Enhanced particle removal by electrosprayed charged droplets in a scrubber

Joon-Yub Kim[1], Myong-Hwa Lee[1,2*]

[1]Department of Integrated Particulate Matter Management, Kangwon National University

[2]Department of Chemical, Environmental and Materials Engineering, University of Miami

*Corresponding author e-mail: myonghwa@kangwon.ac.kr

Introduction

- Wet scrubbing system is widely used to remove both particulate matter and gaseous pollutants. However, its particle removal efficiency is not sufficient to meet the stricter national regulations.
- Introduction of an electrospray system can be a good alternative to improve the collection performance of a wet scrubber, because it helps to capture the fine particles more effectively by electrostatic attraction.
- In this study, the electrospray of a tap water solution was conducted, and the characteristics and size distribution of the charged droplets were analyzed based on electric field orientation, water flow rates, and conductivity. Particle removal efficiency was also measured to investigate the effects of the charged droplets.

Experimental method

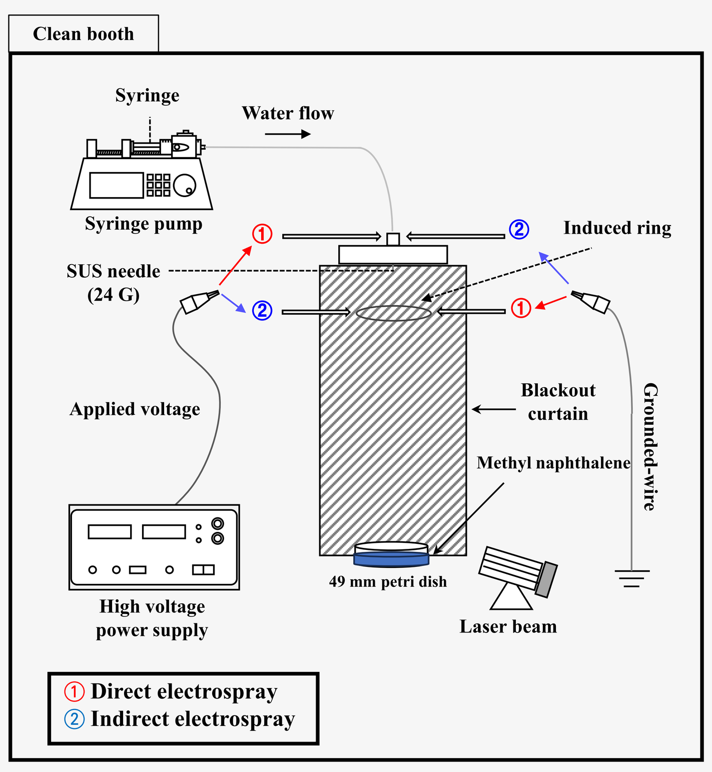


Fig. 1 Illustration of an electrospray system

Characterization of electrospraying

- To characterize electrosprayed droplets, a tap water solution was supplied at 3–5 mL/min using a syringe pump, and visualized with a laser with a wavelength of 532 nm.
- A high voltage (+20 kV) was applied either to the nozzle or to the induced ring, depending on the electrospraying method. When the high voltage was applied to the nozzle, the induced ring was grounded. We define this with "direct electrospray". Conversely, when the high voltage was applied to the induced ring, the nozzle was grounded. We define this with "indirect electrospray".
- Droplet size distribution was measured by collecting droplets on a 49 mm Petri dish, which was placed 30 cm from the SUS needle and filled with a methyl naphthalene solution.
- Droplets were collected for 6 seconds after the start of spraying and analyzed with a microscope(SV-35, Sometech). The droplet size was then measured using a ImageJ software.

