



Technical Note

Comparison of Discharging Electrodes for the Electrostatic Precipitator as an Air Filtration System in Air Handling Units

Dong Ho Shin, Chang Gyu Woo, Hak-Joon Kim, Yong-Jin Kim, Bangwoo Han*

Department of Environmental Machinery, Korea Institute of Machinery and Materials, Daejeon 34104, Korea

ABSTRACT

The quality of indoor air is of increasing concern because it is closely related to human health. An air handling unit (AHU) can be used to control the quality of indoor air with respect to particulate matter and CO₂, as well as providing air conditioning by regulating the temperature and the humidity. Electrostatic precipitators have high collection efficiencies and low pressure drops. However, their chargers can generate ozone, which is a drawback of applying them to indoor air control. In this study, we compared four discharging electrodes: a 50- μm tungsten wire, a 100- μm tungsten wire, 16- μm aluminum (Al) foil, and carbon fabric composed of 5–10- μm fibers. The carbon-fabric electrode exhibited superior particle collection efficiency and lower ozone generation for a given power consumption compared to the 50- and 100- μm tungsten wires, or the Al foil electrode. This low-ozone-generating, micro-sized electrode can be applied as an electrostatic precipitator in AHUs for indoor air control.

Keywords: Air handling unit; Carbon fabric; Discharge electrode; Ozone.

INTRODUCTION

The importance of indoor air quality and the level of public interest in the effects of fine particles on health are both increasing. Ozone is one of the substances found in indoor air that poses a threat to human health because it has adverse effects on the entire respiratory system. Ozone is relatively stable and is generated mainly outdoors by sunlight. However, it can be generated inside by printers or photocopiers (Boelter and Davidson, 1997; Weschler, 2000).

Air handling units (AHUs) are typically used to improve the quality of indoor air via their filtering action. Electrostatic precipitators are used for industrial AHU filters. These have a relatively low pressure drop and are more efficient. However, they are not widely used because they can generate indoor ozone. Ozone filters can be used to collect the ozone generated by electrostatic precipitators, but these

incur additional costs and require management. Carbon nanotubes (Bo *et al.*, 2010) and graphene (Bo *et al.*, 2011) have been used as discharge electrodes with lower ozone emissions, but there are difficulties associated with the use of such materials. Grob *et al.* (2013) developed a charging device based on ultraviolet (UV) light that generates very low amounts of ozone. However, UV generation consumes a large amount of energy. Hyun *et al.* (2017) reported a reduction in the amount of ozone generated by using discharge electrodes coated with silver, but the addition of this coating necessitates an additional step in the device fabrication process.

In this study, a new charging device consisting of a sheet of carbon fiber with a diameter of 5–10 μm was fabricated. Carbon-fiber electrodes can generate large numbers of ions at either the cathode or the anode while emitting minimal levels of secondary pollutants, such as ozone (Han *et al.*, 2009; Park *et al.*, 2011). The particle-collecting performance and ozone emission of our charging device made of carbon fabric were compared to those of a conventional discharge electrode with 50- or 100- μm tungsten wire, and aluminum (Al) foil. A collector at the rear end was used to evaluate the collection performance of the carbon-fabric discharge electrode. This study can probably contribute to a highly efficient improvement in indoor air quality by reducing the operating costs of AHUs with a low pressure drop, which is a key advantage of electrostatic precipitators (Han *et al.*, 2012; Koo *et al.*, 2013; Kang *et al.*, 2016).

*Corresponding author.

Tel.: 82-42-868-7608; Fax: 82-42-868-7284

E-mail address: bhan@kimm.re.kr

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EXPERIMENTAL SETUP AND METHODS

Fig. 1 shows optical images of the four discharge electrodes investigated in this study. Tungsten wires were prepared with diameters of 100 μm and 50 μm from 99.95% tungsten (AVENTION, Korea). The carbon-fabric electrodes were prepared M34-21 carbon sheet (1322P), which uses plain-woven 3K yarn with a density of 14 count inch^{-1} , purchased from Mirae Sinsojae (Korea). Aluminum foil with a thickness of 16 μm was purchased from Daehan Aluminum (Korea) and cut into 15 \times 30-mm rectangles.

