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An Experimental Study for Designing Electrostatic Precipitator: Focused on Collection Efficiency Variation per Area and Corona Power

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Abstract

The Electrostatic Precipitator is one of the most favorable device of particulate control systems because of the relatively higher collection efficiency and easier operation/maintenance. However, it requires very high initial cost especially for discharging electrodes and collecting plates. In dealing with such problems, development of optimum design can be one of the solutions.

In this study, a bench-scale electrostatic precipitator was operated in terms of collection area and corona power, and its performances were analyzed focusing on collection efficiency. A result of this study, a more advanced approach for designing cost-effective precipitator by promoting corona power at a minimized collection area was proposed.

Key words : Electrostatic precipitator, Discharge electrode, Collecting area, Corona power, Collection efficiency

1. INTRODUCTION

Emission standards of air pollutants are getting more stringent. In order to meet these standards, industries have to use a clean energy or build a more efficient control system. With respect to the emission control processes, developing an electrostatic precipitator collecting fine particle more efficiently can be one of the solutions. Some particulate discharged from industrial boilers and manufacturing industries contain noticeable amount of heavy metals and other accumulating hazardous pollutants, which can cause a serious health-related problem after inhalation. Furthermore, fine particles emitted into the atmosphere may scatter and /or absorb the light, which reduces the visibility to a great extent (Lee and Kang, 2000; Chun *et al.*, 1997; Resit, 1993; Flagan and Seinfeld, 1988; Hinds, 1982).

Electrostatic precipitator and fabric filter have been most favored as the most efficient devices for fine particulate removal. But recently, fabric filters started to lose their merits such as low installation cost and simplicity in operation, due to its installation inconveniences and higher labor costs. Meanwhile the electrostatic precipitator has also demerit such as high initial installation cost, which should be overcome by

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cost-effective design and operation (Choi, 1994; Oglesby, 1990). In particular, since most of initial cost is spent for building discharge electrodes and collecting plates, they can be lowered only through the development of an optimum design method for these parts.

In this study, laboratory scale electrostatic precipitator was operated to find out cost effective methods of collecting plate design and operation, and to provide basic design information such as collection efficiencies versus varying collection area and applied voltages.

2. EXPERIMENTALS

A laboratory-scale clean wind tunnel system was designed to examine how collection area and applied voltage of electrostatic precipitator affect its efficiency. Wind tunnel was designed mainly based on the works by Thomson and Davison (Kim, 1999; Kim, 1996; Shaughnessy *et al.*, 1985), and the experimental process is the duplicate of the previous study (Kim *et al.*, 1999).

Air flow rate was adjusted by controlling air velocities in the tunnel, and the tunnel was made of a transparent acrylic plate so that we could observe the inside-air flow. In order to keep inside clean while operating the collector, high efficiency particulate air filter (HEPA) was installed.

Wind tunnel was operated by push-type turbo fan, and the test section, an electrostatic precipitator, was placed to the downwind direction. Air velocity inside the wind tunnel was adjusted within a range of 0 to 7 m/s by changing frequency of an inverter at the fan motor.

Size of HEPA, which is used for keeping the wind tunnel clean, was 600 mm × 600 mm × 700 mm, and its collection efficiency obtained from 0.3 μm DOP test was 99.99%. Air flow was induced by the turbo fan, and plenum chamber was placed between turbo fan and HEPA to buffer the air flow. The HEPA played roles of not only collecting aerosols but also producing stable air flows within the wind tunnel.

In order to determine collection efficiency of the electrostatic precipitator, it was necessary to produce aerosols with similar size distribution and particle concentration to the ones emitted from field stacks. For this purpose, fly ash from B-C oil boiler was used.

In general, concentration of aerosols emitted from an industrial scale B-C oil boiler was known to range from 150 to 180 mg/m^3, depending on type of boiler, combustion conditions and boiler ages (Kim *et al.*, 1995; Choi, 1994). In this study, fly ash was collected from an electrostatic precipitator of B-C boiler, and was sieved (#100) to simulate the concentration, particle size distribution, and ash contents according to the usual commercial combustion process. The physical properties of fly ash used for this experiment are presented in Table 1.

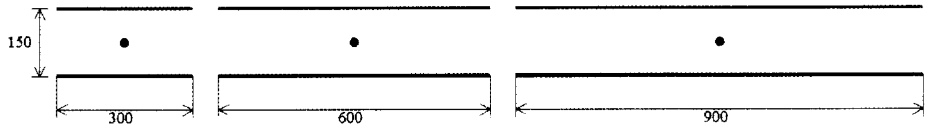
Table 1. The characteristics of fly ash.

