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Voltage–current characteristics of needle-plate system with different media on the collection plate

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ABSTRACT

The hybrid electrostatic precipitator and media filtration system are significantly more promising than traditional filtration methods. This paper investigated the electrostatic characteristics of different filter media types used in the hybrid filtration system. The voltage–current (*V–I*) characteristics of needle-plate system, the collection plate of which is covered by filter media, were measured. Seven types of filter media and collection plate including iron plate, iron grid and activated carbon layer were considered. The glass fiber and polyethylene media reduce approximately 20% of the current value. The bag filter increases the current value because of the back corona effect. Polyester and polyethylene terephthalate materials with activated carbon attached can increase the current value significantly. In addition, this paper studied the effects of cake thickness on *V–I* characteristics. The results show that the cake layer has little influence on the *V–I* character when its thickness is not very big.

1. Introduction

Particulate matter in enclosed environments is related to the health of occupants. Exposure to particulate matter has adverse effects on human health, such as respiratory and cardiovascular diseases, asthma attacks, and cardiac arrhythmia [1]. Filtration and electrostatic precipitation are two efficient methods used to remove particulates in the air [2–4]. However, both methods have their respective defaults. Electrostatic precipitators (ESPs) cannot reach a removal efficiency of 90% for ultrafine particles with size ranging from 0.1 μm to 1 μm [5]. Problems persist even though certain types of air filters can capture submicron particles with a high-efficiency of 99%. The cake layer on the media surface can pollute fresh air and reduce the service time of the filter [6].

A possible solution is to develop a hybrid system that combines electrostatic precipitation and media filtration. The hybrid electrostatic and filter media system can take advantage of the two methods. ESP can capture coarse particles and extend the service time of the air filter. Ions generated by the corona discharge can improve the submicron particle removal efficiency of the air filter. The relatively thin cake layer on the filter media would not pollute fresh air significantly. Many researchers have proposed some types of the hybrid system and investigated their performances. A hybrid air filtration system was designed with carbon fiber ionizer upstream of the glass fiber air filter. Ions generated by the ionizer can improve the ultrafine particle removal efficiency of the air filter by 25% [7]. A new filtration equipment was developed, which consists of a negative ion emitter and the high-efficiency particulate air (HEPA) installed in the heating, ventilation, and air conditioning (HVAC) system. The system was tested by virus-carrying liquid droplets with a diameter below 3 μm. The ion emitter can enhance air filter efficiency from 10% to 40% [8]. Several other papers have studied similar filtration systems combining ESP and air filter [9,10]. The ESP and hybrid electrostatic filtration systems are also investigated by numerical methods [11–15]. Although these studies have been done, the fundamental research is still very lack. The filter media in the hybrid system will be charged due to the electric field. The filter media can be several types, such as glass fiber, the polyethylene, the bag filter, the polyester and polyethylene terephthalate materials, and the activated carbon media. The collection plates in the hybrid system also include some types, such as the iron plate, iron grid and the activated carbon layer. The charge characteristics of the filter media in the hybrid filtration have significant influence on the filter performance. The higher current through the filter media can improve the particle removal efficiency. However, the back corona phenomenon would occur in air channels in the filter media if the current is too high due to the high volume resistivity and porosity [16–22]. Thus, it is necessary to evaluate the charge characteristics of different filter types.

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In this paper, an experimental system was designed to investigate the charge characteristics of different filter media types used in the hybrid filtration system. The filter medias include the glass fiber, the polyethylene (PP), one type of bag filter media, the polyester (PE), the polyethylene terephthalate (PET), the non-woven media and the refined cotton media. Some types of collection plate were also considered, including the iron plate, the iron grid and the activated carbon media. Finally, the influences of the cake layer on the surface the filter media on the charge characteristics were studied.

2. Experimental setup and materials

Fig. 1 shows the experimental test rig for measuring the voltage–current (V–I) characteristics of the needle-plate system, which has compact structure but accurate for electrostatic study. The needle-to-plate system consists of a high-voltage equipment, discharge electrode, collection plate, insulation tank, and ammeter. The high-voltage equipment includes a control box, a high-voltage generator (DC) with negative polarity, and a grounding system. The polarity of the point electrode is negative and the high-voltage range is from 0 kV to 50 kV. The accuracy of the ammeter is 0.1 μA. The discharge electrode is composed of stainless steel wire and the radius of the needle electrode is 0.5 mm. The length of the discharge electrode is 224 mm, and the distance between the discharge peak and the surface of collection plate is 70 mm. The insulation cuboid vessel provides discharge space and the laboratory air has no access to the enclosed space. The cross-section of the cuboid vessel is square with 200 mm side length and the cuboid height is 245 mm. The laboratory environment is controlled by the HVAC system, with air temperature of 22 °C and relative humidity of 45%. The insulation tank is made of the Plexiglas material. It can be charged in the experiments. But the measured V–I characteristics of the system with and without the insulation vessel have no obvious differences, as the charge of the insulation tank is very small. Besides, the practical collector is placed in the insulation duct in the HVAC system.

