Improving Nano-particle Collection Efficiency and Suppressing Particle Re-entrainment in an AC Electrostatic Precipitator with Hole-punched Electrode

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Abstract: the experiments carried out in this study have focused on improving nano-particle collection efficiency and suppressing particle re-entrainment at the same time in an ACESP with hole-punched electrode. a trapezoidal ac high voltage was applied to a collector. the collection efficiencies as a function of particle diameter were studied on three ESP cases, which were the universal DCESP, DCESP with hole-punched electrode and ACESP with hole-punched electrode. as a result, ACESP with hole-punched electrode was successfully developed.

Keywords: Electrostatic Precipitator, nano-particle, re-entrainment

1 INTRODUCTION

An electrostatic precipitator (ESP) has been extensively used for the cleaning of industrial process flue gases, combustion flue gases, and ventilation flue gases of buildings, etc., because of its high collection efficiency. One of the applications of ESP is decontaminating polluted gases and improving the visibility index in road tunnels in order to improve both driver safety and the environment around tunnels. Almost of suspended particles in road tunnels are diesel exhaust particles (DEP).

A conventional ESP has high collection efficiency but still needs to improve collection efficiency for nano or ultra fine particles smaller than 100 nm and suppress particle re-entrainment. Almost of the number of DEP are nano or ultra fine particles[1]. It is also increasingly reported that nano-particles exert a harmful effect on human body[2]. Therefore, it is important to improve the collection efficiency for nano-particles. On the other hand, the particle re-entrainment becomes the cause to decrease the collection efficiency.

Several attempts that are proposed to enhance the collection of nano or ultra fine particles are suggested, which are physical agglomeration[3-7], chemical agglomeration [8-9], thermal precipitations[10], electron particle charging[11, 12], wet electrostatic precipitation[1, 11, 13], electrostatic separation with soft X-ray irradiation[14]. Among these approaches, most of investigations indicate the effectiveness to enhance the collection of nano or ultra fine particles. However, these techniques remain under investigation or need more energy and additional system to ESP. We suggested the DCESP with hole-punched electrode to improve nano-particle collection efficiency[15]. DC high voltages are applied to a pre-charger and a collector. An additional system and more energy are not needed in this ESP.

An ESP with rectangular AC electric field was developed to suppress particle re-entrainment[16]. It has been already installed to several road tunnels in Japan and Korea. The suspended particulate matter is charged by DC corona in a precharger, and charged particles are collected by AC electrostatic force in a collector.

In this paper, the experiments have focused on improving nano-particle collection efficiency and suppressing particle re-entrainment in the same time. The experimental ESP was a two-stage type comprised of a pre-charger and a collector. The pre-charger consisted of tungsten wire and stainless plates. The collector had a parallel-plates configuration, including grounded electrodes and high voltage electrodes. Hole-punched stainless plates were used as the high voltage electrode to improve nano-particle collection efficiency. DC high voltage was applied to a pre-charger, and trapezoid AC high voltage was applied to a collector to suppress particle re-entrainment.

2 EXPERIMENTAL

2.1 Summary Of Experimental System

The electrostatic precipitator used in this paper is shown in Fig. 1. The gases exhausted from the diesel engine were diluted with air in the mixing chamber, then boosted by the fan and introduced into the ESP system. The gases cleaned by the ESP passed through the absorbing fan and then were exhausted. The gas velocity in the duct was approximately 7 m/s.

2.2 ESP Arrangement And Sampling Location

The ESP arrangement is shown in Fig. 2. The two-stage-type ESP consisted of a pre-charger and a collector. The electrode of the pre-charger consisted of wires and plates. The wire of tungsten was 0.26 mm in diameter, and plates were made of stainless. Negative corona discharge [–9.2 kV DC, 0.06mA] was used to charge particles in the pre-charger. The collecting section had a parallel-plates configuration and the spacing between each plates was 9 mm. A negative high voltage of -8 kV DC or a negative trapezoid AC high voltage –8 kV AC were applied. The trapezoid AC high voltage, which is generated by HV generator (Matsusada Precision, HEOPT-20B20-CL), is shown in Fig. 3. The frequency is 2 Hz, the voltage rise time rate dV/dt is 500 V/msec.