Particle removal experiment in a wet scrubber

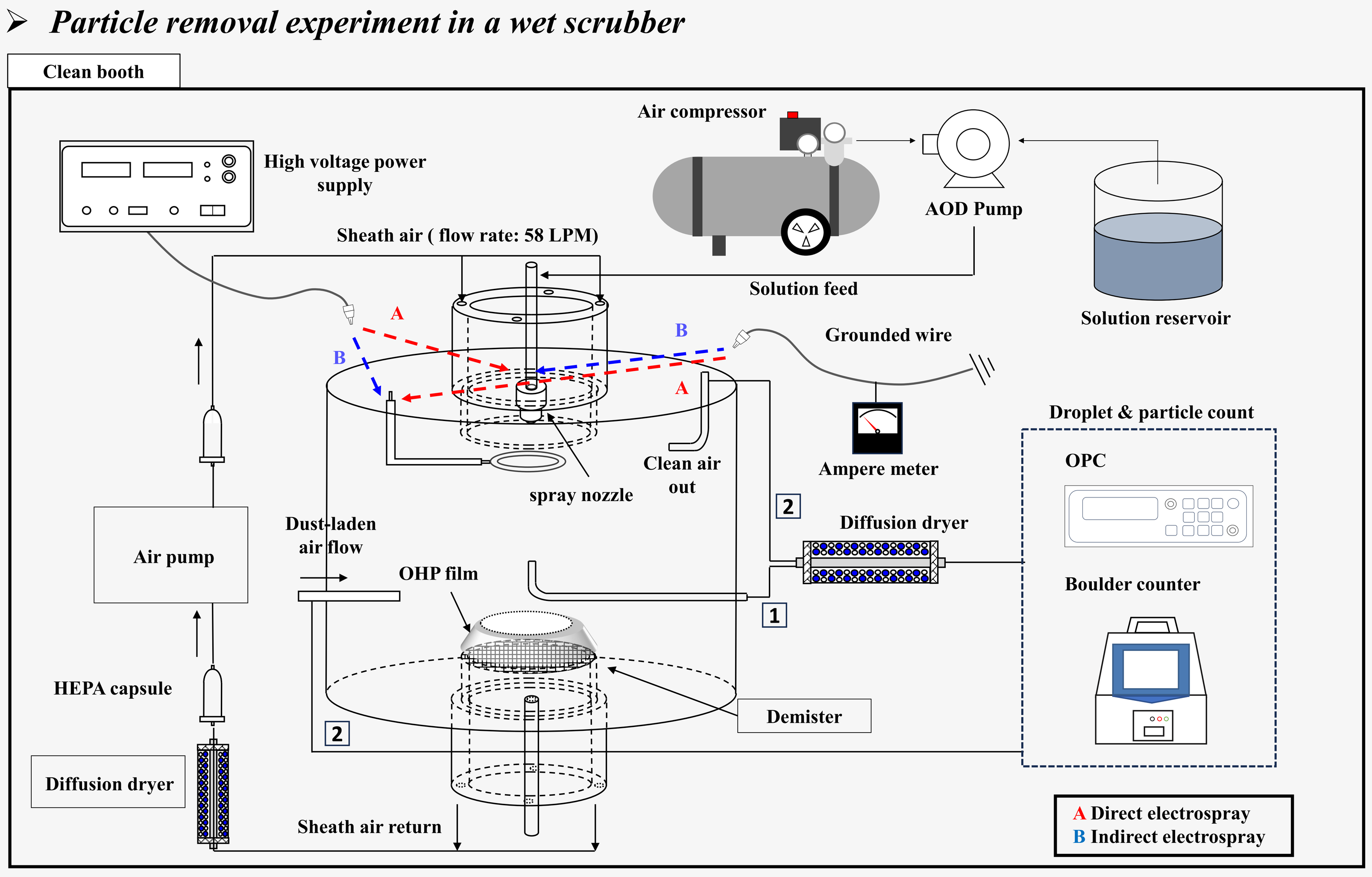


Fig. 2 Schematic of experimental apparatus

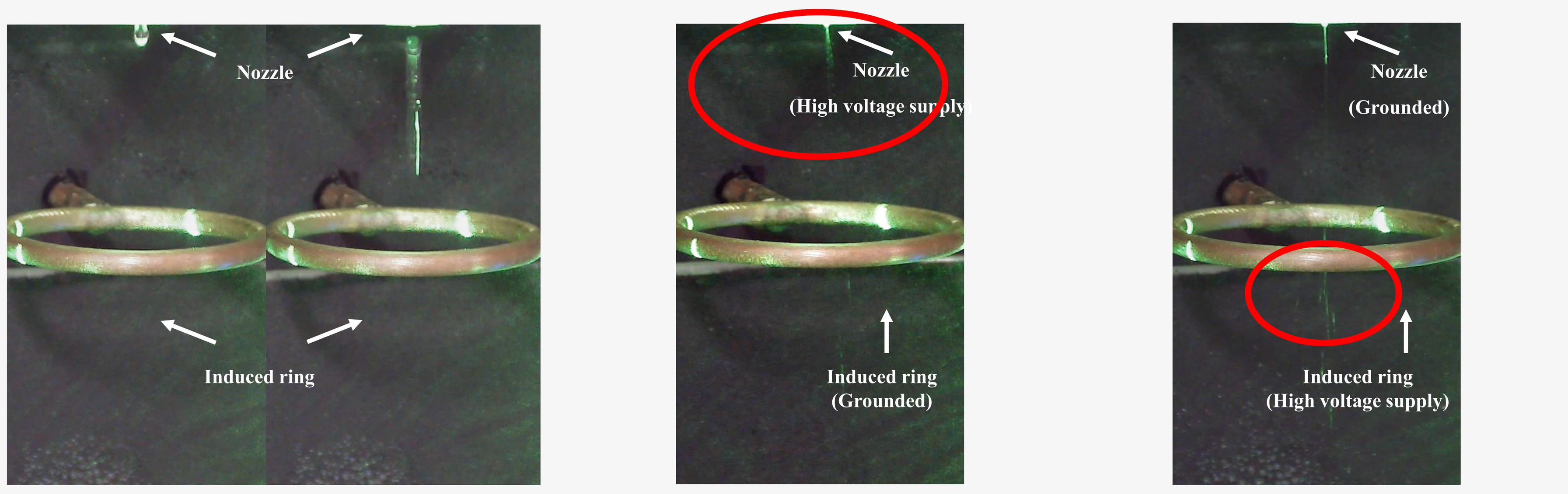
- Water solution with flowrate of 300–500 mL/min was supplied via an air-operated diaphragm pump (AOD pump). Electrospray was performed by applying a high voltage(+20 kV) to either a fog jet nozzle or an induced ring, following previous experiments.
- Droplet size distribution was measured using an OPC (11-A, Grimm) for droplets from 1 to 3 µm in size, and a Boulder counter (SOLAIR, Light House) for droplets of 5–100 µm in size. A diffusion dryer was used to eliminate particles produced along with sprayed droplets in order to measure pure droplet concentration.
- Ambient dust particles was used to measure the removal efficiency of a scrubber system. The removal efficiency was determined by measuring the number concentration upstream and downstream of the scrubber using an OPC.

