Fine particle removal of two-stage ESP using water film collection plates and non-metallic charger

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1 Summary / Abstract:

A novel two-stage wet ESP has been developed using a non-metallic carbon brush precharger and collection plates with a thin water film. The electrical and particle collection performance was evaluated using submicron particles by varying the voltages to the precharger and the collection plates. The experimental results show that the wet ESP using 7 L/min/m^2 of water that uses carbon brush precharger charged particles with approximately 10% particle loss, while producing concentration of ozone less than 30 ppb, which is significantly lower than the current limits of the international agencies, and achieved a high collection performance of average 90% for ultrafine particles, based on the number concentration at 3-5 m/s through the precharger and 1 m/s through the collection plates.

2 Introduction (Heading 1)

Wet ESPs are used for industrial applications where the potential for explosion is high, or when dust is very sticky, corrosive, or has very high resistivity. The water flow may be applied continuously or intermittently to wash the collected particles from the collection electrodes into a reservoir used to collect liquid. The advantage of using wet ESPs is that it does not have problems with rapping, re-entrainment or with back corona so that it is effective for controlling ultrafine particles, comparing with dry ESPs[(1)] and also efficiently remove corrosive liquid phase particulates such as SO_3, PAH and HCl mists etc.[(2),(3)] However, in the wet ESPs, disruptions due to spraying (misting) of water, formation of dry spots due to the effects of water surface tension (channeling), and corrosion of the collector surfaces may limit applicability of current wet precipitators.[(4)]

The carbon fiber ionizers are made of an anticorrosive material, carbon graphite, which may be utilized easily and inexpensively by applying a voltage of a few kV to a bundle of carbon fibers in order to generate ions. These can produce stable unipolar ions at sufficiently high concentrations, while generating negligible concentrations of ozone, and thus, they have been used in indoor air purifiers to generate ions as an alternative to corona discharge using thin metallic wires and spikes.[(5),(6)]

We are unaware of any previous attempts to combine a carbon brush charger with wet collection plates cleaned by a thin water film for a two-stage wet ESP for an industrial purpose. In the study reported herein, the electrical and particle collection performance characteristics of the newly developed two-stage wet ESP were investigated by changing an applied voltage and its polarity to the ESP. The important byproduct from ESPs, ozone concentration, was also measured by changing an applied voltage to the precharger and its polarity. Dust loading tests with a standard dust was also performed in order to assess the long term performance of the ESP with and without a water film.

3 Experimental setup

Fig. 1 shows the experimental setup used in the study. Potassium chloride (KCl) aerosol particles with diameters in the range 0.01~0.5 μm were generated by nebulizing a solution of KCl (w/w 0.05% in water) using an atomizer with a constant output (Model 3076, TSI Inc., US) and passing them through a Kr-85 neutralizer and a diffusion dryer. The mean diameter, number concentration, and geometric standard deviation of the particles

generated were approximately 0.045 μm, 2.5 x 10^5 particles/cm^3, and 1.7, respectively. The charged fractions of the test particles were removed using a plate condenser (to which a high voltage of -10 kV was applied), and uncharged particles were then introduced into upstream of the carbon brush precharger. Clean compressed air was mixed with these particles and the mixture was then passed through the carbon brush precharger and collection cell. The total air flow rate through the wet type ESP was maintained at 95 L/min, which was corresponded to 4 m/s through the carbon brush precharger and to 1.0 m/s through the collection cell, using mass flow controllers (MFCs, Model Tylan® FC-2920 Series-100 slpm, Mykrolis Corporation, USA).

High voltage power supplies (Max +/- 30 kV/ 10 mA, Korea Switching, Korea) were connected to the precharger and the collection cell. The applied voltages and corona currents were measured by using digital multimeters (Model 286, Fluke Corporation, Japan). The voltage to the precharger was varied from 2 kV to 8 kV, and that to collection cell was from 4 kV to 8 kV to understand the effect of the applied voltages to the performances of the charger and the whole ESP. The polarity of the applied voltage to the precharger was also changed to understand the effect of the polarity on the performance of the precharger and the ESP. For wetting the collection plates, the water flow rate per collection surface area was 6.5 L/min/m^2 (0.16 x 0.095 m^2). The size distributions of the test particles at the downstream of the collection cell were measured using a scanning mobility particle sizer (SMPS, Model 3081, TSI Inc., US) system, together with a condensation particle counter (CPC, Model 3076, TSI Inc., US). The concentration of ozone from the precharger was measured using an ozone monitor(API 400E, Teledyne Technologies Inc., US) while varing the voltage to the precharger.