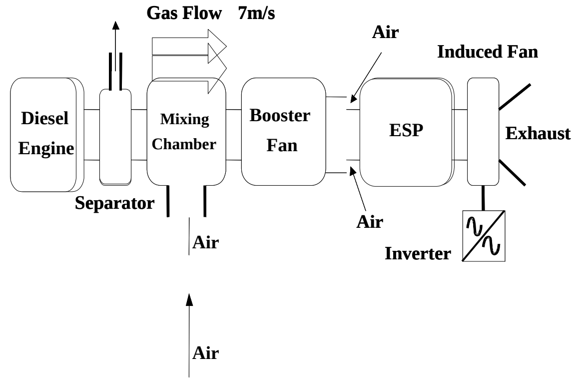


Fig. 1 Schematic diagram of electrostatic precipitator

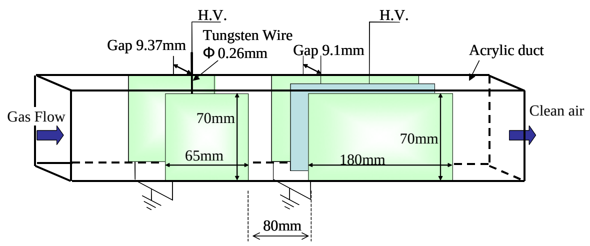


Fig. 2 Structure of electrode on two-stage type ESP

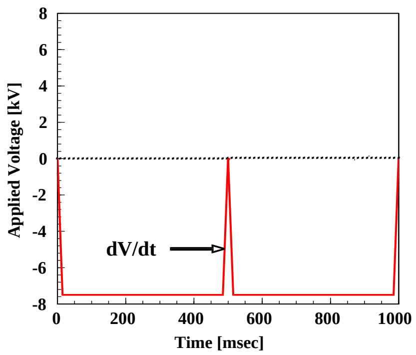


Fig. 3 Wave form of trapezoid AC high voltage

The upstream and downstream particle concentrations were measured to estimate the ESP performance by a scanning mobility particle sizer (SMPS, TSI, Model3080) and particle counter (PC, RION, KC-01C). The SMPS can measure the particle concentration between 20 to 500 nm. The PC can measure it between 500 nm to 5000 nm. The collection efficiency is calculated by

$$\eta = (1 - N_D/N_U) \times 100\ [\%] \tag{1}$$

where N_U is the upstream particle concentration and N_D is the downstream particle concentration in the ESP.

2.3 Structure of Collecting Electrode

The collector had a parallel-plates configuration, including a grounded electrode and a high voltage electrode. The experiments were done in three cases of collectors. The condition of three cases is shown in Table 1. The Case 1 is DC ESP, which has plate electrodes and is applied DC high voltage to the collector. The Case 2 is DC ESP with hole-punched electrode, which has hole-punched electrodes and is applied DC high voltage in the collector. The Case 3 is AC ESP with hole-punched electrodes, which has hole-punched electrode and is applied trapezoid AC high voltage in the collector. A hole-punched stainless plate was used as the high voltage electrode in order to improve nano-particle collection efficiency. The structure of the hole-punched electrode is shown in Fig. 4. The size of electrode is 70 mm by 160 mm. The electrode has holes, which are 2.5 mm in diameter. The aperture rate is 17.2%. The trapezoid AC high voltage was applied to collector for preventing particle re-entrainment.

Table 1 Condition of experiments

Case	Voltage in precharger	Structure of electrode in Collector: Grounded electrode	Structure of electrode in Collector: High voltage elecrode	Voltage in collector
1	- 9.2 kV DC, 0.06 mA	Plate	Plate	- 8.0 kV DC
2	-9.2 kV DC, 0.06 mA	Plate	Hole punched plate	-8.0 kV DC
3	-9.2 kV DC, 0.06 mA	Plate	Hole punched plate	-8.0 kV, 2 Hz of trapezoid AC

