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The effect of an external DC electric field on bipolar charged aerosol agglomeration

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Abstract

A direct-current (DC) electric field was exerted in a bench-scale electrostatic precipitator (ESP) to induce the agglomeration of bipolar charged aerosol particles. The test aerosol particles were generated from water with an atomizer and their average diameter was 7.71 μm. A phase doppler anemometer (PDA) was used to measure the size distribution and the number concentration of the particles. Systematic experiments were conducted to investigate the agglomeration efficiency of the system. The percentage decrease in number of sub-micron sized particles was found to be about 10.7%.

Keywords: Agglomeration; Aerosol; Bipolar charge; Electrostatic precipitator; Corona

1. Introduction

An electrostatic precipitator (ESP) is one of the most commonly used particle collectors from stack emission for preventing air pollution. In the ESP, particles are charged by corona discharge and then collected by a strong electric field perpendicular to the main gas flow. As we know, the total mass collection efficiency of a well-designed ESP can be above 99%. However, the penetration of sub-micron particles may still be as high as 15% [1] due to their low charging efficiency of corona chargers. So now more and more attention has been put on the removal of these small particles.

Bipolar agglomeration in a direct-current (DC) electric field (DC-agglomeration) is such a method to increase the collection efficiency of small particles. The principle of DC-agglomeration is presented in Fig. 1. Particles are first charged by the bipolar corona discharges. Next they enter the agglomeration chamber with a DC electric field. The direction of the DC field intensity is determined by the relative position of the two discharge electrodes. In such an electric field the particles with opposite charges can be forced to move towards each other and agglomerate more efficiently. Then the larger particles are easily removed by a conventional ESP.

Recently, Wang et al. [2] have developed an analytical solution for the coagulation coefficient of bipolarly charged particles with an external DC electric field. The result showed that an external electric field played an important part in the agglomeration process.

Several authors have already studied electrical agglomeration through experiments. Kobashi [3] studied the particle agglomeration induced by alternating electric field in a parallel plate agglomerator. The agglomeration caused a concentration reduction of approximately 30% in the particle size range of 0.3–2 μm. Watanabe and Suda [4,5] used a so-called quadrupole agglomerator. It is based on an electrical quadrupole field to focus charged particles in the middle of the quadrupole [6]. Their results suggested that the agglomeration caused a 20% concentration reduction for particles under 1 μm. Hautanen et al. [7] used both parallel plate and quadrupole agglomerators. They found the sub-micron particle concentration had a reduction of 4–8%. Laitinen et al. [8] observed the effect of bipolar charging on the agglomerate efficiency of a parallel plate agglomerator. The decrease in number concentration of sub-micron sized particles was between 17% and 19%.

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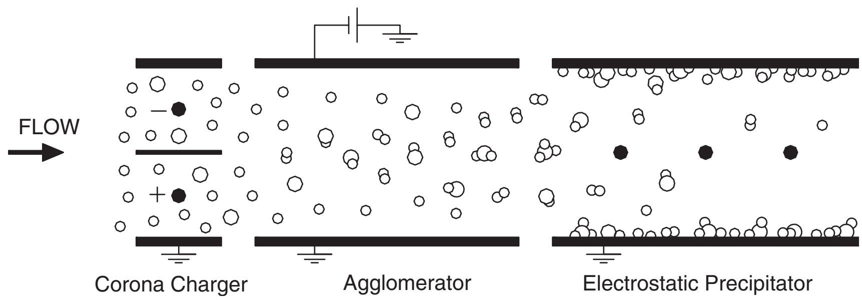

Fig. 1. The principle of flue gas particle removal with an external DC electric field. Particles are first charged by the bipolar corona discharges. Next they enter the agglomeration chamber with a DC electric field, where the particles with opposite charges can be forced to move towards each other and agglomerate more efficiently. Then the larger particles are easily removed by a conventional ESP.

The purpose of our work is to find out the effect of an external DC electric field on the efficiency of a parallel plate agglomerator. Particle size distributions were measured with a phase doppler anemometer (PDA).

