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# Removal of Gaseous Acetaldehyde and Fine Particles Using Corona Discharge with Wet Electrostatic Flocking Electrode

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Electrostatic precipitator (ESP) has been widely utilized to collect airborne particles in industrial and indoor ventilation systems. However, conventional ESP has not been used to remove gaseous pollutants from a gas flow. Recently, a wet-type ESP has been used for removing them. In this study, to improve the removal performance of gaseous pollutants and particulate matters, a wet-type ESP with a wet electrostatic flocking electrode was experimentally studied by measuring the removal efficiency of acetaldehyde and fine particles. And a carbon fabric plate as a collecting electrode was suggested to effectively remove ozone and fine particles in ESPs. Removal efficiency of acetaldehyde ($CH_3CHO$: about 30 ppm) in one-pass test was about 68.2% at 8.4 W of input power with residence time of 2.1 s and high collection efficiency was obtained to submicron particles (0.3-0.5 μm in diameter) with residence time of 1.05 s. The combined system of the wet type ESP and ESP with a carbon fabric plate electrode also was examined for removing them. These results suggest that the wet-type ESP has a potential of the simultaneous removal of gaseous and particulate pollutants.

## 1. Introduction

Electrostatic precipitator has been widely utilized to control particulate matter in industrial and indoor ventilation systems for cleaning gas flow [1-4]. The collection efficiency is usually more than 99%, and fine particles causing adverse effects on human health also can be collected effectively[3]. However, ESP has not been used to remove gaseous pollutants from a gas flow[4]. Recently, a wet-type ESP had been reported to remove soluble and non-soluble pollutants such as $NO_2$, $SO_2$, HCl, and dioxins [3-5]. Especially, it is very useful for treating them because odor pollutants existing in indoor air such as acetaldehyde ($CH_3CHO$), formaldehyde (HCHO) and ammonia ($NH_3$) are water-soluble. Volatile organic compounds (VOCs) from numerous industries are also typical gaseous pollutants, and their presence in our environment has been considered to be serious environmental challenge because of causing health hazard. Therefore, it is very important to control not only particulate matters but also these gaseous pollutants in the atmosphere environment.

Previous work using an rectangular ESP equipped with an electrostatic flocking electrode (E.F.Electrode) demonstrated high collection performance on capturing airborne particles such as tobacco smoke [6-7]. Purpose of this study is to test the feasibility of simultaneous removal of gaseous pollutants and airborne particles using a wet-type ESP equipped with a wet E.F.Electrode. Voltage and corona current characteristics (V-I characteristics), removal efficiencies of acetaldehyde and fine particles were measured. Furthermore, in order to remove the ozone generated by dc corona discharge, an ESP with a carbon fabric plate electrode (C.F.P.Electrode) as a collecting plate was experimentally examined.

## 2. Experimental

### 2.1 Experimental reactor

Figure 1 shows the details of a wet-type ESP. It consists of an E.F.Electrode backed with swelled polymer (wet E.F.Electrode) as a collecting electrode and a stainless steel wire discharge electrode of 0.1 mm diameter. The E.F.Electrode was made of a metal mesh (20 mesh) using electrostatic flocking of nylon fibers with following characteristics: volume resistivity of less than $10^8$ Ωm,