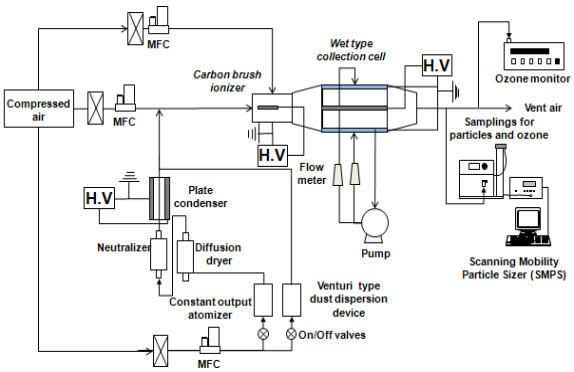


Fig. 1: Experimental setup for this study

The performance of the ESP used in this study was expressed in terms of the particle loss or particle collection efficiency (η), which may be obtained by using the following equation:

$$\eta = (1-C_2/C_1) \times 100 \qquad (1)$$

where η is the particle loss or collection efficiency, C_1 is the number concentration of the particles downstream of the ESP without any applied voltage to it, and C_2 is the number concentration of the particles downstream of it with applied voltages to its charger or collection cell.

The long-term collection performances of dry and wet type ESP during dust loading were compared using a standard dust (Class 8, mean diameter 1.6 ~ 2.3 μm, JIS standard dust, Japan) for the dust loading of the collection plates, and submicron KCl particles for measuring the transient collection efficiency of the ESP during the test. A venture-type dust dispersion device was used to generate and supply the dusts throughout the upstream of the precharger. The mass concentration of the loading dust that flowed into the ESP was maintained at approximately 50 mg/m^3. Prior to dust loading, the initial collection efficiency of the ESP was measured, and the transient collection efficiency was then measured every 15 minutes after each dust loading of 1 g, by means of KCl particles. The polluted water was removed periodically from the down reservoir. During the experiments, the operational parameters of the precharger and collection cell were varied in order to investigate their effect on the performance of the wet type ESP.

4 Result and discussion

4.1 Electrical performance and ozone emission of the carbon brush precharger

Fig. 2 shows the variation in currents against voltages applied to the carbon brush precharger. The test air flow rate was maintained at 95 L/min, which was corresponded to 4 m/s through the carbon brush precharger. A negative corona led to higher corona currents than a positive corona for the same applied voltage, because of the higher electrical mobility of the negative ions due to the lower clustering of the molecules and the photoelectric effects from the surface of the discharging electrodes at the negative corona Fig. 3 shows the variation in the concentration of ozone emitted from the carbon brush precharger, plotted against the applied voltage to the precharger for different polarities at a constant air velocity of 4 m/s. The average ozone concentration was proportional to the applied voltage to the

precharger, and the ozone generation with a negative high voltage was much higher than that with a positive. In particular, when the applied voltage to the charger was less than 4 kV, the ozone concentration was less than less than 30 ppb, which was significantly lower than the 60~120 ppb limit set out in the FFA-recommended level and the EPA's National Ambient Air Quality Standard.

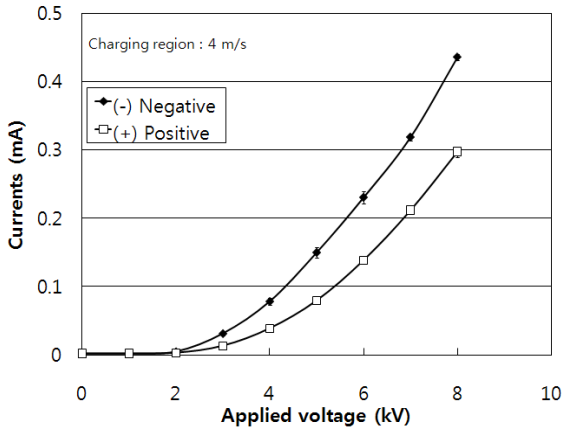


Fig. 2: Voltage-current curves of the carbon brush precharger for a negative and positive polariry