2. Experimental system

2.1. Principle

The efficiency of an agglomeration system is affected by several processes, such as the losses of particles to the walls, the particles charging and coagulation. In order to separate the contribution of the DC electric field from the total efficiency, the transmission efficiency (η) is used to calculate the reduction efficiency (r), which often acts as the performance standard of an agglomerator.

An assumption is made that the different processes do not affect each other and the total transmission efficiency with the DC electric field is

$$\eta_{\text{on}} = \eta_{\text{wall}}\eta_{\text{bi}}\eta_{\text{DC}}, \quad (1)$$

where η_{wall} represents the transmission efficiency from the losses of particles to the walls, η_{bi} from the effect of bipolar corona charging and η_{DC} from the agglomeration induced by the DC electric field. When the DC voltage is off, the total transmission efficiency becomes

$$\eta_{\text{off}} = \eta_{\text{wall}}\eta_{\text{bi}}. \quad (2)$$

The total reduction efficiencies of the system with the DC electric field (r_{on}) and without the DC electric field (r_{off}) are

$$r_{\text{on}} = 1 - \eta_{\text{wall}}\eta_{\text{bi}}\eta_{\text{DC}}, \quad (3)$$

$$r_{\text{off}} = 1 - \eta_{\text{wall}}\eta_{\text{bi}}. \quad (4)$$

Combining Eqs. (3) and (4) the reduction efficiency of the bipolar charged particles caused by the DC electric field (r_{DC}) can be estimated as

$$r_{\text{DC}} = 1 - \eta_{\text{DC}} = 1 - \frac{\eta_{\text{on}}}{\eta_{\text{off}}} = 1 - \frac{1 - r_{\text{on}}}{1 - r_{\text{off}}}. \quad (5)$$

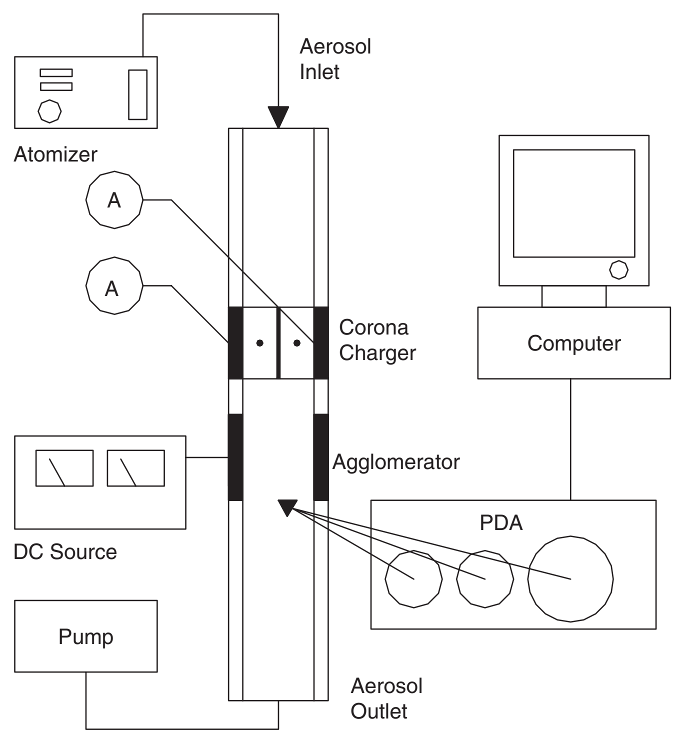

Fig. 2. Agglomerator test system. The aerosol generator, high voltage source and pump are shown on the left. The measurement system is shown on the right.

2.2. Experimental setup

Fig. 2 shows the diagram of the experimental system. It was mainly consisted of a particle generator, a corona charger, an agglomerator and a PDA. Test particles were generated by an atomizer and charged by bipolar corona discharges. Then the particles entered the DC electric field of an agglomeration chamber, where their number concentrations and size distributions were measured with a PDA.

The test particles were generated from water with a commercial atomizer (TSI 6 jet Atomizer Model 9306). Their initial number concentration and mass concentration distributions are shown in Fig. 3. The count median diameter was 7.71 μm and the mass median diameter was 10.82 μm.