP is by 3%–5% higher than the dry metal one at an equivalent discharge corona power consumption.

1. Introduction

Electrostatic precipitators (ESPs) are widely used to reduce the emissions of smoke, fumes and dust, because of their low pressure drop, low energy consumption, high collection efficiency and long service life [1–3]. The overall mass-based collection efficiency for ESPs is in excess of 99% [4,5]. However, the number-based collection efficiency for ESPs is below 50% [6–8], because most of particles that escape from ESPs are fine particles. Such fine particles tend to be more highly enriched with toxic heavy metals and other pollutants due to the large surface area. Many current ESPs are not adequate for the challenges of fine particle collection [9].

The low collection efficiency of fine particles in ESPs is mainly due to the charging and re-entrainment of the particles. Particles with an aerodynamic diameter range of 0.1–2 μm are difficult charged to levels higher than a few elementary charges due to the inherent charging mechanism limitation [10]. Meanwhile, the collected fine particles can easily re-enter the gas stream due to the periodic rapping of the collection electrode [11], flow instabilities [12] and back corona for high resistively fly ash [13,14].

Several innovative methods to conventional ESP have been proposed to enhance the collection of fine particles, such as particle agglomeration [15,16], electron particle charging [17,18], wet electrostatics scrubbing (WES) [19] and so on. However, most of these techniques remain under investigation and their effectiveness must be still validated at industrial scale. Wet electrostatic precipitators (WESPs) are suitable for controlling fine particles, due to the effective control of re-entrainment. In addition, the WESPs exhibited good control for sulfuric acid aerosols and heavy metals [20] in field applications due to the decreased gas temperature. Nowadays, the WESPs have been widely used in conjunction with the wet flue gas desulfurization (WFGD) system [21]. As a result of the high cost, easy corrosion and non-uniform distribution of flushing water over the surface of the metal collecting electrode, a membrane-based WESP was first proposed by Pasic [22]. The experimental studies of Bayless [23] found that the ESP with wet membranes collecting electrodes has higher collection efficiencies than the metal ones under the same conditions. Chang [24,25] completed research on the capillary penetration of the polypropylene collecting electrode, as well as the sulfuric acid aerosol

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removal characteristics of ESP with wet membranes collecting electrodes.

Removal characteristics of ESP with wet membranes collecting electrodes have received significant research attention. However, the mechanisms causing excellent removal characteristics of ESPs with the wet membranes collecting electrodes are insufficient. In this paper, the removal and charging characteristics of fine particles were investigated experimentally. With respect to the discharge and particles charging characteristics, the differences between collection efficiency of ESP with the dry metal and wet membranes collecting electrodes were discussed. In addition, the electrical power consumption for these two types of ESP is discussed.

2. Experimental

2.1. Measurement method

Particle charge distribution and number concentration were measured with an electrical low pressure impactor [26] (ELPI+™) (Dekati, Finland) in real time. The ELPI+™ is mainly consisted of five components, cyclone, corona charger, impactor, electrometers and vacuum pump. The vacuum pump was coupled to the ELPI+™ to maintain a constant air flow rate. The ELPI+™ setup for particles concentration and charging measurement is shown in Fig. 1.

A cyclone with a cut diameter of 10 μm was first employed to remove the coarse particles from the aerosol. Then, the particles were charged to a known charge level in a corona charger. After charging, the charged particles were size classified and collected in a low-pressure cascade impactor according to their aerodynamic diameter. The impactor stages were electrically insulated from each other and were connected to sensitive multichannel electrometers. The charged particles collected in a specific impactor stage produce an electrical current, which is recorded by the respective electrometer channel. The current is proportional to the number concentration of particles on each stage. Next, the corona charger was turned off and a raw electrical current was produced by the particles with original charges collected in the impactor stage. The ELPI+™ measures particles in 14 size fractions in the range from 6 nm to 10 μm. The 13 impactor stages operating in the range from 17 nm to 10 μm, the final stage measuring in the range of 6–17 nm is a back-up filter stage.