As shown in Fig. 2, the four prepared discharge electrodes were positioned at the center between two stainless-steel (SS) ground plates. A negative voltage of several kV was applied between the discharge electrode and the ground plates to provide unipolar charging. The outer case of the charging device was made of nonconductive polyvinyl chloride (PVC).

The collector comprised seven SS plates, as shown in Fig. 3. A high voltage was applied across three of these plates while the others were grounded, which generated an electric field so that particles collected inside the collecting device. The spacing between the plates was 3.2 mm, and the collector was designed so that most of the singly charged 0.3- μm -diameter particles that passed through it at -5 kV could be collected.

Fig. 3 shows the duct system used to evaluate the performance of the chargers in this study. Potassium chloride (KCl) particles were generated by injecting 1% KCl solution into an atomizer (Model 3076 Constant Output Atomizer; TSI, USA) to produce test particles 0.3 μm in diameter that were then supplied to the upstream side of the 32 \times 32-mm test duct. The particles then mixed with test air introduced by a blower located downstream of the test duct.

The number concentration of 0.28–0.3- μm particles was maintained within $1 \times 10^3 \text{ cm}^{-3}$ upstream of the duct. To minimize the inflow of contaminating particles, a high-efficiency particulate air (HEPA) filter was installed upstream of the test duct. The charged particles generated by the particle generator were neutralized with a ^{85}Kr neutralizer (Model 3012 Aerosol Neutralizer; TSI). The airflow rate was set to 12 L min^{-1} (face velocity: 0.3 m s^{-1}) for

comparisons of the particle collection efficiency. The 0.3- μm -particle collection performance and ozone concentration were measured at different applied voltages, from -4 to -9 kV, and a fixed voltage of -5 kV was applied to the collector. The particle number concentration and ozone concentration were measured using a dust spectrometer (Portable Aerosol Spectrometer 1.109; Grimm Aerosol Technik Airring GmbH & Co. KG, Germany) and ozone meter (Model 202 Ozone Monitor; 2B Technologies, USA), respectively. Particle sampling was conducted at a location downstream of the collector. The particle-collection efficiency was calculated using the equation:

$$\eta = \left(1 - \frac{n_1}{n_0} \right) \times 100 \quad (1)$$

where

η = particle collection efficiency (%),

n_0 = number concentration when the charging device is off and the collector is on (cm^{-3}), and

n_1 = number concentration when the charging device is on and the collector is on (cm^{-3}).

RESULTS AND DISCUSSION

Fig. 4 shows the change in current according to the voltage applied over the charging device. The current was measured by connecting the discharge to the ammeter and the ground plate in series. Higher currents were measured at the same applied voltage in the order of the carbon fabric, 50- μm tungsten wire, 100- μm tungsten wire, and Al foil. The currents increased when the size of the discharge electrode decreased in the cases of the carbon fabric, 50- μm tungsten wire, and 100- μm tungsten wire, but the discharge electrode of the Al foil was smaller than the tungsten-wire electrodes used in this experiment, and this device had the highest onset voltage, of -8 kV. The thickness of the Al foil was 16 μm . However, the ductility of the Al foil electrode caused it to have a rough surface during the preparation steps.

Fig. 5 shows the collection efficiency with respect to the voltage applied over the discharge electrode. The discharge

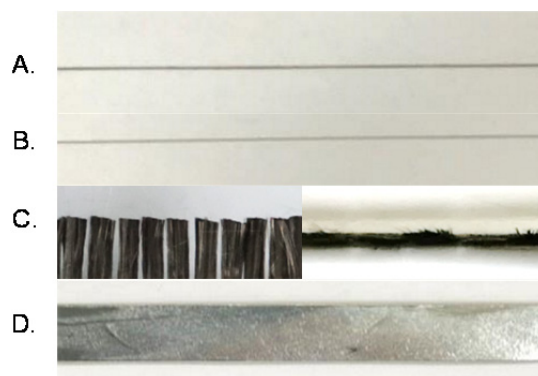


Fig. 1. Picture of the charging element used in this study. A: tungsten wire 100 μm in diameter, B: tungsten wire 50 μm in diameter, C: carbon fabric (thickness: 5–10 μm), D: aluminum foil (thickness: 16 μm).