Size range	0.1 ~ 12.0 μm
Mass concentration	170 ~ 180 mg/m^3
Specific Resistivity	4.3×10^7 ohm-cm

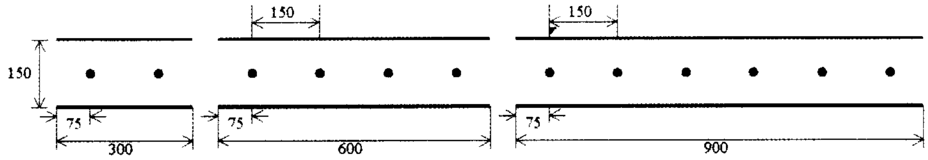
An aerosol generating apparatus was upward cyclone type generator. The fly ash, which was simulated as commercially used ones, was sprayed in all four directions through the nozzle. The adjusted fly ash concentration was ranged from 170 to 180 mg/m^3. For the particle size distribution as shown in the duplicate of the previous study (Kim *et al.*, 1999), there was no significant difference from those generated in commercial ones (Martin *et al.*, 1996; Yun, 1994; Joma *et al.*, 1992).

In-stack cascade impactor(Sierra's Series 220, Anderson) was used in this study for measuring particle size distribution, which is a radial-slot in-stack cascade impactor with ten plus one stages. Stack sampler (CE-22ASM, Jung Eng.) was used to determine the collection efficiency.

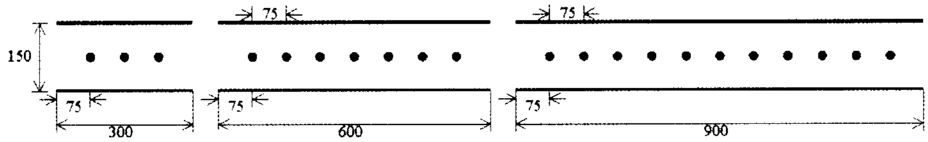
In this study, the collection efficiency was determined by various collection area and applied voltage of the electrostatic precipitator. Fig. 1 shows scaled map in which the various configurations of wire-plate electrostatic precipitator are represented with the distances



a) single wire



b) wire to wire spacing 150mm



c) wire to wire spacing less than 150mm

Fig. 1. Wire to wire spacing in collecting area (unit : mm).

from wire to wire and from collecting plate to collecting plate. Discharge of one-stage method was applied to charge particles. Collecting areas were changed from 0.09 m^2 (L 0.3 m × W 0.3 m), 0.18 m^2 (L 0.3 m × W 0.6 m) and 0.27 m^2 (L 0.3 m × W 0.9 m). Rod type of wire (ϕ 1.5) was used for discharge electrode. The number of discharge electrodes was also varied with the changes of collecting area as shown in Fig. 1. Applied voltage varied from 20 kV to 35 kV. In the meantime experimentation, particles were generated steadily by the aerosol generator which was explained before. Another test conditions are like as Table 2.

Table 2. Test conditions.

Applied voltage range	20 ~ 35 kV
Air velocity	1 m/s
Temperature	20°C

3. RESULTS AND DISCUSSION

Currents versus discharge electrode number and its interfacial distance in each collection plate are presented in Fig. 2. When the discharge electrode was only one, minimum current was recorded. When 35 kV of voltage was applied for the collection plate areas of 0.09 m^2, 0.18 m^2 and 0.27 m^2, recorded currents were 7.6 μA, 7.8 μA and 8.4 μA, respectively. The current values were measured according to the change of electrode number. The maximum values were found when two, four, and six electrodes were used for 0.09 m^2, 0.18 m^2, and 0.27 m^2 plate areas, respectively. Under these conditions, the measured currents were 9.5 μA, 14.8 μA, and 22.0 μA. When the distance between electrodes became closer, the current values increased, but when the same distance between discharge electrode and collection plate, the current values were maximum, and after then the current values decreased. Therefore, increasing the number of discharge electrodes was not the methods of increasing current value. If the distance of discharge electrodes became closer than a critical distance, the current flow might be hindered by the interference of electric field which pro-

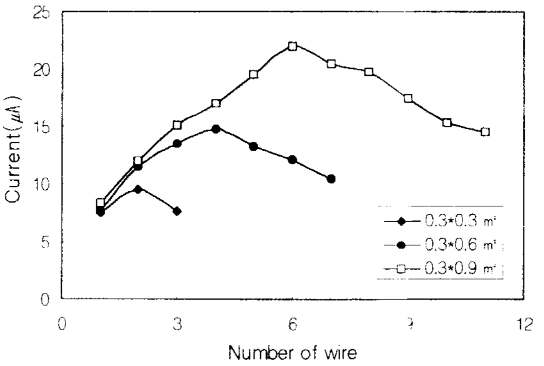


Fig. 2. Current according to wire number.

