Nanoparticle Collection Using Electrostatic Precipitator with Spike Corona Electrodes

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***Abstract*—Aerosol particles are considered as a source of risk for diseases, such as respiratory and cardiac related diseases. Reducing aerosol particles to improve air quality has thus gained considerable attention. Electrostatic precipitator is one of the devices that are used to collect aerosol particles. A two-stage electrostatic precipitator usually consists of at least a charger and a collector. The charger charges incoming particles by the effect of corona discharging. When charged particles enter the collector, the induced electrostatic forces alter the trajectories of those charged particles, making those charged particle settle down on the collecting electrode. A conventional charger is usually composed of wire corona electrodes and plate exciting electrodes, and has insufficient corona discharging efficiency, making the collection efficiency of the electrostatic precipitators low for nanoparticles. This paper presents alternative corona electrodes that better charge nanoparticles and improve the collection efficiency of the electro-static precipitators. The results show that replacing conventional wire corona electrodes with spike corona electrodes in the charger ends up with a higher corona current at the same corona voltage, making the collection efficiency higher. The collection efficiency of the electrostatic precipitators using spike corona electrodes is up to 18% higher than those using wire corona electrodes at a specific condition. This paper also examines two parameters of interest: the number and the tip curvature of the spike corona electrodes. The results show that the corona current and the collection efficiency gets higher with the increasing number of the spike corona electrodes. When the tip curvature of the spike increases, the collection efficiency also increases.**

I. Introduction

Filtering aerosol particles has raised serious concerns because aerosol particles are considered as a source of risk for diseases such as ischemic stroke and cardiovascular diseases, causing millions of deaths [1, 2].

Electrostatic precipitators (ESPs) are air filters that have advantages such as the absence of plugging, low pressure drop, low operation cost, and the capability of treating large amount of gas [3-5]. Thus, ESPs are widely used, from power plants to offices, to reduce the concentration of aerosol particles, playing an important role in maintaining air quality [3, 4, 6].

ESPs can be classified into two configurations, single-stage and two-stage. Single-stage ESPs charge and collect particles at the same time in the same region. Two-stage ESPs charge and collect particles in separate regions, as shown in Fig. 1. For a two-stage ESP, particles are charged when passing by the charger where has a high-voltage corona electrode and a grounded exciting electrode. Because of the induced electrostatic forces, those charged particles are then settled down on the collecting electrode in the collector where has a strong electric field between the repelling electrode and collecting electrode. The electric field strength in the collector of a two-stage ESP can be much stronger (in an average sense) and uniform than that in a single-stage ESP, making the collection efficiency of two-stage ESPs high and stable.

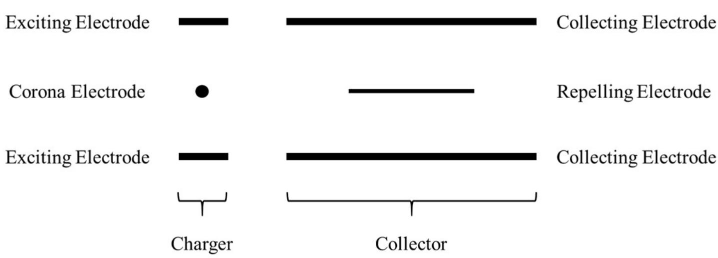

Fig. 1. Schematic of a two-stage ESP

In the charger of a two-stage ESP, particles are charged because of the effects of corona discharging occurring around the corona electrode [7]. The region that mainly produces ions and charges are called ionization region that is actually a region with strong electric field strength around the corona electrode [8]. Thus, larger ionization region implies higher ion/charge production rate. According to the Kaptsov's assumption [9], the electric field strength at the boundary of the ionization region should equal the breakdown electric field strength of the fluid, which is air in this case. Therefore, of those factors that affect the collection efficiency, the volume of the ionization region certainly determines how well particles get charged and thus the collection efficiency.

This paper demonstrates how spike corona electrodes helps two-stage ESPs improve the collection efficiency. Instead of the conventional corona wire used in the charger, the spikes corona electrodes are placed in a row, normal to the direction of the air flow. The tip curvature of the spike is higher than that of the wire, resulting in a stronger electric field around the spike tip and making particles charged better. Consequently, using spike corona electrodes improves the collection efficiency of ESPs.