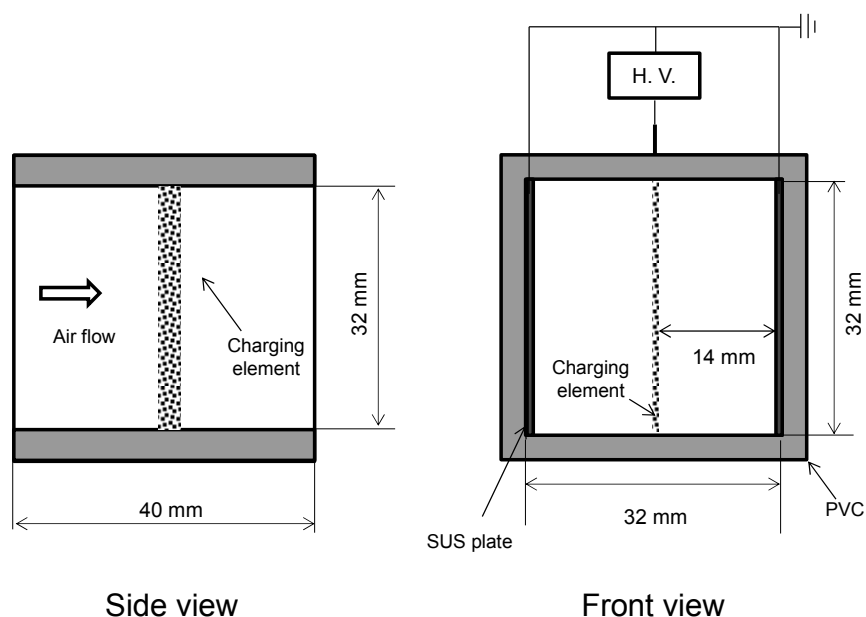


Fig. 2. Schematic of the charger used in this study.

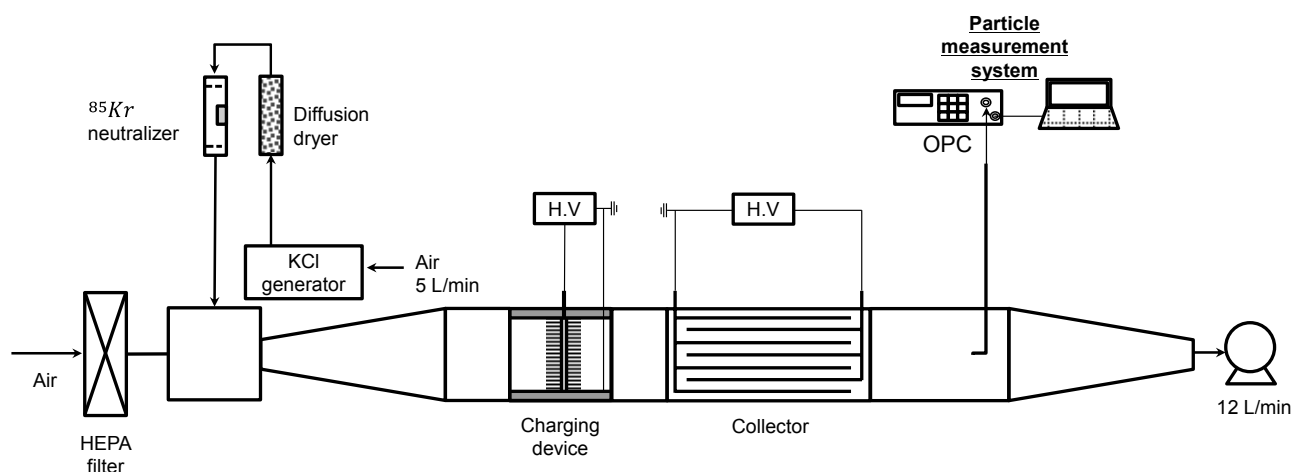


Fig. 3. Schematic of the experimental setup for the measurement of particle collection efficiency.

