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Filtration characteristics of fibrous filter following an electrostatic precipitator

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ABSTRACT

This study presents the results of investigations of a hybrid electrostatic filtration system (HEFS), which combines an electrostatic precipitator (ESP) and a fibrous filter installed downstream of the ESP. The particles escaping from the ESP carry large amount of charge and this can increase the filtration efficiency of the fibrous filter. The filtration characteristics, including the efficiency, pressure drop and ozone generation, were investigated experimentally. The influence of system parameters, including the filter type, applied voltage, and distance between the ESP and fibrous filter on the overall efficiency were also studied. The measured results show that utilizing the non-high-efficient fibrous filter to remove the charged particle could provide a much higher efficiency without adding the pressure drop due to the electrostatic force. If the efficiency was similar, the ozone generated by HEFS was much lower than that of the single ESP. The results proved that filter efficiency increased with a higher applied voltage and higher initial mechanical filtration efficiency. The distance between the filter and ESP had no influence on the system filtration efficiency. The efficiency of filter in HEFS supplied with the positive voltage was slightly lower than for the negative voltage. In addition, the mathematical model was utilized to model the air filter efficiency in HEFS. The modeled and measured results agreed reasonably. Overall conclusion is that the HEFS could operate at a high efficiency with the lower applied voltage, ozone generation and pressure drop.

1. Introduction

Buildings, transportation vehicles (such as airplanes or automobiles) and industrial enterprises (such as coal-fired power stations, steel plants and cement mills) release large amounts of particulate matter and cause serious air pollution [1–3]. Exposure to particulate pollution in indoor or outdoor environments has seriously negative effect on human health [4,5]. Some researches indicated that the seriously polluted indoor air (PM2.5: 100–600 $\mu g/m^3$) should be filtered in order to create the healthy environment for human [6–8]. Electrostatic precipitation (ESP) and fibrous filter are widely utilized to remove particulate matter. Some types of fibrous filter is high efficient, such as HEPA (high efficiency particulate air filter), but their operation is not satisfactory because the pressure drop increases with the dust loading [9,10]. The dirty filters should be replaced periodically due to the increased pressure drop. Differently from the fibrous filter, the electrostatic precipitators (ESP), generating high electric field and charging the particles electrically, could be used to capture particles more economically [11–13]. The pressure drop of ESP could be ignored compared to HEPA [11]. The ESP should be cleaned periodically rather than be replaced. However, it is difficult to obtain very high efficiency for the fine particles and its efficiency decreases with the dust loading [11,12]. Moreover, the corona discharge in ESP could generate some by-products (such as ozone or VOC), which have negative effect on human health [14–18].

In order to overcome these disadvantages, a hybrid electrostatic filtration system (HEFS) consisting of an ESP and porous filter has been developed with the fibrous filter placed downstream of the ESP. The particles escaping from the ESP carry some electric charges. The electrostatic force between the charged particles and the filter medium could enhance the filtration efficiency of the filter without increasing the pressure drop. A previous study developed a hybrid system combining ESP and air filter in a real building environment [19]. The efficiency of the filter was clearly improved due to the particle charging. However, that study did not provide

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fractional filtration efficiency and detailed parameter sensitivity analyses. Some papers investigated filtration performance of HEFS experimentally and numerically in the lab scale, but these studies only focused on the V-I characteristics, electric field and space charge distribution, air flow field and particle deposition pattern [20–23]. The most important two factors (electrostatic efficiency enhancement of filter and by-product generation) were not investigated experimentally. Some studies investigated the influence of particle charge level on the filtration efficiency of electret filters [24–26]. The particle charge level was assumed to obey the approximate Boltzmann distribution [26] or so-called natural charge distribution [24]. The measured results showed that the particle charge can enhance the filter efficiency. Moreover, the above studies focused on the influence of small particle charge (such as Boltzmann distribution) only. However, particles can carry much more charges in the intensive corona discharge electric field [22,27]. The effect of efficiency increase due to the intensive charging process may be quite different.

In this study a new type of HEFS combining an ESP and a fibrous filter in series has been developed. The system performances (such as pressure drop, filtration efficiency and ozone generation) were investigated experimentally. The efficiency enhancement of the filter in HEFS due to the particle charging in the upstream ESP was also analyzed. The influence of some system parameters (such as applied voltage, filter type and discharge polarity) on efficiency were also studied. In addition, the mathematical model was utilized to model the air filter efficiency in HEFS. The modeled and measured results agreed reasonably.