**Key words** electrostatic precipitator, acetaldehyde, ozone electrostatic flocking, carbon fabric

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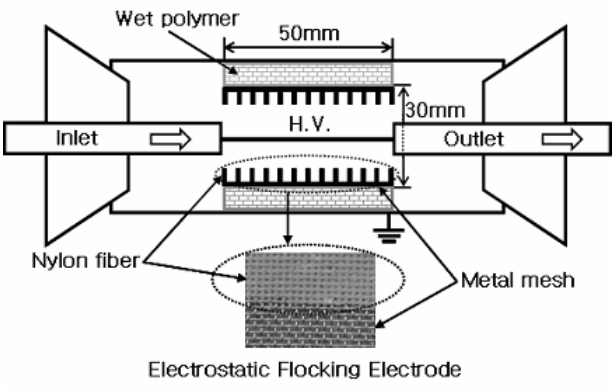
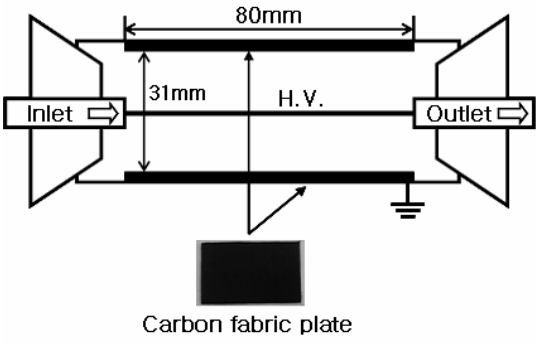
diameter 19.5 ㎛ and length 1 mm [6-7]. Wet E.F.Electrode of which length was 50 mm was placed on the inner wall of an acryl cylinder (O.D.: 50 mm, length: 200 mm). The polymer layer was swelled with $CaCl_2$ solution (5%, 50cc). Figure 1(b) shows the details of an ESP equipped with a carbon fabric plate as a collecting electrode. The ESP consists of a cylindrical carbon fabric plate, which has thickness of 1.5 mm and length of 80 mm, and discharge electrode of 0.1 mm stainless steel wire at the center. The collecting plate was placed in an acryl cylinder with inner diameter of 34 mm and length of 150 mm.




(a)




(b)

Fig. 1 Details of a wet-type ESP with a wet E.F.Electrode(a) and an ESP with a C.F.P.Electrode (b)

**2.2 Experimental setup**

Figure 2(a) shows a schematic diagram of experimental setup for measuring collection efficiency for submicron particles.

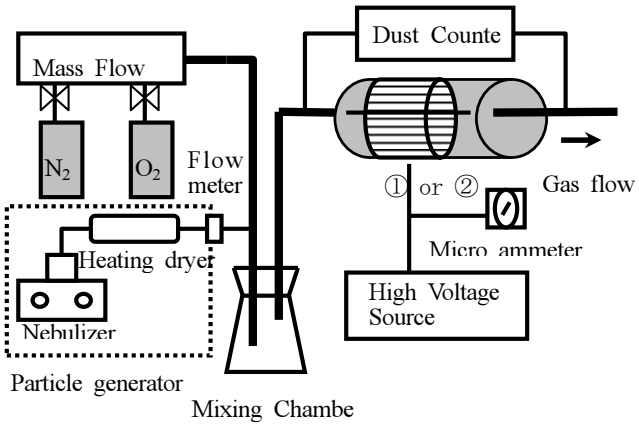
Fluorescent particle (Fluoresbrite Multfluorescent 0.5 μm Microspheres) was used as tested submicron particles. The fluorescent particle stock solution of concentration of $3.9\times10^{11}$/mL was diluted 4000 times with pure water and the diluted solution was sprayed by a nebulizer and introduced into the duct after drying by using a heating dryer. The generated submicron particles were mixed in a mixing chamber with particle-free clean air ($N_2$: 80% and $O_2$: 20%, 0.5 L/min) to obtain desired flow rates and introduced into the ESP. Total gas flow rate was set at 2L/min resulting in the residence time about 1.05 s in the wet type ESP or 1.8 s in the ESP with C.F.P.Electrode. The collection efficiency of the particles from 0.3 μm to 0.5 μm in a geometric mean diameter was measured by using a dust counter (Dan-science 82-1800). The average number concentration of inlet aerosol was $1.37\times10^4$ count/L. The collection efficiency η is given by Eq.(1).