II. EXPERIMENTAL SETUP

Fig. 2 shows the experimental setup. The setup includes a rotary fan, a lab-scale ESP under test, two high-voltage power suppliers, and a particle counter. Air flow is drawn into the ESP under test using a rotary fan at the flow rate of 28 x 10^{-6} m^3/s (1.68 LPM). A particle counter (MSP-1000XP) is placed right after the ESP to measure particle concentration in the air. A high voltage power supply (YSTC-HVPS) provides high voltage to the corona electrodes (spikes or wire), and a separate power supply (YSTC-HVPS) provides high voltage to the repelling electrode (plate). The exciting electrode (plate) and the collecting electrode (plate) are grounded. All the plate electrodes are made of aluminum. The operating conditions are summarized in Table 1.

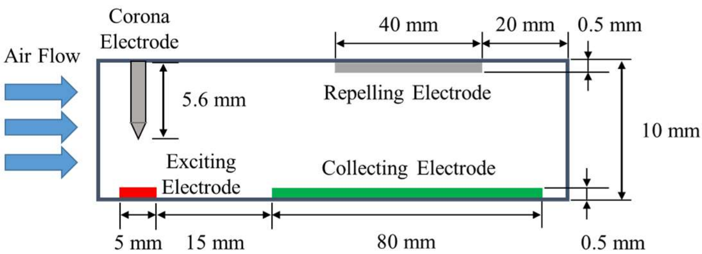

Fig. 2. Physical dimensions of the ESP under test (side view). The width (out-of-plane) of the ESP under test is 77 mm. Not drawn to scale.

Table 1: Operating conditions of the experiments.

Parameter	Value
Air flow rate	28 x 10^{-6} m^3/s (1.68 LPM)
Corona Voltage	6800 V
Repelling Voltage	12000 V

This paper also examines spike corona electrodes by different tip curvatures and numbers of spike corona electrodes, as listed in Table 2. Spike A, Spike B, and Spike C represents different tip curvatures of the spike corona electrodes. Fig. 3 shows the configurations of different numbers of spike corona electrodes. Note that the spike corona electrodes are placed perpendicular to the exciting electrode, while the wire electrode, as shown in Fig. 3(D), is placed parallel to the exciting electrode. The distance from the tip of the spike to the exciting electrode is 3.9 mm, exactly the same as that from the wire corona electrode to the exciting electrode. The diameter of the wire corona electrode is 0.1 mm.

Table 2: Parameters of spike corona electrodes.

Name	Tip curvature	Number of spike corona electrodes
Spike A	33 (1/mm)	4/8/12
Spike B	50 (1/mm)	4/8/12
Spike C	67 (1/mm)	4/8/12

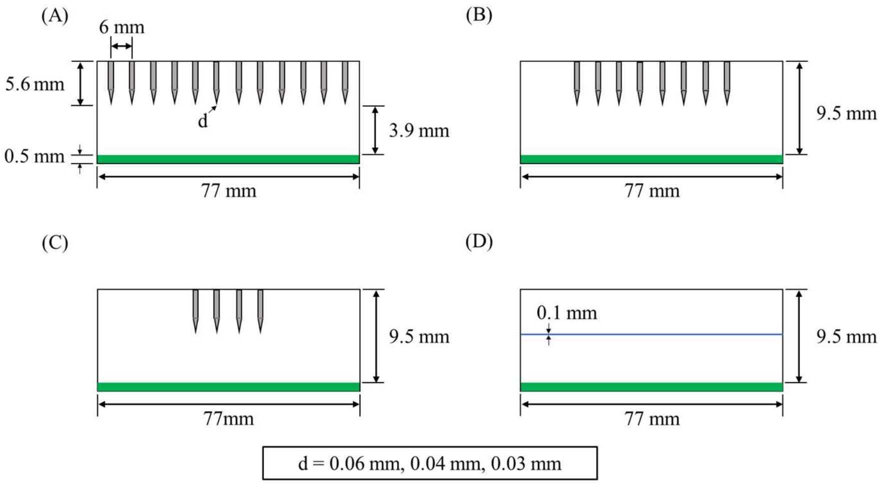

Fig. 3. Configurations of different numbers of the spike corona electrodes. (A) 12 spike electrodes (B) 8 spike electrodes (C) 4 spike electrodes (D) wire. Not drawn to scale.