current increased with the applied voltage because higher discharge currents arise when more ions are generated at the discharge electrode. This increases both the probability of charging the particles and the collection efficiency of the collector. Figs. 4–5 show that higher collection efficiency can be reached by using a discharging electrode with a higher discharging current at the same voltage. Comparing the two tungsten wire-discharge electrodes, which were made from the same material but had different diameters, the collection efficiency of the smaller tungsten wire electrode (diameter of 50 μm) was higher at the same applied voltage. The carbon-fabric discharge electrodes had markedly higher collection efficiencies than the 50- μm tungsten wire electrode because of their smaller diameter.

Fig. 6 shows the collection efficiency as a function of power consumption. The highest particle-collection efficiency at a given power consumption was obtained using the carbon-

fabric discharge electrode. In the case of the tungsten wire, the 50- μm tungsten wire had a higher particle collection efficiency than the 100- μm tungsten wire for the same power consumption. Although the Al foil electrode was smaller than the wires, with the same voltage and power consumption, its collection efficiency was lower because of its higher onset voltage.

Fig. 7 shows the changes in ozone concentration as a function of power consumption for each discharge electrode. Ozone measurement was performed 200 mm downstream of the charging device with an airflow of 7 L min^{-1} without using a collector. When the power consumption was held constant to within 0.5 W, the carbon-fabric discharge electrode generated several to several dozen ozone parts per billion, which was significantly less (10 times lower) than the other discharge electrodes, which generated several hundred ozone parts per billion. These results show that

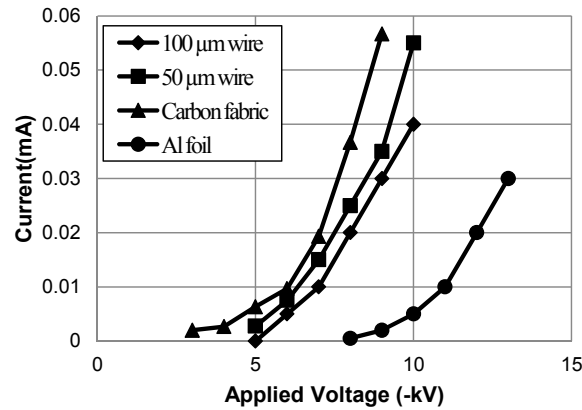


Fig. 4. Changes in current with respect to the voltage applied to the ionizers by changing the charger materials.

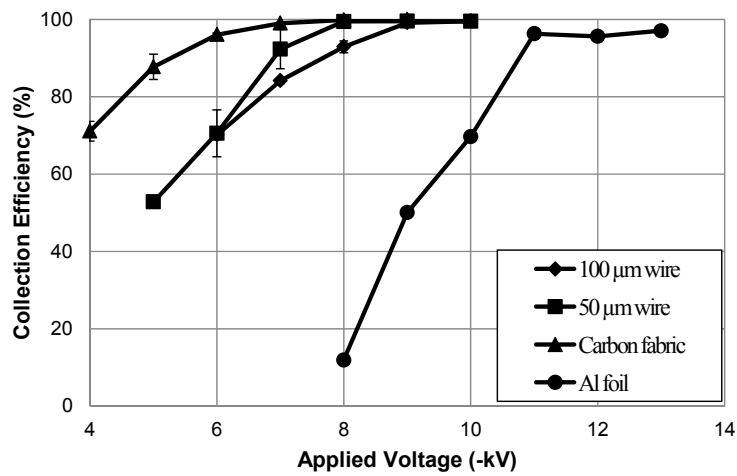


Fig. 5. Collection efficiency as a function of the voltage applied to the ionizers for different charger materials.