$$\eta\ (\%) = \frac{N_{inlet} - N_{outlet}}{N_{inlet}} \times 100 \qquad (1)$$

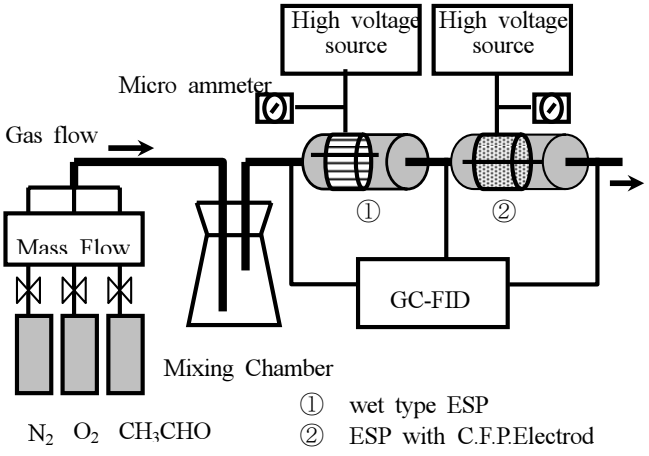
Where, η = collection efficiency of the tested ESP

$N_{inlet}$ = Particle number concentration of inlet of the tested ESP

$N_{outlet}$ = Particle number concentration of outlet of the tested ESP




(a)




(b)

Fig. 2 Schematic diagram of the experiment setup:
(a) particle treatment system (b) gas treatment system using the combined system

Figure 2(b) shows a schematic diagram of experimental setup for treatment of gaseous pollutants using the combined system of the wet type ESP using wet E.F.Electrode and ESP with C.F.P.Electrode. Test gases were prepared from gas cylinders ($CH_3CHO$: 285 ppm ($N_2$ base), $N_2$: 99.9%, $O_2$: 99.9%). Total gas flow rate was set at 1L/min using mass flow controllers, and the gas residence time in wet-type ESP with a wet E.F.Electrode and ESP with a carbon fabric plate electrode (C.F.P.Electrode) was about 2.1 and 3.6 s, respectively. Acetaldehyde diluted with nitrogen and oxygen ($N_2$: base, $O_2$: 20%) was selected as a simulated gas. 30 ppm of acetaldehyde was used in this experiment. Inlet and outlet concentrations were analyzed using a gas chromatograph (Shimadzu Corp., GC-14B) equipped with a flame ionization detector (FID). The operating temperature of GC-FID was set at 150°C.

The removal efficiency of acetaldehyde defined in Eq.(2) was calculated by measuring the concentration at the inlet and outlet in each reactor of the combined system.

$$\text{Removal efficiency}\ (\%) = \frac{C_{in} - C_{out}}{C_{in}} \times 100 \qquad (2)$$

Where, $C_{in}$ (ppm)＝Inlet concentration of tested ESP

$C_{out}$ (ppm)＝Outlet concentration of tested ESP

In both tests, a high-voltage power supply (Pulse Electronic Engineering Co., Ltd, Model-502) was used to apply a various dc negative high voltage. A micro ammeter and a high voltage probe were used to measure corona current according to applied voltages. Ozone concentration was also measured with gas detection tubes (GASTEC Co., Ltd). All the experiments were carried out at room temperature and atmospheric pressure.

## 3. Results and discussion

### 3.1 Removal of fine particles

#### 3.1.1 Wet-type ESP equipped with a wet E.F.Electrode

In order to examine the corona discharge in the wet-type ESP, voltage and corona current characteristics were measured and compared to those of a dry-type ESP with dry flocking fibers. The results were plotted in Fig. 3. In the wet-type ESP, corona onset voltage was -5 kV and flashover occurred at -11 kV. In case of the dry type ESP onset and flashover voltage were -5.5 kV and over -9 kV, respectively. Corona current of the wet-type ESP was higher than that of the dry-type one. This is due to lower electrical resistance of the wet flocking fibers compared with dry flocking fibers. In case of the wet ESP, the back corona can be also effectively suppressed than the ESP with dry flocking fibers irrespective of humidity condition of the air.