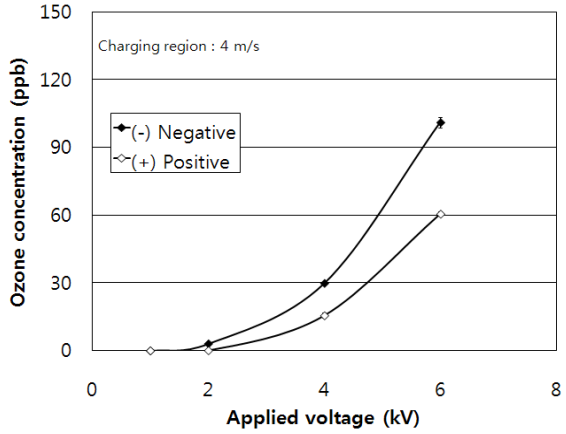


Fig. 3: Ozone emission as a function of the applied voltage to the precharger for a negative and positive polarity

4.2 Particle loss of the carbon brush precharger

Fig. 4 shows the variation in particle loss of the submicron particles with applied voltage at different corona polarities for particle sizes of 0.045, 0.093, 0.191 μm. The test air flow rate was kept at 95 L/min, which was corresponded to 4 m/s through the carbon brush precharger. The diffusion loss in the ESP was negligible because there was little difference between particle number concentrations at the inlet and outlet of the ESP in the absence of an applied voltage. The particle loss for both polarities was proportional to the applied voltage to the precharger. With increasing applied voltage and thus increasing corona current in the precharger, the particle number concentration decreased across the whole range of particle sizes due to the higher charging probability of particles and the higher electrostatic force between the high voltage carbon brushes and the grounded S/S tube. A negative corona led to a higher collection efficiency of the particles compared to a positive corona for a given applied voltage, due to the higher ionic mobility of negative ions. However, with the applied voltage less than 4 kV for both polarities, the particle loss less than 10 % was obtained. In order to minimize ozone generation less than 30 ppb and the particle loss in the precharger less than 10 %, the applied voltage to precharger was kept at 4 kV for the performance tests for particle collection of the ESP developed in this study.

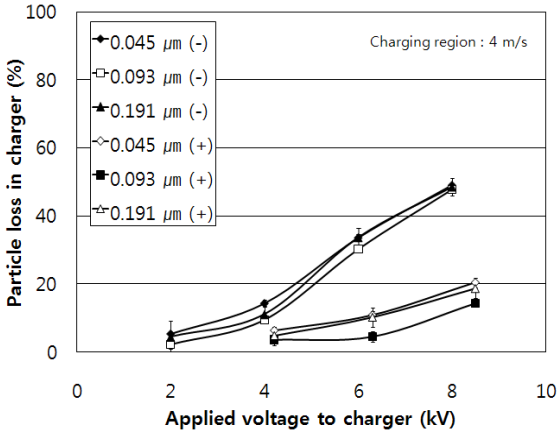
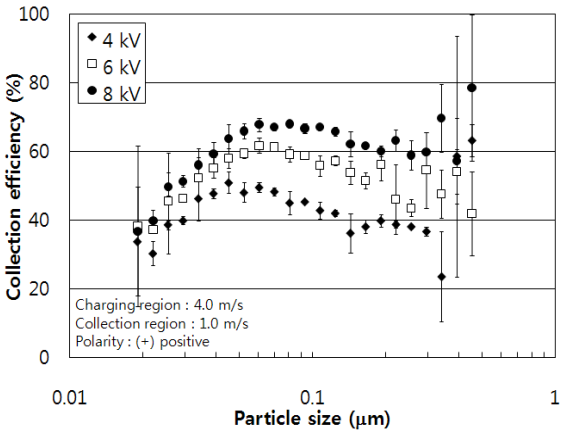


Fig. 4: Collection efficiency against applied voltage at different high voltage polarity to the precharger for submicron particles.

