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Research article

A combined wet electrostatic precipitator for efficiently eliminating fine particle penetration

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ABSTRACT

Improving the removal efficiency of fine particle is significant for the elimination of particle emission from coal-fired power plants. This work reports a combined wet electrostatic precipitator (WESP) enhanced by a novel perforated pre-charger to efficiently remove fine particle from wet flue gas. Penetration and charging characteristics of fine particle through the WESP were evaluated as a function of particle size. The collection performance was investigated under controlled gas temperatures and varied electrical conditions. Results showed that there was a maximum penetration ratio around 0.1 μm and it decreased with the increasing applied voltage. A portion of the escaping fine particles were not charged through the WESP, and the size limit for partial charging can be reduced to 0.025 μm when the applied voltage increased to 32 kV. Reducing gas temperature leaded to an obvious improvement in collection efficiency for particles in the size range of 0.1–1.0 μm. The test results of different electrodes showed that both the corona current and maximum collection efficiency ranked in the order of pin > sawtooth > rod. With the assistance of pre-charger, the particle charging was significantly improved and the charge amount was more than doubled. Consequently, the effective migration velocity for $PM_{0.1}$, $PM_{1.0}$ and $PM_{2.5}$ increased by 69.9%, 65.7% and 34.2%, respectively. Actual application results showed that the average PM emission level can be reduced to 0.43 mg/m^3 by the combined WESP in a 1000 MW coal-fired power plant.

1. Introduction

Many pollutants can be generated during energy utilization, particularly in processes of coal combustion. Among all pollutants, fine particulate matter (PM) attracts special attention due to its undesirable effects on air quality and human health [1]. In China, nearly 50% of the coal are consumed in coal-fired power plants, which contributes to serious environmental problems [2,3]. Consequently, strict emission standards have been issued for coal-fired power plants in order to satisfy the requirements of cleaner production.

Electrostatic precipitator (ESP) is one of the most cost-effective technology for PM removal in coal-fired power plants [4,5]. Its overall collection efficiency can be as high as 99.9%, thus most of the coarse particle can be removed from the flue gas [6]. However, it is still facing challenges when cleaning flue gas enriched with fine particles [7]. As concluded in numerous studies, particles in the range of 0.1–1.0 μm are easy to escape from the ESP due to the inherent low electrical mobility [8,9]. Consequently, the proportion of fine particles at the outlet of ESPs increased significantly [10–12]. Toxicological studies showed that fine particles could exert stronger physiological effects than coarse particles [13]. Therefore, increasing attention is paid on the fine particle penetration characteristics through ESPs [14]. Some enhancement methods such as acoustic agglomeration, electrical agglomeration and chemical agglomeration are recently developed to improve fine particle collection efficiency by enlarging the particle size [15–17]. Lab-scale investigation indicated that these technologies were promising when combined with dry ESP, however, they were not developed for the purification of wet flue gas.

Wet electrostatic precipitators (WESP) have been widely used to purify wet flue gas from stationary sources. Typically, they are installed after wet flue gas desulfurization (WFGD) to control fine particles such as dust, slurry droplet, and sulfuric acid mist. The fine particle penetration can be significantly restrained in WESP because the accumulated dust is washed off the collection plates [18]. Due to this reason,

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back corona can be prevented and the corresponding corona power level can be raised for more sufficient particle charging. WESP with various configurations including plate type [19] and tube type [20], and even some novel types [21,22] are developed in recent years. Researchers have also attempted various methods, i.e., optimizing geometric [23], and humidifying flue gas [8,24], to further improve the WESP performance for realizing PM ultra-low emission. Although WESP has been well established and developed in the past few years, it is still inadequate in the mechanism of particle penetration and charging through WESP. Moreover, the utilization of multi-stage dry ESP [25] also arises the interests of some researchers to develop two-stage WESPs. Preliminary results showed the collection efficiency of ultrafine particle increased significantly by combining a carbon brush precharger with a plate-type WESP [26]. However, multi-stage WESP makes it more complicated for particle penetration and charging.

Insights into particle penetration and charging through WESP will help to improve the fine particle collection efficiency. In this study, a lab-scale WESP experimental system was designed to investigate the penetration and collection characteristics of fine particles under simulated gas conditions. The penetration ratio and charging characteristics were evaluated and presented as a function of particle size. Gas temperature was adjusted to investigate the impacts on collection performance. With respect to the characteristics of corona discharge and particle charging, the combined WESP was developed for efficiently eliminating the particle emission level. Finally, the combined WESP was successfully utilized in a 1000 MW coal-fired power plant and the emission level was compared before and after installing the precharger.