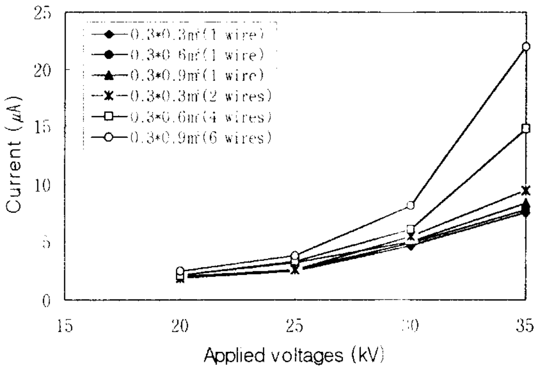


Fig. 3. Applied voltages versus current.

duced around each electrodes. White (1962) also supported this by reporting that in a circular discharge electrode, interfacial electrode distance is usually within a range of 0.5 ~ 1 of collection plate distance but 0.7 ~ 0.9 is most widely used (White, 1962).

Since circular-shape electrodes were used in this study, maximum current flow was produced when the distance between discharge electrodes was maintained equally to the collection plate distance. Current value produced from a corona discharge depends largely upon the shape of discharge electrode and the conditions of gas. But the shape is known to be the most predominant factor. Recently, different shapes of electrodes such as barbed and square show very different performance from the circular shape electrode. Thus, interfacial distance for those electrodes giving maximum current flow must be determined from the practiced experiments.

Fig. 3 presents data of the measured currents for the applied voltage when a single discharge electrode was installed, and the 150 mm discharge electrode distance. Generally, as applied voltage was elevated, current also increased, and for the single discharge electrode, there was no significant difference in currents measured at the collection electrode. However, when the distance between discharge electrodes were maintained 150 mm, the current noticeably increased with the increase of applied voltage.

The graph in Fig. 4 shows collection efficiencies versus the applied voltages obtained when a single discharge electrode per collection plate was installed with distance of 150 mm between discharge electrodes. Fig. 4 indicate that collection efficiencies increase as the applied voltage and collecting area increase. When one discharge electrode was installed under the lower applied voltage (20 kV), collection efficiency was less than 60% but for the higher applied voltage (35 kV), about 87% of collection efficiency was obtained. The differences in collection efficiencies versus the change of collecting area was about 10 ~ 20% at a lower applied voltage but at the 35 kV higher voltage, the efficiency difference was within only 2%, indicating that the area effect was negligible.

When the current reached the maximum value, collection efficiencies were above 95% in both of the 0.18 m^2 area with more than 35 kV applied voltage and the 0.27 m^2 area with more than 25 kV. It is apparent, therefore, that designing an electrostatic precipitator with a small collecting area and operating it at a high applied voltage can be a way of obtaining higher collection efficiency.

Also, this can be explained by using a Deutsch-Anderson equation. That is, since collection area (A) and particle migration velocity (ω) in Equation (1) are exponentially proportional to the collection efficiency (η_d), A and/or ω values can be adjusted to obtain a constant performance. Equation (2) is a numerical expression describing a particle migration velocity.

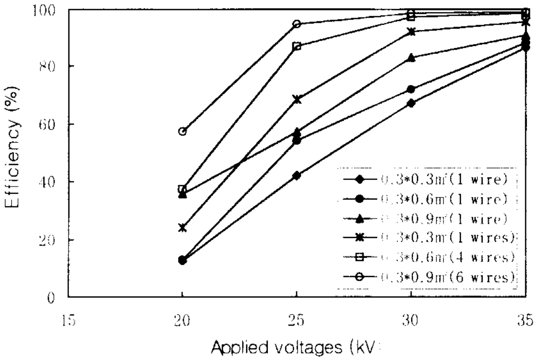


Fig. 4. Applied voltages versus collection efficiency.