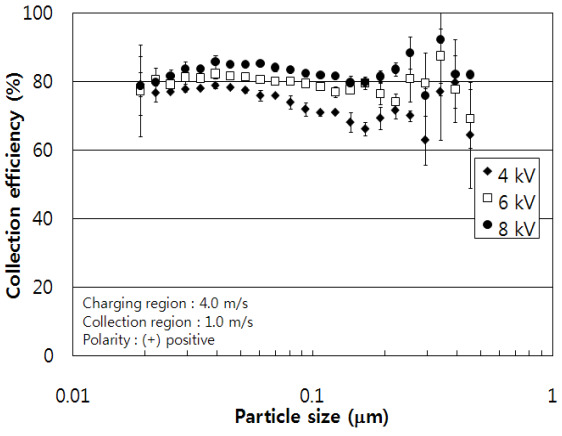
4.3 Collection performances for submicron particles of the two-stage wet ESP

Figure 5 shows the relationship between the collection efficiency of submicron particles in the ESP and applied voltage to the collection plates of it. The polarity of the applied voltage to the precharger and collection plates was positive. The applied voltage to the precharger was 4 kV, and the test air flow rate was 95 L/min corresponding to 4 m/s through the charger and 1.0 m/s through the collection cell, respectively. The water supply onto the collection plates was maintained at 6.5

L/min/m^2, and the particle loss in the precharger without any voltage to the collection cell was approximately less than 10 %. Shown in the Figure 5 (a), an increase in the applied voltage to collection plates resulted in an increase in the collection efficiency of the almost entire particles due to the increase of migration velocity of the particles to the plates by increasing electrostatic intensity.[7] However, for the particles ranged in the sizes less than 0.05~0.06 μm, the decrease in the particle size led to the decrease of the efficiency for all applied voltages due to the partial charging effect for the particle sizes, and this finding was good agreement with the results of the previous studies.[8],[9] In particular, for the particles ranged less than 0.03 μm, the increase in the electrostatic intensity between the collection plates almost no effect on the collection efficiency because the particle collection was restricted by the charging fraction of the size range particles in the charger[10], and this phenomenon can be regarded as a non ideal effect which cannot be explained by the Deutch theory.[8] Shown in Figure 5 (b), the collection efficiency was also enhanced with increasing the applied voltage to the collection plates. The collection efficiency in the peak sizes with the applied voltage to precharger of 4 kV was average 85% and was enhanced by 10~30%, in particular the efficiency for the very small particles less than 0.03 μm was increased significantly by 20~40%, and the peak size of the efficiency was shift to the left, compared to the results with 2 kV applied voltage to the precharger. This higher increase of the collection efficiency in the smaller size range could be resulted from the fact that the collection efficiency become significant high when the number of ions is large enough, and the particles are almost fully charged by acquiring only one ion because particles in the ultrafine size range usually have very high electrostatic migration velocity. However, as the number of ions is decreased, the efficiency for very small particles drops dramatically due to the decreased charging fraction.[10] Figure 6 shows the relationship between the collection efficiency of submicron particles in the ESP and applied voltage to the collection plates of it. The polarity of the applied voltage to the precharger and collection plates was negative. The applied voltage to the precharger was 4 kV, and the test air flow rate was 95 L/min corresponding to 4 m/s through the charger and 1.0 m/s through the collection cell, respectively. The water supply onto the collection plates was maintained at 6.5 L/min/m^2. The particle losses in the precharger with 4 kV were approximately 10 %. Shown in Figure 6, size and electrostatic field dependent collection efficiencies were a good agreement with those from the experiments with the positive applived voltages. However, the entire collection efficiencies were enhanced by approximately 10% for the applied voltage to the precharger of 4 kV, compared to those for the same applied voltage of the positive polarity.