2. Experimental set-up

Fig. 1 show the experimental system used to measure the filtration efficiency. This system consisted of four parts: air flow control section, dust generation section, HEFS and the particle concentration measurement section. In the air flow control section, a dehumidifier was utilized to remove the water vapor. The mass flow controller (MFC) was used to accurately control the air flow. Its measurement range was 250 L/min and the accuracy was 1 L/min. The cross section of the duct was square with 200 mm side length, and the overall duct length was 3 m. The duct was made up of Plexiglas material. In order to ensure safety, envelop of HEFS and the material of ducts near the HEFS should be dielectric. The air flow velocity in this study was 0.1 m/s. The compressor supplied the filtered air to dehumidifier. After passing through the MFC and dehumidifier, the clean air was supplied into the duct. The dashed line box in Fig. 1 described how the air flow was forced into the channel. Before the clean air was supplied into the duct, it was divided into four parts after the MFC. The four parts entered the experimental channel from four sides of the duct. Then the air flows through a porous medium to create a uniform flow field in the upstream section of the duct [28]. The dioctylphthalate (DOP) particles were generated from a three-jet Collision nebulizer (Model CN24J, BGI Inc. USA) and injected into the testing system. The MFC (Range: 0–50 L/min, Accuracy: 0.1 L/min) and dehumidifier were also used in the aerosol generation section. For the aerosol concentration measurement, an Aerodynamic Particle Sizer (APS, Model 3302A, TSI Inc. USA) andan aerosol dilutor (Model 3302A, TSI Inc. USA) were used to measure the particle concentration upstream and downstream of the electrostatic filtration system. The fractional filtration efficiency could be determined from the particle concentration data. The high efficient air filter installed at the terminal of the testing duct was used to capture the residual particles and protect the indoor laboratory environment. Fig. 2 provides the particle size distribution in the upstream section of the duct.

Fig. 3 shows the detailed geometry of the HEFS. The corona discharge wires with 0.05 mm diameter were made of copper. The iron sheets were utilized as the collection plates. Four collection plates divided the ESP into three channels and the width of each channel was 66.7 mm. The overall length of ESP was 500 mm. There were five discharge wires in each channel. The distance between two wires was about 83.3 mm. Two types of porous medium were used in the HEFS as the fibrous filter. The main difference between

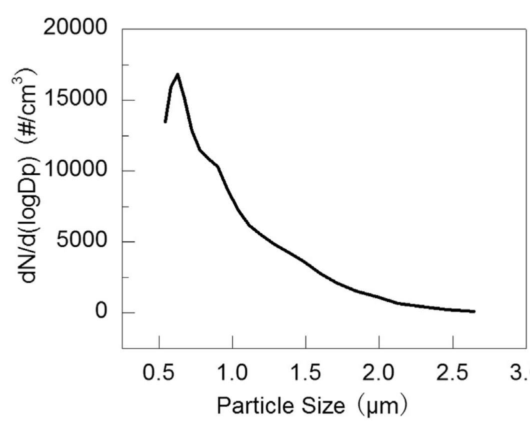

Fig. 2. The particle size distribution upstream of the filtration system.

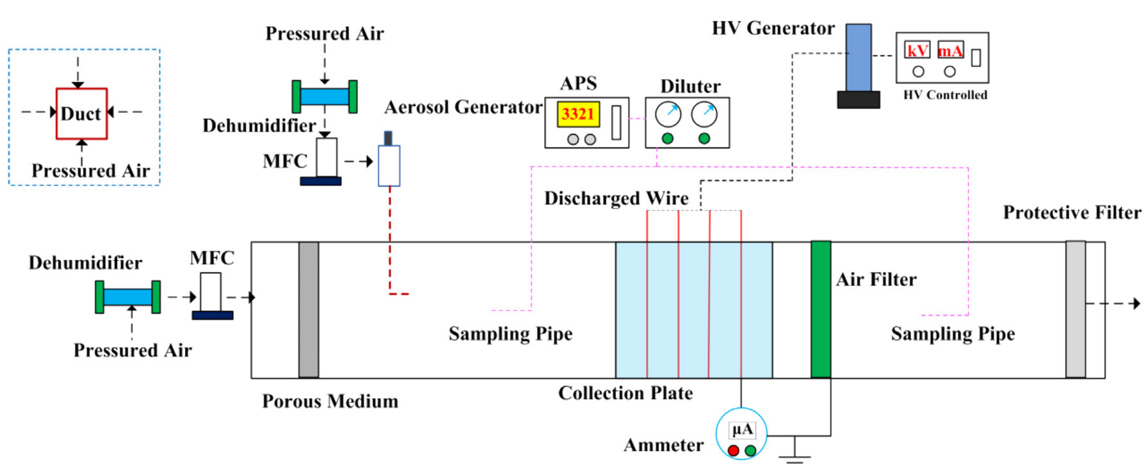

Fig. 1. The experimental configuration of the hybrid electrostatic filtration system.