III. Results and Discussions

A. Current-voltage characteristics

Fig. 4, Fig. 5, and Fig. 6 show the characteristic curves of the ESPs with Spike A, Spike B, and Spike C, respectively. Every data point represents the average of three consecutive measurements, while the error bar indicates the standard deviation. The onset corona voltages and the sparkover voltages are collected and summarized in Table 3.

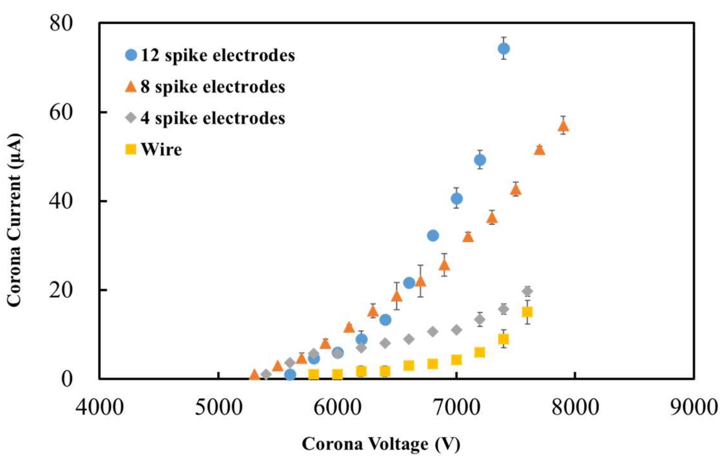

Fig. 4. The current-voltage characteristics of Spike A.

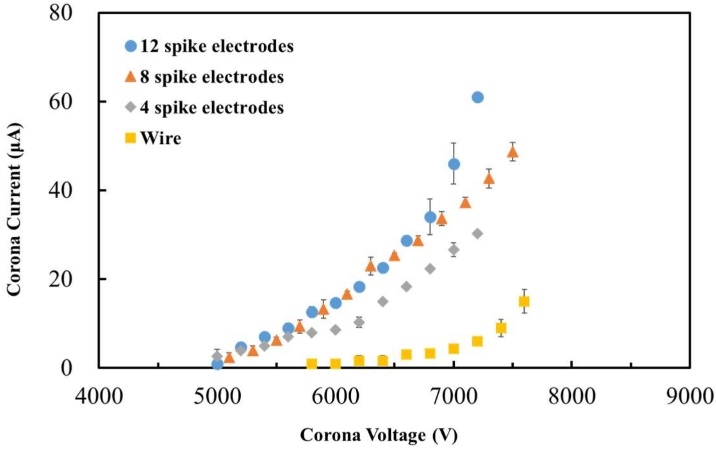

Fig. 5. The current-voltage characteristics of Spike B.

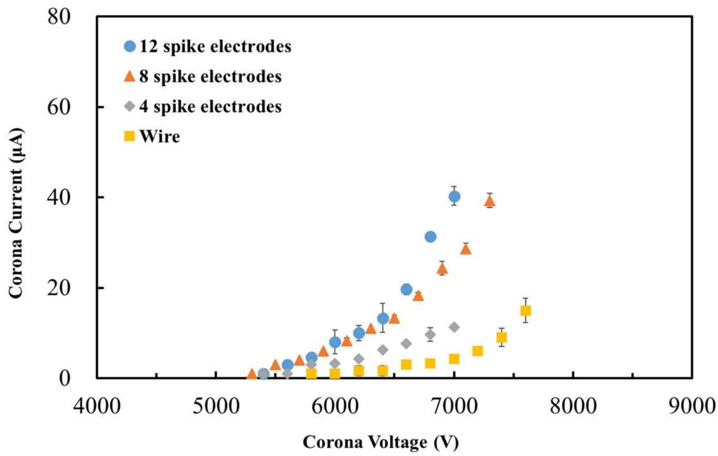

Fig. 6. The current-voltage characteristics of Spike C.

Table 3: The onset corona voltages and the sparkover voltages of the ESPs under test. The naming rule of "Spike-X-Y": X indicates the tip curvature shown in Table 2 and Y indicates the number of the spike corona electrodes.