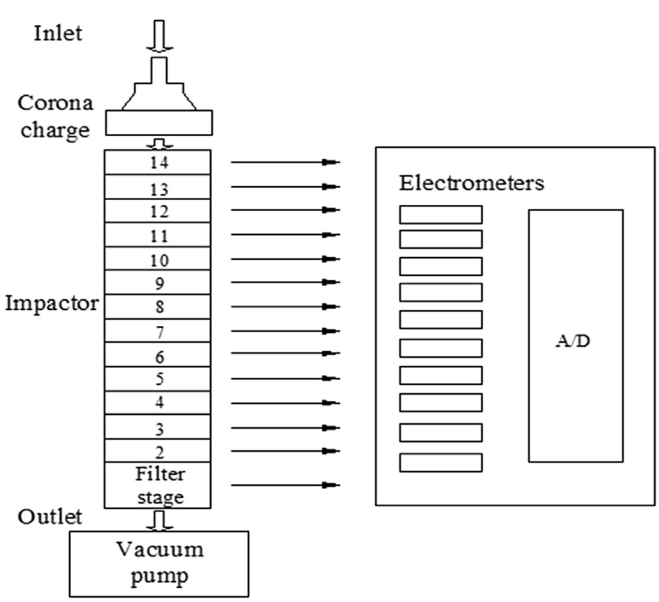

Fig. 1. ELPI+™ setup for particles concentration and charging measurement.

The fractional collection efficiency $\eta(D_i)$ can be calculated with the following equation:

$$\eta(D_i) = \frac{N_0(D_i) - N_m(D_i)}{N_0(D_i)} \times 100\% \tag{1}$$

where $N_0(D_i)$ is the number concentration of the particles at *0* kV supplied voltage (1/cm^3) and $N_m(D_i)$ is the number concentration of the particles at *m* kV supplied voltage (1/cm^3).

The average number of elementary charges on a particle $n_m(D_i)$ with an aerodynamic diameter D_i can be calculated with the following equation [27]:

$$n_m(D_i) = \frac{I_m(D_i)}{eQN_m(D_i)} \tag{2}$$

where $I_m(D_i)$ is the raw electrical current in each stage when the charger is turned off (fA), Q is the constant air flow of the ELPI+™ (10.01 L/min) and e is the elementary charge (1.602×10^{-19} C).

2.2. Experimental setup

Fig. 2 illustrates the experimental setup used in this study, it mainly consisted of a solid aerosol generator system, an ESP model and the measurement system.

The compressed air was introduced into the solid aerosol generator system, which was composed of an aerosol generator (Topas SAG-410, Germany) and an aerosol electrostatic neutralizer (Topas EAN-581, Germany). The fly ash from the last ESP stage ash hopper of a pulverized coal boiler was effectively dispersed and controllably neutralized into the compressed air. A buffer tank between the solid aerosol generator system and the ESP model was used to maintain the stability of the aerosol particles. The size distribution of the fly ash (Fig. 3) was tested with ELPI+™, the number concentration of the fly ash was kept at $(5.2 \pm 0.2) \times 10^4$ 1/cm^3 in the experiments. The characterization of the fly ash (Table 1) was tested with the X-ray fluorescence (XRF) (Thermo Scientific PW4400, USA). The particles entered the ESP model through the perforated plate. The ESP model consisted of three wire discharge electrodes and two plate collecting electrodes. All the electrodes were placed inside a cuboid acrylic box (150 × 120 × 250 mm). The distance between the discharge and collecting electrodes was 50 mm. The wire discharge electrodes were made of stainless steel with a diameter of 2 mm and a length of 50 mm. The wire discharge electrodes were energized with a negative high voltage supply (Tslaman TRC2020N70-150, China). The high voltage supply could provide a negative voltage in the range of 0–70 kV. The total discharge current and applied voltage could be acquired directly from the display panel of the high voltage supply. Two types of collecting electrodes were used in the experiments. The size of the collecting electrode is 100 mm (H) × 150 mm (L). One of the collecting electrodes was a rigid carbon steel collecting electrode and the other was a wet membrane collecting electrode, which was a water penetrating polypropylene (Table 2). The water flow rate over the membranes was 2.5 L/(m·h)$^{-1}$ per unit length in the direction of gas flow. The collecting electrode could be changed between the metal and the wet membranes collecting electrode.

All the experiments were carried out in a laboratory environment, the operating conditions and typical parameters of the ESP model are summarized in Table 3.

2.3. Charging mechanisms

In ESPs, electrical energy is required for gas ionization, with