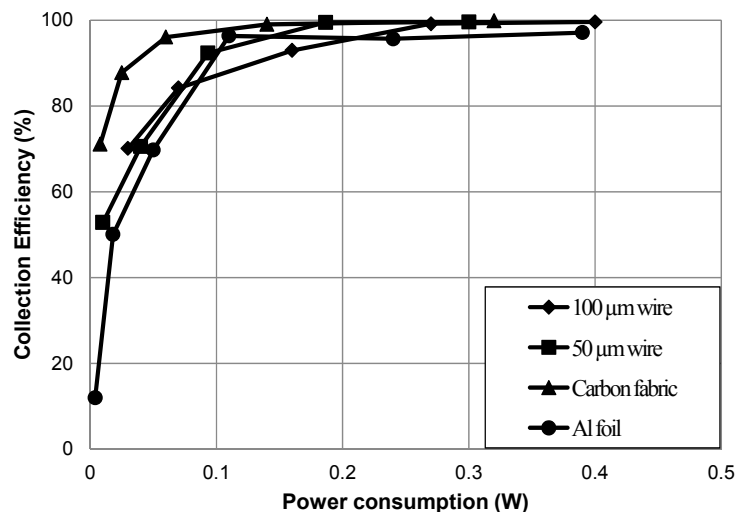


Fig. 6. Collection efficiency as a function of the power consumption of ionizers composed of different charger materials.

the carbon-fabric charging device developed was superior to the other charging devices tested in terms of both power consumption and ozone generation.

However, due its small diameter of several microns, the durability of the charging device and whether particles

become attached to the carbon fabric after prolonged use need to be considered. Additionally, the effect of humidity on particle-collection performance should also be considered in future studies, prior to applying our results to AHU collecting equipment.

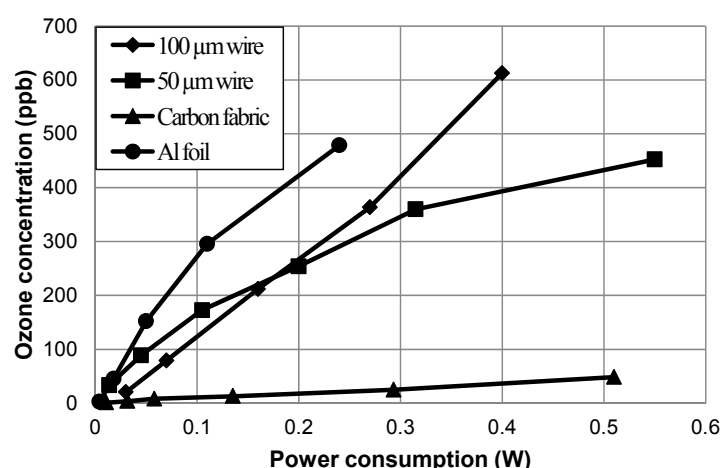


Fig. 7. Ozone concentration as a function of power consumption for each discharge electrode.

CONCLUSION

In this study, the collection performance and amount of generated ozone were evaluated for different types of discharge electrodes in a charging device while varying the applied voltage. The conclusions are as follows:

- (1) At the same voltage, the discharge current and collection efficiency of the 50- μm tungsten wire were higher than those of the 100- μm tungsten wire. However, carbon fabric with a smaller discharge electrode was more effective than the tungsten wire, which is usually used in electrostatic AHU precipitators, in either size.
- (2) For the same power consumption, the carbon-fabric discharge electrode generated less ozone than the other electrodes.
- (3) Considering power consumption, particle collection performance, and ozone generation, the carbon-fabric discharge electrode was superior to the 50- and 100- μm tungsten wire discharge electrodes usually used in conventional electrostatic precipitators.

Based on our results, to improve the indoor air quality while maintaining a low pressure drop, carbon-fabric discharge electrodes should be considered for use as the electrostatic precipitator in AHU filtration systems instead of the conventional fiber filters, which require periodic cleaning and replacement. The use of several micro-sized carbon-fabric discharge electrodes yields excellent particle-collection performance with low power consumption and little ozone generation.

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