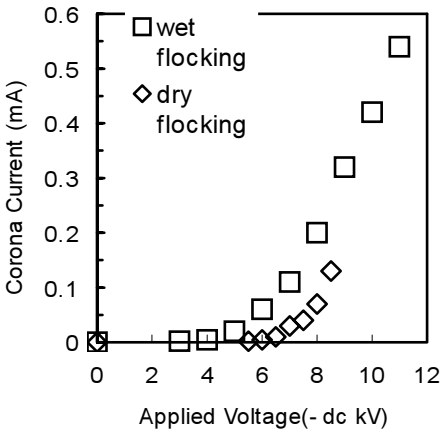



Fig. 3 V-I characteristics: 2L/min of total gas flow with particle loading

Figure 4 shows the collection efficiencies for particles between 0.3-0.5 μm in diameter using the wet-type and dry-type ESP. Without any voltage application, collection efficiency of the wet-type ESP and the dry-type ESP were about 31.4%, 15.7%, resulting from spontaneous particles deposition on the collecting plate and inner wall of the reactor. Collection efficiency rapidly increased with applied voltage and then reached a plateau of about 94% and 87-89% respectively at –7 kV. The time-lapse change of the collection efficiency was measured at –7 kV as shown in Fig. 5. During operation for 90minute collection efficiency showed almost constant value. Judging from Figs. 4 and 5, overall collection performance of the wet-type ESP for submicron particles was higher than that of the dry-type one. These results can be attributed to the following reasons: 1) a wet-type E.F.Electrode more effectively suppressed re-entrainment of precipitated particles by a water film on the surface of the collecting plate in addition to suppression of re-entrainment due to gradient force produced by convergence of electric field at the tip of fibers as well as the suppression of backward gas stream [6,7),9)] 2) as shown in Fig. 3, the higher corona current in case of wet-type ESP also enhanced the amount of the particle charge resulting in the higher migration velocity of the particles to the collecting plate.

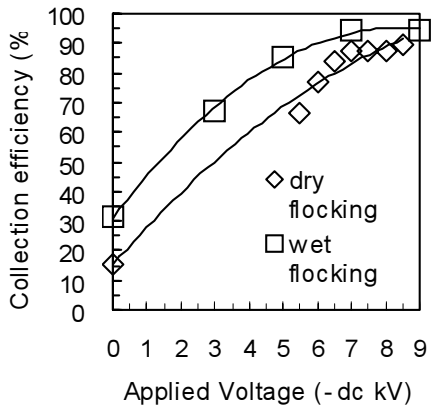



Fig. 4 Collection efficiency for submicron particles of 0.3–0.5 μm in diameter: gas flow of 2 L/min, residence time of 1.05 s

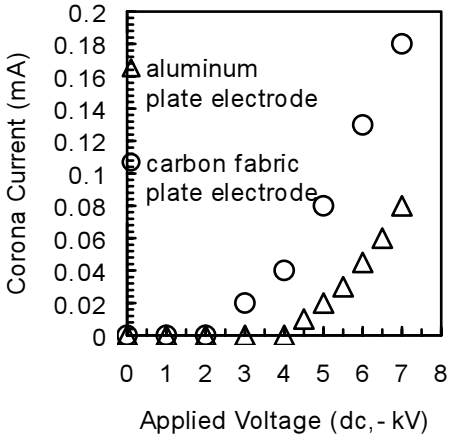



Fig. 6 V-I characteristics of ESP equipped with a C.F.P.Electrode: gas flow-2 L/min ($O_2$: 20%, $N_2$: base)