$$Removal\ efficiency = 1 - \frac{(outlet\ particle\ number\ concentration)}{(Inlet\ particle\ number\ concentration)} \quad (1)$$

- In order to adjust the electrical conductivity of the solution, a surfactant was added to tap water. The concentration was set to 0.00025%(surfactant of 0.25 mL was added to water of 1 L), ensuring that no electrical breakdown occurred between the nozzle and the induced ring during electrospraying.
- An ampere meter was connected to the grounded wire to measure the number of charges in a droplet.

Results

Characteristics of sprayed droplets by high voltage application methods



(A) Nozzle spray (B) High voltage applied to nozzle (C) High voltage applied to Induced ring

Fig. 3 Comparison of nozzle spray and electrospray (Water flowrate : 3 mL/min, Applied voltage : +20 kV)

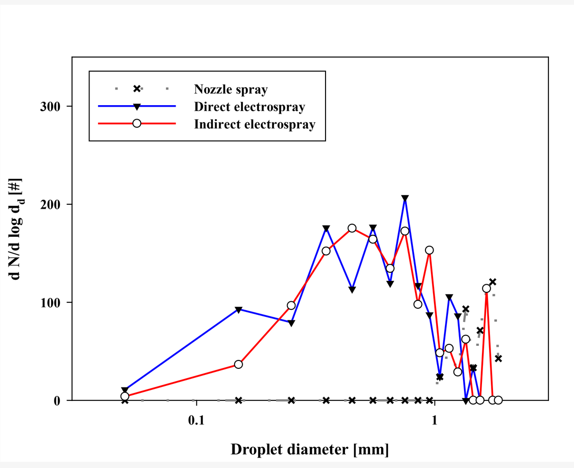


Fig. 4 Droplet size distribution.
(Water flowrate: 5 mL/min, Applied voltage : +20 kV)