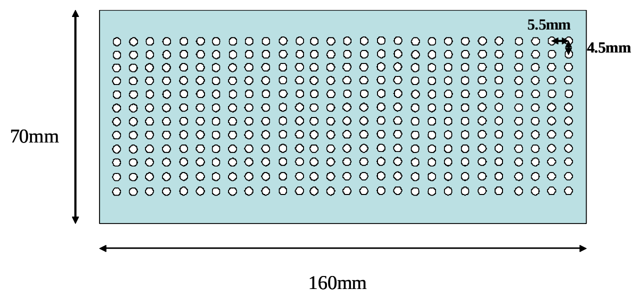


Fig. 4 Structure of hole-punched electrode

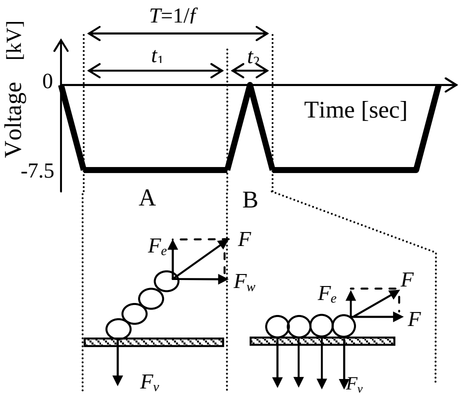
3 RESULT AND DISCUSSION

3.1 Model Of Collecting Nano-particle

ESP with hole-punched electrode is suggested for improving nano-particle collection efficiency. It is improved due to the effect of the hole edge of hole-punched high voltage electrodes in a collector. This effect is increasing the electric field near the hole edges. Therefore, the particle migration velocity is increases due to increasing the electric field [15].

3.2 Model Of Preventing Re-entrainment

Collected particles on collector agglomerate like a pearl-chain and re-entrain in DC ESP, because of low resistively. The model of preventing re-entrainment in AC ESP, which is the Case 3, is shown in Fig. 5. Electrical force Fe and wind force F_w act to collected particles in the period t_1 of Fig. 5. Particles agglomerate like a pearl-chain in period t_1 same as DC ESP. However, agglomerated particles change the shape in the period t_2 due to decreasing the electrical force F_e. Therefore, the contact area increases in AC ESP compared



with DC ESP, so that particle re-entrainment is prevented.

Fig. 5 Structure of hole-punched electrode

3.3 Effect of Hole-Punched Electrode On Nano Particle Collection

The particle size distribution upstream and down- stream gases in DC ESP, which is the Case 1, is shown in Fig. 6. The upstream particle concentration between 10 nm to 1000 nm decreases compared with downstream. However, the downstream particle concentration between 1000 nm to 2000 nm is almost same with upstream. That between 2000 nm to 5000 nm increases compared with upstream.

The upstream and downstream particle size distribution in DC ESP with hole-punched electrode, which is the Case 2, is shown in Fig.7. The downstream particle concentration between 10 nm to 1000 nm decreases compared with upstream. The decreasing amount in DC ESP with hole-punched electrode shown in Fig. 7 is greater than that of DC ESP shown in Fig. 6 due to effect of electrical field near the hole edge [15]. However, effect on the particle concentration between 1000 nm to 5000 nm does not indicate.

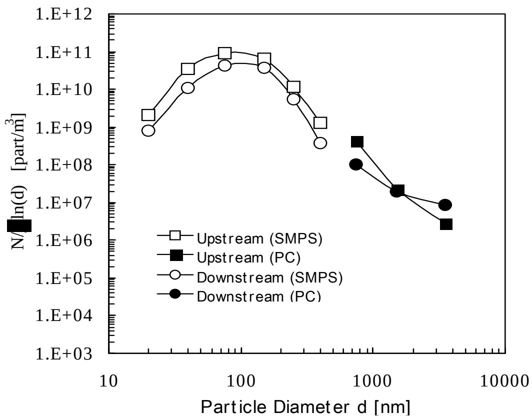


Fig. 6 Particle size distribution in DC ESP (Case 1)

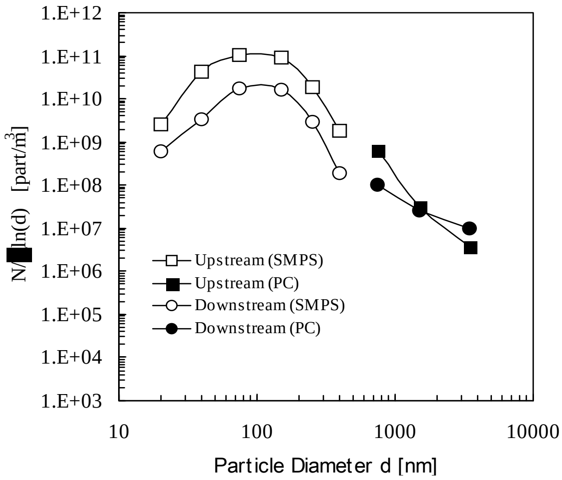


Fig. 7 Particle size distribution in DC ESP with hole-punched electrode (Case 2)

3.4 Effect Of Trapezoid AC high voltage

The particle size distribution upstream and downstream ESP in AC ESP with hole-punched electrode, which is the Case 3, is shown in Fig. 8. The downstream particle concentration between 10 nm to 1000 nm does not only decreases, but that between 1000 nm to 5000 nm also decreases compared with upstream. This result is the effect of trapezoid AC high voltage on suppression particle re-entrainment.