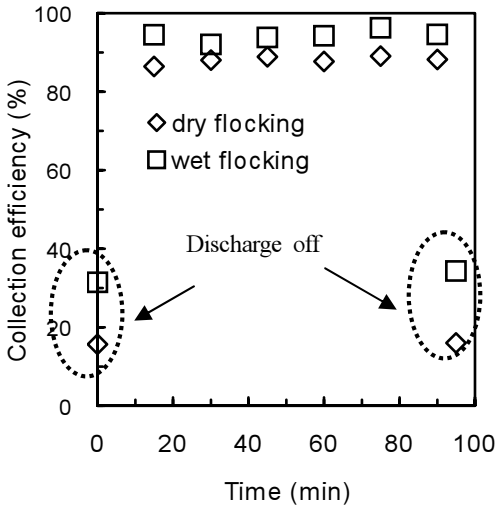



Fig. 5 Time-lapse change of collection efficiency: applied voltage -7 kV, gas flow of 2 L/min, residence time of 1.05 s

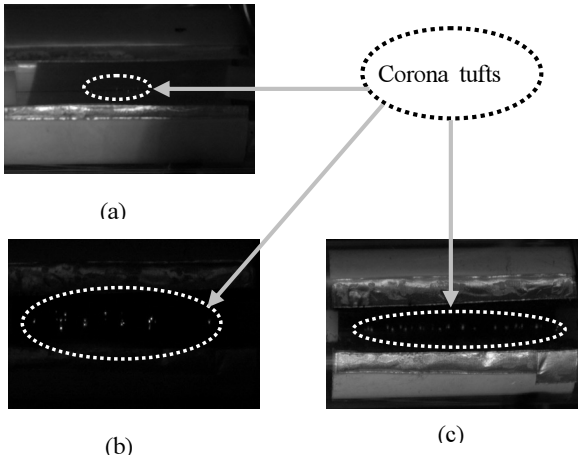



Fig. 7 Discharge image: (a) aluminum plate -4.5 kV (b) carbon fabric plate -3.5 kV (c) carbon fabric plate -4.5 kV

**3.1.2 ESP equipped with a C.F.P.Electrode**

V–I characteristics of the ESP equipped with a C.F.P. Electrode was shown in Fig. 6. The V–I characteristics of an aluminum plate electrode is also shown in the figure. In case of the C.F.P. Electrode, when negative dc high voltages were applied to the wire electrode, the corona onset voltage was about –3 kV and flashover was observed at –7 kV or –7.5 kV. On the other hand, in case of the aluminum plate electrode, the corona onset voltage and the flashover voltage were about –4.5 kV and at –12 kV, respectively. Corona current of the C.F.P. Electrode was much higher than that of the aluminum plate electrode. This is partly because of the difference of the discharge configurations as shown in figure 7.

Figure 7 shows the photographs of the discharge image in both cases. In case of aluminum plate, a small number of bright spots were observed on the discharge wire as shown in (a). This is quite similar to typical negative corona discharge. In case of the C.F.P.Electrode shown in (b) (c), a large number of bright spots were observed. In this case, some carbon fiber particles were attracted to the high voltage electrode and stuck on its surface. These particles triggered the corona discharge. Actually, there were two types of bright spots observed when the C.F.P.Electrode was used. One was the normal corona spots along the wire similar to those in case of aluminum plate, and the other was found at the attracted carbon fiber particles on the discharge wire. The

number of corona spots can be a good explanation for the higher corona current in case of C.F.P.Elelectrode.

Ozone generation in ESPs is a serious problem in the real applications [8), 10-11)]. In this experiment, to suppress the ozone generated by corona discharge using the C.F.P.Eelectrode was examined.

Figure 8 shows the comparison of ozone generation between C.F.P.Electrode and aluminum plate electrode typically used in conventional ESP. As a result, ozone concentration of the C.F.P.Electrode was much lower than that of the aluminum plate electrode. For example, comparing in case of the same corona current of 20 μA, the ozone concentration in case of the C.F.P.Electrode was 0.2 ppm but in case of aluminum plate electrode, it was about 60 ppm. These results suggest that ozone was adsorbed or decomposed on the C.F.P.Electrode.