Corona electrode	Onset corona voltage	Sparkover voltage
Spike A-12	4400 V	7400 V
Spike A-8	5100 V	7900 V
Spike A-4	5400 V	7600 V
Spike B-12	5000 V	7200 V
Spike B-8	5100 V	7500 V
Spike B-4	5000 V	7200 V
Spike C-12	5400 V	7400 V
Spike C-8	5300 V	7300 V
Spike C-4	5400 V	7000 V
Wire	5800 V	7600 V

It makes sense that the sparkover voltage of Spike A is higher than those of Spike B and Spike C because the tip curvature of Spike A is small (blunt). However, the onset corona voltage and the corona current of Spike A is not significantly different from those of Spike B and Spike C at the same corona voltage. This is probably due to the insensitivity of the measuring instrument. The results also show that the corona current gets higher with increasing number of the spike corona electrodes. The wire corona electrode has relatively low corona current and relatively high onset corona voltage because of relatively low curvature when compared with the spike corona electrodes. Besides, it is obvious that the corona current increases with the corona voltage.

B. Collection efficiency

Fig. 7, Fig. 8, and Fig. 9 show the collection efficiencies in terms of particle diameters with the corona voltage of 6.8 kV and the repelling voltage of 12 kV. Every data point represents the average of four consecutive measurements. Note that these voltages are for comparison purpose only and are not optimal for collection efficiency.

Talking about Spike A shown in Fig. 7, the collection efficiency of Spike A-4 is worse than that of wire corona electrode because the number of the spike corona electrodes is not enough to charge most of the incoming particles. One can see that the collection efficiency of Spike A-8 is higher than that of wire corona electrode when the particle diameter is larger than 75 nm. Thus, generally speaking, the collection efficiency increases with the number of spike corona electrodes. Looking at Spike B and Spike C shown in Fig. 8 and Fig. 9, respectively, the collection efficiencies of using spike corona electrodes are higher than those of using wire corona electrode, no matter what the number and the tip curvature of the spike corona electrodes are. This is because the spike corona electrode is sharp enough to create larger ionization volumes when compared with blunt spikes. The average collection efficiencies of the ESPs using Spike A-12, Spike B-12, and Spike C-12 are about 10%, 15%, and 18% higher than those of using wire corona electrode.

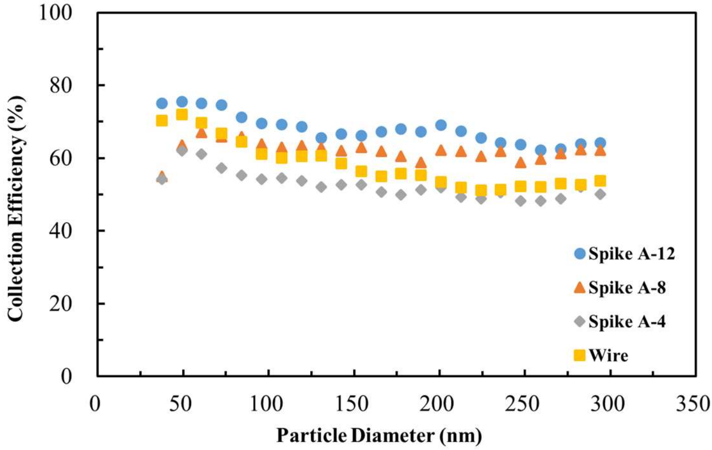

Fig. 7. Collection efficiency of Spike A and wire corona electrode. The standard deviation ranges from 1.5 to 12.5.

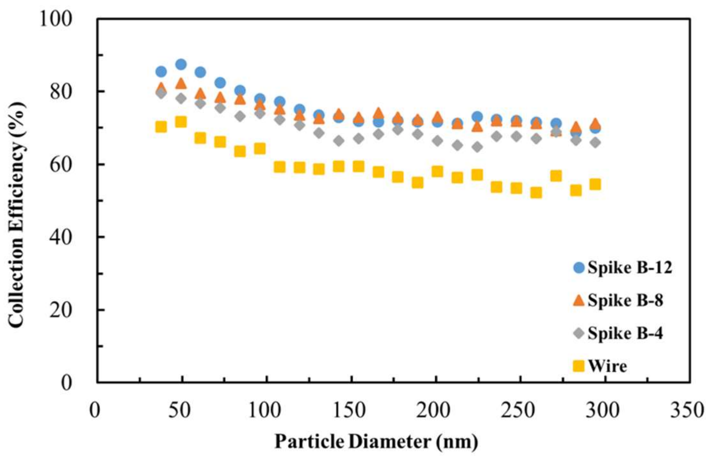

Fig. 8. Collection efficiency of Spike B and wire corona electrode. The standard deviation ranges from 1.8 to 12.2.