2. Experimental setup and methods

2.1. Experimental setup

As illustrated in Fig. 1, the experimental system mainly consists of a simulated gas generation system, a WFGD system, a horizontal WESP and a particle measurement system. The main stream of the simulated flue gas was produced by a fan. The test dust was carried from a 1000 MW coal-fired power plant, which is equipped with a five-stage dry ESP. As the flue gas passed through the ESP, particles are separated from the flue gas and collected on the collection plates. In this study, the test particle was exactly carried from the fifth-stage ash hopper because the fine particle is harvested in the last-stage. To inject the particle into the simulated gas, a reliable aerosol generator (SAG 410, Topas, Germany) was used, which helped to obtain stable feeding rate and avoid aggregates. The generator works on the principle of feeding the particle by a special feeding belt, and the particle concentration can be exactly adjusted by setting the feeding belt speed. A dual-stream ejector nozzle and a tube connection are used to disperse the particle by using compressed air. The gas temperature was raised to approximately 100 °C by an electric heater and controlled by changing the electric heating power. To reduce undesired heat loss, all pipes were covered with thermal insulation material. The high temperature simulated gas went through scrubbing in the WFGD and the gas temperature was quenched below 50 °C. Afterwards, the saturated flue gas entered into the WESP and the particle concentration was measured at the outlet of the WESP.

A two-stage WESP consisting of a pre-charger stage and a collection stage was developed in this study. It was arranged horizontally and equipped with two high-voltage DC power supplies. The pre-charger was arranged with perforated configuration, which was placed at the inlet of the WESP. As can be seen from Fig. 1, it took full advantages of the existing air distribution plates of the WESP. The spike-wire electrodes were used for discharge and the air distribution plates were used as grounded plates. With such a configuration, no extra installation space is needed and thus the overall specific collection area (SCA) can be reduced. For more detailed information, it can be found in the previous work for highly efficient removal of sulfuric acid mist [27]. In the pre-charger, a pin-type discharge electrode was utilized to generate high-density ions for particle charging. A high frequency power supply operating in a range of 0–20 kV was connected with the discharge electrode.

In the collection stage, a 10-wire discharge electrode was used for simultaneous particle charging and collection, and a schematic of the discharge electrode geometry is presented in Fig. 2. The wire interval was 100 mm and the distance between the wire and the plate was 60 mm. Three types of discharge electrodes, including pin, sawtooth and rod, were examined for the performance of particle collection, while generally it was rod-type electrode unless otherwise specified. The discharge electrode was inserted into two Teflon insulators for position fixing and electrical insulation. The insulator surface was heated to eliminate the potential of vapor condensation. Another high frequency power supply (0–40 kV) was connected with this discharge electrode to establish the electrostatic field and generate ions. The collection plates were made of stainless steel, the length and height of which were 1200 mm and 300 mm, respectively. The charged particle was captured on the surface of the collection plates and was cleaned by water film. Three nozzles were installed in the middle of the collection stage to spray water droplet and form water film on the collection plates. A lower water reservoir was used to restore the water and a water circulation pump was connected with the nozzles. The water

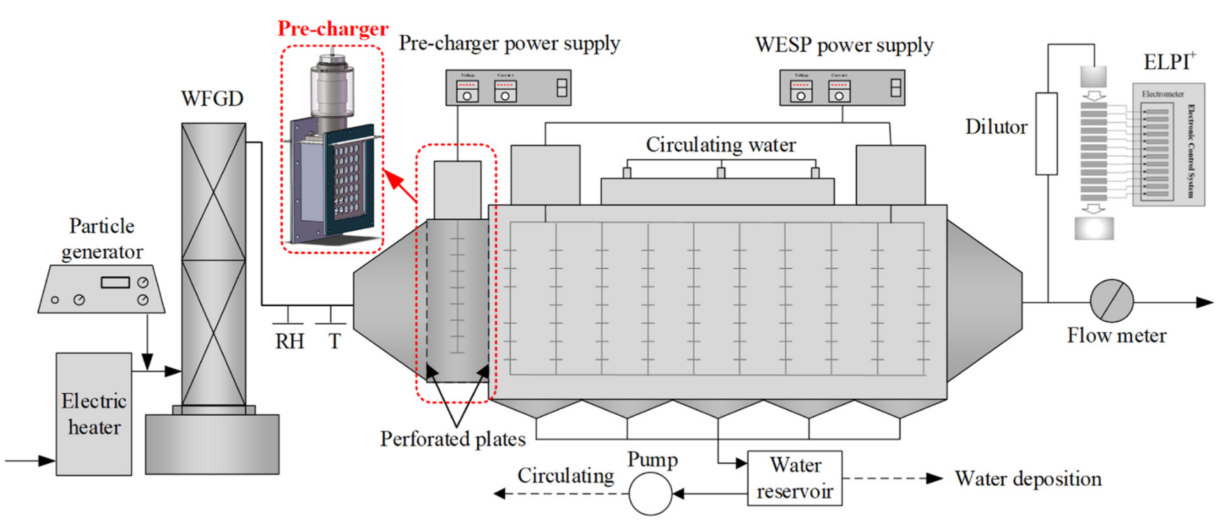

Fig. 1. Schematic of the experimental system.