Collection efficiency for the submicron particles using the C.F.P.Electrode was examined. Figure 9 shows collection efficiency as a function of applied voltage. As shown in Fig. 9, when the applied voltage was only −3 kV, collection efficiency was more than 90%. We achieved collection efficiency of about 92-95% when the applied voltage exceeded −3 kV, and at the same time ozone concentration was about 0.2-6 ppm (corona current was about 20−130 μA). These results suggest that the process using the combination of corona discharge and C.F.P.Electrode is effectively applicable not only to suppress ozone but also to capture fine particles as well as low voltage operation.

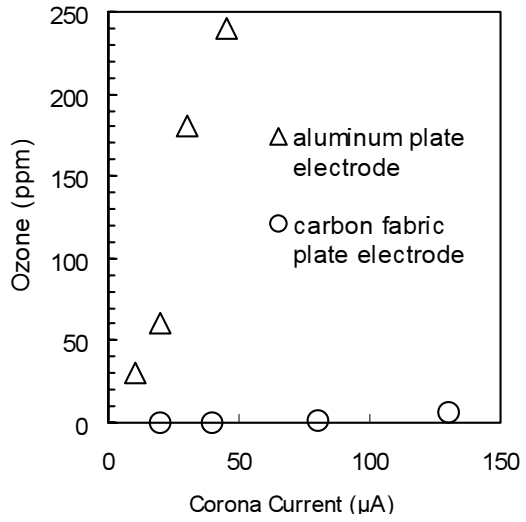



Fig. 8 Ozone generation with two different types of collecting plates as a function of corona current: gas flow-2 L/min ($O_2$: 20%, $N_2$: base)

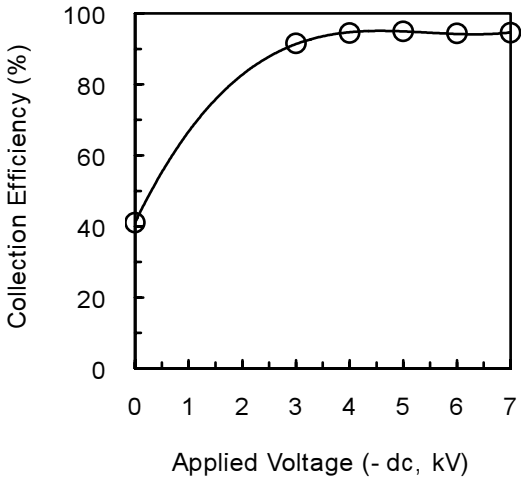



Fig. 9 Collection efficiency for submicron particles of 0.3-0.5 μm in diameter: gas flow of 2 L/min, residence time of 1.8 s.

**3.2 Removal of acetaldehyde and ozone**

The combined system shown in Fig. 2(b) was tested for removal of acetaldehyde and ozone. The results were shown in Table 1. Figure 10 shows the removal efficiencies of acetaldehyde for one-pass test in the wet-type ESP as a function of input power. And the results were compared with those of the wet-type ESP and the dry-type ESP with and without flocking fibers. Without any voltage application, acetaldehyde removal efficiency was about 10% in the wet-type ESP and the combined system due to adsorption. The removal rate increased with input power and when the input power exceeded 6 W the removal efficiency was saturated and maximum removal efficiency of the wet-type ESP alone was about 68.2% at 8.4 W of input power. Comparing at the same input power of about 6 W, the wet-type ESP achieved removal efficiency 28% higher than dry-type ESP without flocking fibers. Using the combined system, the maximum removal efficiency was 71.1%. The increase in the removal efficiency with applied voltage can be attributed to the following reasons: 1) ionic wind by corona discharge accelerated gas flow toward collecting plate resulting in enhanced absorption, 2) wet collecting plate promoted absorption of acetaldehyde because of its water-soluble characteristic, 3) OH radical by corona discharge in humid condition might have played a role to decompose acetaldehyde to $CO_2$ and $H_2O$ [4)].