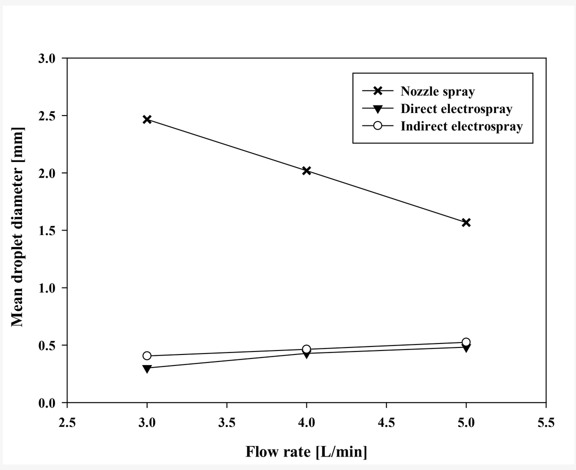


Fig. 5 Change in mean droplet size by water flowrate.

- Water droplet was fragmented around the nozzle for direct electrospray, while it was broken up around the ring for indirect electrospray (Fig. 3).
- The droplets size produced by indirect electrospray is larger than that by direct electrospray. In addition, the size increased with increasing water flowrate (Figs. 4, 5).
- Mean droplet size decreased from 1.5–2.5 mm to 0.3–0.5 mm by electrospray (Fig. 5).

Particle removal using droplets produced by electrostatic spraying

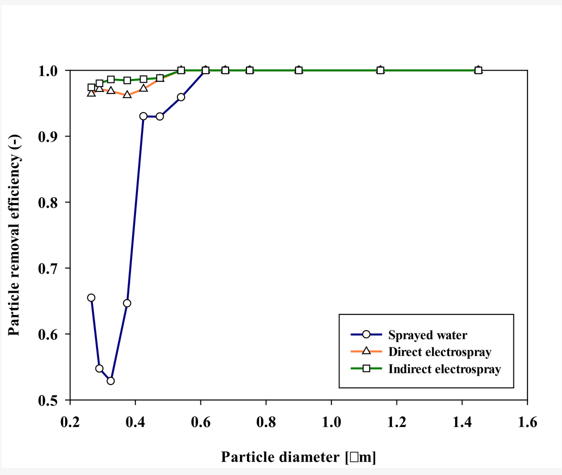


Fig. 6 Particle removal efficiency by spraying methods.

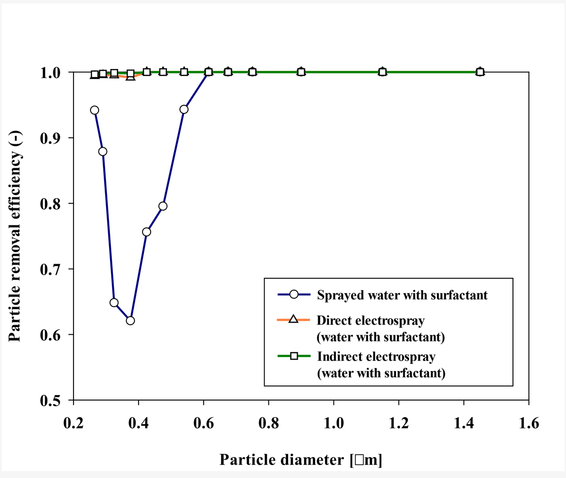


Fig. 7 Enhanced removal efficiency by adding surfactant.