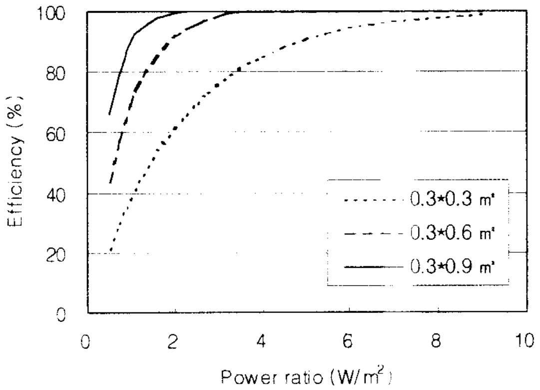


Fig. 5. Corona power ratio versus collection efficiency.

Table 3. Factors for expected efficiency.

Area (m²)	a	b	R²
0.3×0.3	100.36	0.47	0.94
0.3×0.6	102.16	1.12	0.95
0.3×0.9	100.94	2.14	0.98

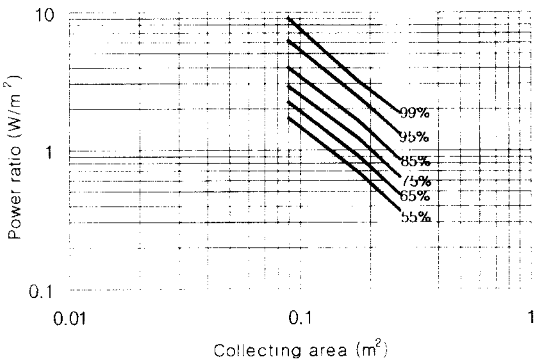


Fig. 6. Corona power ratio versus collecting area.

According to Equation (2), collection performance can be improved by elevating applied voltage with a constant intensity of electrical field, i.e., a constant interfacial electrode distance,

$$\eta_{dp} = 1 - \exp\left(-\frac{\omega A}{Q}\right) \tag{1}$$

$$\omega = \frac{qE_pC_s}{3\pi\mu d_p} \tag{2}$$

where Q is the flow rate (m^3/s), q is the charge (C), E_p is the electrical field strength (V/m), C_s is the Cunningham slip factor, μ is the viscosity (kg/m · s), and d_p is the particle diameter (μm).

Also, increasing applied voltage requires a higher power consumption because corona power (W) is a product of corona current and voltage (Cooper, 1986; Oglesby and Nichols, 1978).

Fig. 5 shows the efficiencies versus the corona power per unit area of the collection plate. Values of constants used in equation (3) to construct the curves in Fig. 5 are presented in Table 3. Actual removal efficiency can not exceed 100% (physically) but that would be possible here because it was estimated by using constants incorporated in the best curve-fit equations. However, calculated efficiencies exceeding 100% were indicated in Fig. 5 as a upper limit (100%).

The efficiencies obtained from the 3 W/m² corona power on each area of the 0.18 m² and 0.27 m² was about 98% but from the 0.09 m², it was around 80%. In order to get higher efficiency than 98% from 0.09 m², it appears that the corona power applied per unit square meter should be more than 10 W/m².

$$y = a(1 - e^{-bx}) \tag{3}$$

Correlation between collecting area and power ratio obtained by using best-fit equations in Fig. 5, are presented in Fig. 6 which shows that the power ratio is inversely larger collecting area; i.e., in order to get a given collection efficiency, the larger collecting area, the less power and vice versa. From these results, it can be concluded that designing electrostatic precipitator with a small collecting area provided with a large power supply may be very cost-effective.

When installing an electrostatic precipitator, since collecting plate part requires most of the initial capital, decreasing collection area may be one of the solutions to saving some of the investment cost. Amount of energy consumption in operating electrostatic precipitator depends on various factors such as size, ID fan and corona power but, as a result of applied voltage increase, energy increment is negligible.

In this aspect, recent research on a wide-side electrostatic precipitator are gaining popularity due to its cost-effective design and performance. It is therefore reasonable that, when designing electrostatic precipitator based on a specific collecting area, reducing its collecting area but compensating for that via an increased corona power could be very economical.

4. SUMMARY AND CONCLUSIONS

In this study, the cost-effective method of electrostatic precipitator design and operation was examined and reviewed.

In the present design method, a specific collecting area (SCA) has been considered as a design factor, using a higher applied voltage while having a smaller collecting area improved the performance of electrostatic precipitator.

It is also possible to optimize the distance between electrodes and applied voltage giving the most cost-effective collection area, and furthermore, adjusting electrode distances or applied voltage during the operation and maintenance programs was found to be a useful way of increasing collection efficiency of existing collection facilities

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