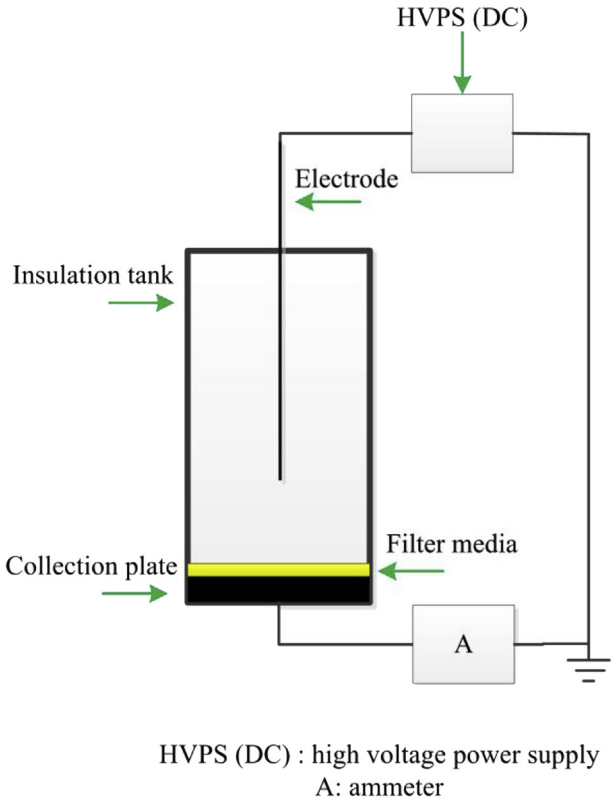

Fig. 1. Experimental system setup for the V–I characteristics.

The collection plate in the needle-plate system is covered by different filter media types to investigate the electrostatic characteristics of the filter media. The activated carbon layer, iron grid and iron plate are utilized as collection plates. Detailed information on the collection plates and filter media are presented in Table 1. All experimental cases are based on the structure of a practical air filter, the filter media, activated carbon later and iron grid are widely used in air filtration system. The filter media can capture particulate matter and the activated carbon layer removes the gaseous pollutant. The hybrid filter media combing activated carbon layer and common filter media layer has the dual effects. The air filter with iron grid fixed on the media surface would increase structural strength and avoid serious deformation. The collection plate in Cases 1 and 2 is iron plate or iron grid without filter media. Activated carbon media is used as the collection plate in Case 2. This investigation had tested six types of activated carbon media, including activated carbon fiber media, activated carbon spongy media, activated carbon photo catalyst media, cold catalyst media, and hybrid activated carbon media. The structure of the activated carbon layer is non-woven. In other cases described in Table 1, the filter media is placed on the collection plate. The activated carbon media used in Cases 4–10 is non-woven activated carbon fiber media with a thickness of 5 mm. The iron grid used in this study is composed of an iron wire, with a radius of 0.5 mm, and the distance between the two iron wires is 10 mm.

This research also investigates the effects of cake thickness on the electrostatic characteristics of the system. The V–I characteristics of the needle-plate system with cake layer on the collection plate is measured. The insulation cylindrical vessel is composed of Plexiglas (245 mm-high and 200 mm in diameter). The collection plate on the bottom of the insulated vessel is made of iron, with radius of 100 mm and thickness of 3 mm. The distance between the discharge peak and iron plate is 70 mm. The cake thickness includes 0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm, and 1 mm. Fig. 2 describes the process of changing the cake layer thickness on the dust collection plate. Thickness accuracy is controlled by the fine finishing. The total cake porosity of all the cases is 0.6. The cake zone is divided equally into six subzones, with each subzone filled up with 1/6 of the total cake weight to ensure a relatively uniform porosity distribution. The dust cake is composed of fly ash, with the grain diameter following the Rosin–Rammeler distribution, and the dust density is 2460 kg/m^3.

3. Results

3.1. The volume resistivity of different filter types

The volume resistivity values of all types of filter media material are summarized in Table 2. The resistivity of glass fiber/PP/bag/PE/

Table 1
Experimental cases.

Case no.	Filter media type	Collection plate
1	None	Iron plate
2	None	Iron grid/activated carbon media
3	Glass fiber	Iron plate/Iron grid/activated
4	PP (polyethylene)	carbon media
5	Bag filter media	
6	PE (polyester)	
7	PET (polyethylene terephthalate)	
8	Non-woven media	
9	Refined cotton media	