(a)



(b)

Fig. 5: Collection efficiency of submicron particles as a function of particle size for different positive applied voltages to the collection plates. (a) 2 kV, (b) 4 kV to the carbon brush precharger

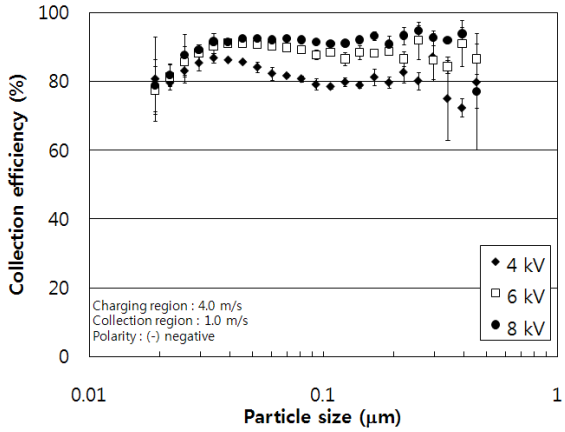
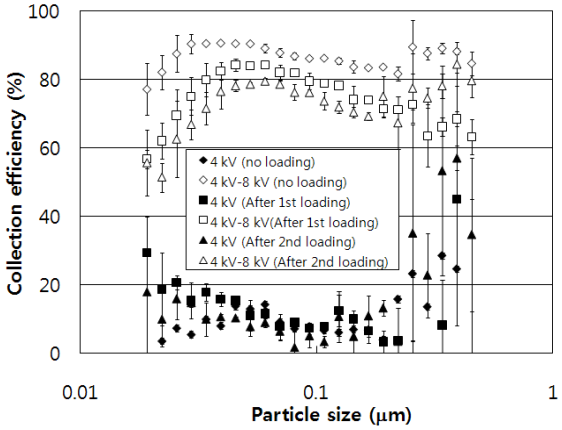


Fig. 6: Collection efficiency of submicron particles as a function of particle size for different negative applied voltages to the collection plates. -4 kV to the carbon brush precharger

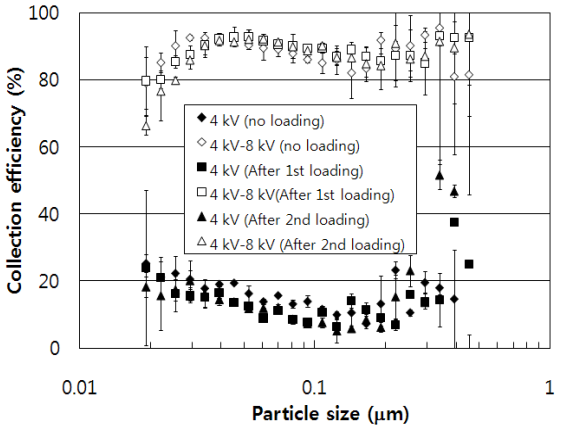
In particular, the average particle collection efficiency was more than 90% for the submicron particles with the negative applied voltages to the precharger and collection plates of 4 kV and 8 kV, respectively.

4.4 Long-term collection performance of two-stage dry and wet type ESP during dust loading

Figure 7 shows the variation in collection efficiency of the ESP plotted against particle size for different particle loadings without and with the water films on the plates. The collection plate was polluted intentionally using dust loading using a mass concentration of approximately 50 mg/m^3. The applied voltages to the precharger and the collection plates were 4 kV and 8 kV, respectively, and the air velocity through the precharger and the collection plates were 4 m/s and 1.0 m/s. As shown in Figure 7 (a), the collection efficiency for submicron particles was approximately 90% for the clean collection plates at the beginning of the experiment over the whole size range. The average collection efficiency of the ESP fell from 90% to 75% after the first dust loading and to 70% after the second, while particle loss without any voltage to the collection cell was maintained at approximately 10%. This finding was the result of the reduction in electric field strength in the collection cell due to the accumulation of JIS dusts on the collection plates[(11)], and no significant particle deposition in the precharger. However, shown Figure 7 (b), the collection efficiency of the wet ESP whose collection plates were continuously cleaned by water films of 6.5 L/min/m^2 on them was not degraded but maintained at approximately 90% of the initial collection efficiency of the ESP after twice the JIS dust loading. This finding shows that a long-term performance of particle collection with a high level of efficiency could be achieved by continuously cleaning the collection plates with a thin water film, while conventional dry ESPs require rapping and water spraying onto the collection plates in order to maintain the collection efficiency and the devices generate particle reentrainment which results in the low collection efficiency for submicron particles.