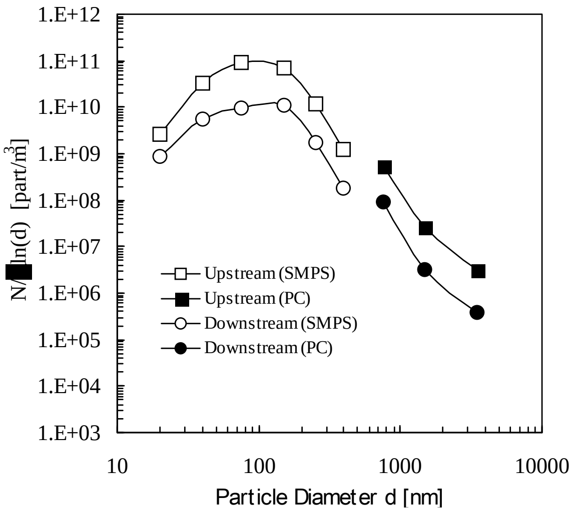


Fig. 8 Particle size distribution in AC ESP with hole-punched electrode (Case 3)

3.5 Effect On Collection Efficiency

The collection efficiency between 10 nm to 500 nm as a function of particle diameter for various cases is shown in Fig. 9. The collection efficiency has a minimum value in diameter of approximately 150 nm in DC ESP. The collection efficiencies of all diameters in DC ESP with punched electrode is greater than that in DC ESP due to increasing the electric field near the hole edge. The collection efficiency in AC ESP with hole-punched electrode is almost same with DC

ESP with hole-punched electrode.

The collection efficiency between 500 nm to 5000nm as a function of particle diameter for various cases is shown in Fig. 10. The collection efficiencies in DC ESP and DC ESP with hole- punched electrode decrease with increasing the particle diameter due to particle re-entrainment. On the other hand, the collection efficiency in AC ESP with hole- punched electrode significantly improves compared with another cases due to the effect of trapezoid AC high voltage

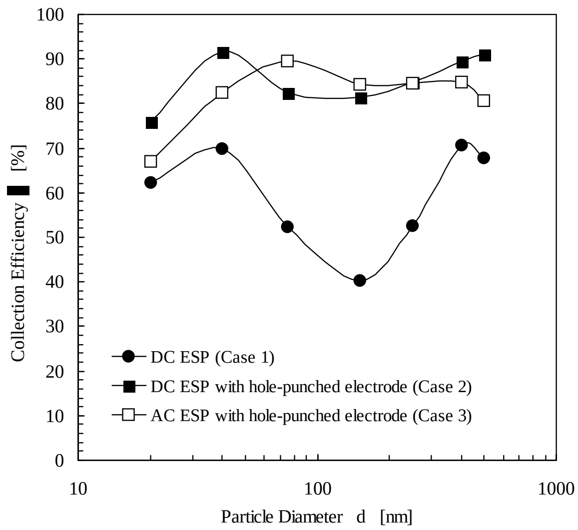


Fig. 9 Collection efficiency as a function of particle diameter for various cases. (Particle size: 10 nm to 500 nm)

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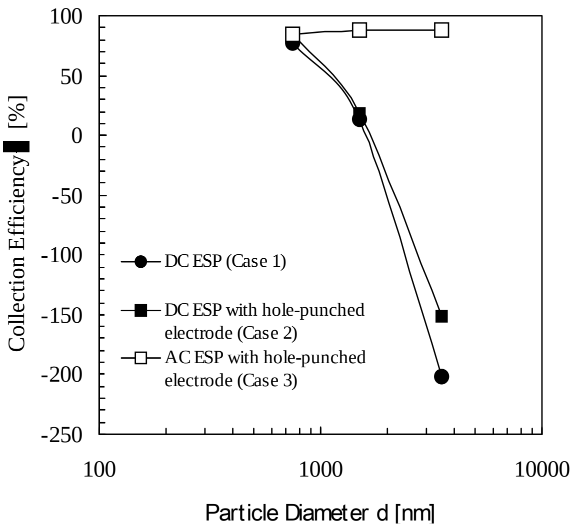

Fig. 10 Collection efficiency as a function of particle diameter for various cases. (Particle size: 500 nm to 5000 nm)

4 CONCLUSIONS

AC ESP with hole-punched electrode was suggested to improve the nano particle collection efficiency and suppress particle re-entrainment. As a result, it is clear that the nano particle collection efficiency improved due to the effect of hole-punched electrode. It is also clear that the particle re-entrainment is suppressed due to the effect of trapezoid AC high voltage.

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