Table 1 Acetaldehyde and ozone concentration in the combined system: $C_{a1}$ (outlet of the wet type ESP), $C_{a2}$ (outlet of the combined system), $C_{oin}$ (generated ozone in the wet type ESP), $C_{o1}$ (without voltage application in the ESP with C.F.P.Electrode), $C_{o2}$ (with –dc 5 kV, 80 μA in the ESP with C.F.P.Electrode)

| Applied voltage (-dc, kV) | Acetaldehyde (ppm) | | Ozone (ppm) | | |
|---|---|---|---|---|---|
| | $C_{a1}$ | $C_{a2}$ | $C_{oin}$ | $C_{o1}$ | $C_{o2}$ |
| 0 | 26.1 | 25.6 | - | - | - |
| 8 | 16.8 | 16.0 | 60 | 55 | 8 |
| 9 | 14.3 | 13.8 | 100 | 90 | - |
| 10 | 12.4 | 12.2 | 105 | 100 | 12 |
| 11 | 9.7 | 9.0 | 100 | 100 | 12 |
| 12 | 9.2 | 8.4 | 100 | 100 | 13 |

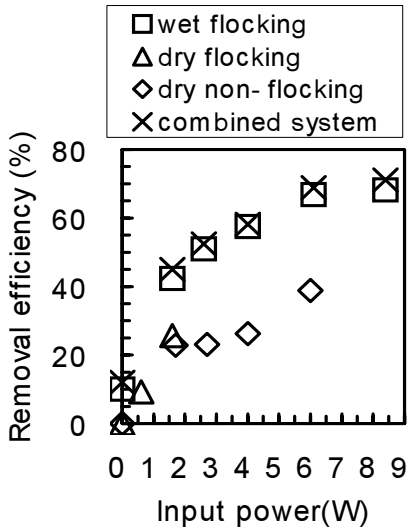



Fig. 10 Removal efficiency of acetaldehyde as a function of input power: gas flow of 1 L/min, residence time of 2.1 s (the wet type ESP) and 3.6 s (ESP with C.F.P.Electrode).

Wet-type ESP showed high removal efficiency for submicron particles and acetaldehyde but high concentration ozone was also generated. To cope with this problem, ozone removal using the combined system was examined. The results are summarized in Table 1. For various applied voltages to the wet-type ESP, ozone concentration at down -stream of the wet-type ESP and ESP with C.F.P.Electrode was measured in the combined system. Ozone of 100 ppm, which was generated in the wet-type ESP, was reduced to 12-13 ppm by passing through the ESP with C.F.P.Electrode fixed at –5 kV (80 μA) during operating the combined system.

## 4. Conclusions

The dc corona discharge with a wet electrostatic flocking electrode has been employed in order to examine the performance of simultaneous removal of gaseous pollutants and particulate matters. And carbon fabric plate as a collecting electrode was experimentally studied to suppress ozone generation by dc corona discharge in ESPs. The results are summarized as follows:

1) Removal efficiency of acetaldehyde using the wet-type ESP alone was about 68.2% at 8.4 W of input power with residence time of 2.1 s.

2) The collection performance of wet E.F.Electrode for submicron particles (0.3-0.5 μm in diameter) was higher than that of dry type one. In case of wet E.F.Electrode collection efficiency was achieved 94.2% at –dc 7kV. On the other hand in case of dry E.F.Electrode was 87.1% at the same voltage.

3) The process using the combination of corona discharge and carbon fabric plate is effectively applicable not only to suppress ozone but also to achieve high collection efficiency for submicron particles.

Consequently, the wet-type ESP and the combined system have a potential of the simultaneous removal of gaseous and particulate pollutants and can cope with the well-known problems of ESPs, such as abnormal re-entrainment of particles with low resistivity and back corona for high resistivity particles.

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