(a)



(b)

Fig. 11 Variation in collection efficiency of the ESP plotted against particle size for different particle loadings without and with the water films on the plates. (a) Without the water film, (b) With the water film of 6.5 L/min/m^2

5 Conclusion

We have developed a novel two-stage wet ESP that uses a carbon brush precharger and collection plates with a thin water film. The performance of the ESP was evaluated experimentally for ultrafine particles in the range 0.01~0.5 μm by varying the voltages that were applied to the precharger and the collection plates and those polarity. The long-term performance of the ESP with and without water films was also investigated using a standard JIS dust with a size range measured in micrometers. The experimental results show that the two-stage wet ESP that uses carbon brush precharger charged particles with approximately 10% particle loss, while producing concentration of ozone less than 20~30 ppb at the applied voltages up to 4 kV, regardless of polarity, which is significantly lower than the current limits of the international agencies. In particular, the ESP achieved a high collection performance of average 90% with negative applied voltages and of average 80% even with positive applied voltages, respectively, for ultrafine particles based on number concentration. It was also found that a high collection efficiency of the ESP could be achieved by increasing the voltages that were applied to the precharger and the collection plates. In addition, it was found that the decreased collection efficiency that occurred during dust loading without water films was completely was avoided by forming a thin water film at a water flow rate of 6.5 L/min/m^2. The ESP described herein is thus a promising post-treatment system for the removal of ultrafine particles, especially in the industries where small particulates are emitted in acidic and corrosive gases that could degrade the performance of conventional dry ESPs, and also this could be applied to the air cleaning device with high removal efficiency over 80% for ultrafine particles of indoors with generating negligible ozone significantly less than the regulation limit of indoors by using positive polarity.

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7 Literature

[1] R., Altman; G., Offen; W., Buckley; I., Ray; I. Wet electrostatic precipitation demonstrating promise for fine particulate control – Part I; Power. Engineer; 105(1); 2001; pp.37-39.

[2] R.E., Snyer; A.L., Moretti; D.P., Tonn; A.A., Silva; S., Kumar; A., Lau; SO3 and fine particulate mitigation at AES deepwater; In Proceedings of the power plant air pollutant control “Mega” symposium 2008; Baltimore, MD; BR-1814.

[3] A., Bologa; H., Paur; H., Seifert; T., Wascher; K., Woletz; Novel wet electrostatic precipitator for collection of fine aerosol; J. Electrostat.; 67; 2009; pp.150-153.

[4] D.J., Bayless; M.K., Alam; R., Radcliff; J., Caine; Membrane-based wet electrostatic Precipitation; Fuel. Process. Technol.; 85; 2004; pp. 781-798.

[5] B., Han; N., Hudda; Z., Ning; H.J., Kim; Y.J., Kim; C., Sioutas; A novel bipolar charger for submicron aerosol particles using carbon fiber ionizers; J. Aerosol. Sci.; 40; 2009; pp.285-294.

[6] H.J., Kim; B., Han; Y.J., Kim; S.J., Yoa; Characteristics of an electrostatic precipitator for submicron particles using non-metallic electrodes and collection plates; J. Aerosol. Sci.; 41; 2010; pp.987-997.

[7] W.C., Hinds; Aerosol Technology: properties, behavior, and measurement of airborne particles. 2nd ed; John Wiley & Sons, Inc: New York, 1999.

[8] K.H., Yoo; J.S., Lee; M.D., Oh; Charging and collection of submicron particles in two-stage parallel-plate electrostatic precipitators; Aerosol. Sci. Tech.; 27(3); 1997; pp.308-323.

[9] S.H., Huang; C.C., Chen; Ultrafine aerosol penetration through electrostatic precipitators.; Environ. Sci. Technol.; 36; 2002; pp.4625-4632.

[10] M., Li; P., D. Christofides; Collection efficiency of nanosize particles in a two-stage electrostatic precipitator; Ind. Eng. Chem. Res.; 45; 2006; pp. 8484-8491.

[11] G., Lin; C., Tsai; S., Chen; T., Chen; S., Li; An efficient single-stage wet electrostatic precipitator for fine and nanosized particle control; Aerosol. Sci. Tech.; 44; 2010; pp.38-45.