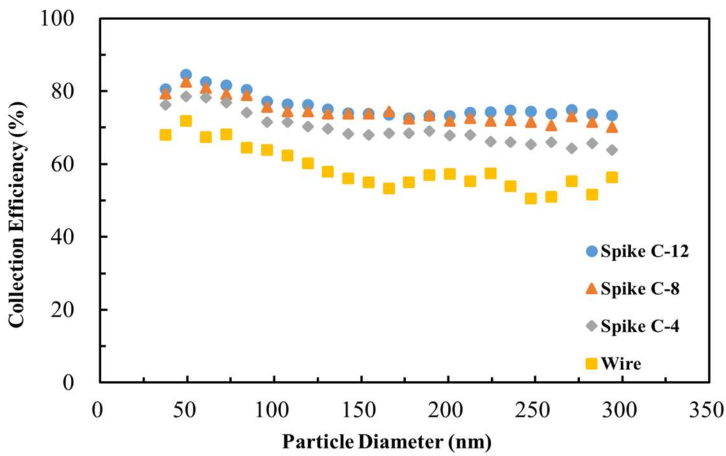

Fig. 9. Collection efficiency of Spike C and wire corona electrode. The standard deviation ranges from 1.2 to 8.4.

IV. Conclusions

This paper demonstrates the results of current–voltage characteristics and the collection efficiencies of the ESPs using spike corona electrodes and wire corona electrode. This paper also carries the parametric study out for the spike corona electrodes including the tip curvature and the number. The collection efficiency increases with the number of the spike corona electrodes because of the increasing the ionization region. The results also show that the collection efficiency has a dependence upon the tip curvature of the spike corona electrodes. The higher the tip curvature, the higher the collection efficiency.

References

[1] World Health Organization, "Health aspects of air pollution with particulate matter, ozone and nitrogen dioxide: report on a WHO working group, Bonn, Germany 13-15 January 2003," 2003.

[2] G. Oberdörster, E. Oberdörster, and J. Oberdörster, "Nanotoxicology: An emerging discipline evolving from studies of ultrafine particles," *Environmental Health Perspectives*, Review vol. 113, no. 7, pp. 823-839, 2005.

[3] Mizuno, "Electrostatic precipitation," *IEEE Transactions on Dielectrics and Electrical Insulation*, Article vol. 7, no. 5, pp. 615-624, 2000.

[4] J. S. Chang, "Next generation integrated electrostatic gas cleaning systems," *Journal of Electrostatics*, Article vol. 57, no. 3-4, pp. 273-291, 2003.

[5] X. Xu et al., "Effect of electrode configuration on particle collection in a high-temperature electrostatic precipitator," *Separation and Purification Technology*, vol. 166, pp. 157-163, 2016.

[6] H. Nouri, N. Zouzou, L. Dascalescu, and Y. Zebboudj, "Investigation of relative humidity effect on the particles velocity and collection efficiency of laboratory scale electrostatic precipitator," *Process Safety and Environmental Protection*, vol. 104, Part A, pp. 225-232, 2016.

[7] T.Y. Wen, I. Krichtafovitch, and A. V. Mamishev, "Reduction of aerosol particulates through the use of an electrostatic precipitator with guidance-plate-covered collecting electrodes," *Journal of Aerosol Science*, vol. 79, pp. 40-47, 2015.

[8] N. E. Jewell-Larsen, S. V. Karpov, I. A. Krichtafovitch, V. Jayanty, C.-P. Hsu, and A. V. Mamishev, "Modeling of corona-induced electrohydrodynamic flow with COMSOL multiphysics," in *Proc. ESA Annual Meeting on Electrostatics, 2008*

[9] N. Kaptsov, "Elektricheskie yavleniya v gazakh i vakuume," Moscow, OGIZ, 1947.