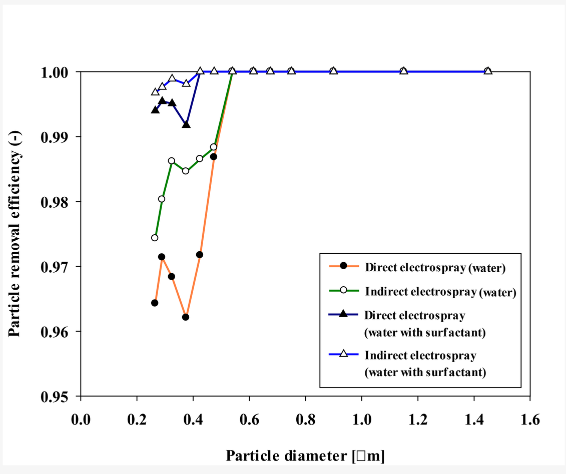


Fig. 8 Particle removal efficiency by spraying methods.

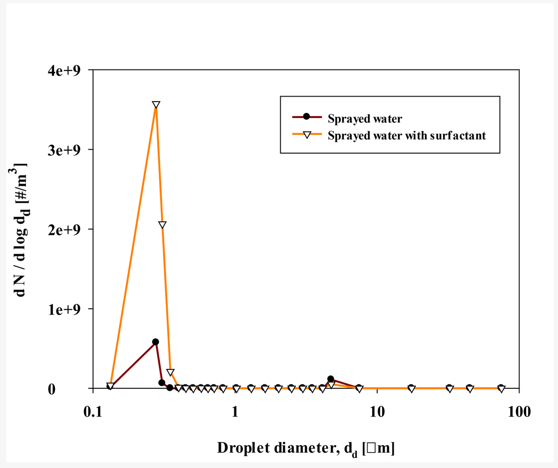


Fig. 9 Size distribution of sprayed droplets.

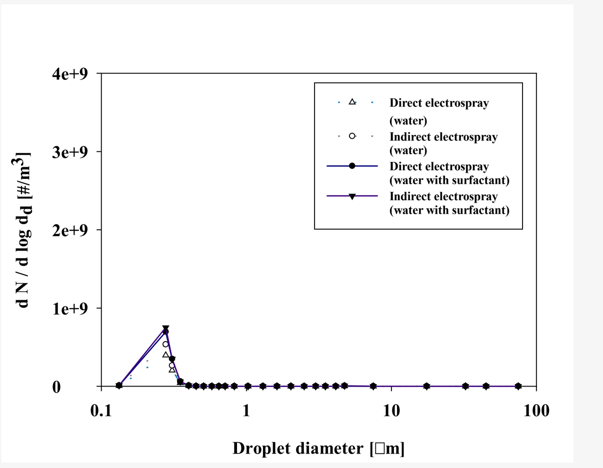


Fig. 10 Size distribution of electrosprayed droplets.

Table 1. Measured conductivity of two liquids

Liquid	Conductivity (S/m)
Tap water	87.4
Water with surfactant	94.7

Table 2. Measured electrical current.
(Water flowrate: 500 mL/min, Applied voltage : +20 kV)

Electrospraying method	Electrical current (µA)	
	Water electrospray	Water+surfactant electrospray
Direct electrospray	4.6	6.4
Indirect electrospray	5.1	7.0

- Water spraying without electrospray had a low particle removal efficiency for submicrometer particles. However, even those particles were effectively captured by water or water with surfactant electrospraying, although droplet number concentration of water droplet without electrospray was extremely higher than that by electrospray.
- It is conceivable that produced charged droplets can effectively capture submicrometer particles by electrostatic attraction and be removed in the system.
- Particle removal efficiency was slightly improved by increasing electrical conductivity of a solution.

Conclusion

- Electrospray-assisted wet scrubber has produced a large amount of small charged droplets, which improved the collection efficiency for submicrometer particles comparing to the conventional wet scrubber.
- Addition of a surfactant in a water solution can help to produce charged droplets by increasing electrical conductivity of the solution.
- Indirect electrospray had higher particle removal efficiency than direct electrospray. In addition, it can solve the electrical safety issue because high voltage is applied to an induced ring instead of a nozzle. Therefore, indirect electrospray is more promising technology to generate highly charged droplets and to solve an electrical damage in the electrospray system.

*Acknowledgement : This study was supported by the Korea Environmental Industry & Technology Institute grant funded by the Korean government (Ministry of Environment)) (No. RS-2023-00219242).