Diesel Exhaust Particle Reduction using Electrostatic Precipitator

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Abstract

Electrostatic precipitators (ESPs) are used to decontaminate polluted environment. Conventional ESPs has high collection efficiency but still has a problem in that collection efficiency decreases due to particle re-entrainment for collection of low resistive deisel particulates such as marine engines. In this study, the effect of electrode configuration on collection performance of deisel particulates was investigated using a one-stage and a two-stage ESP. The particle concentration for the particle size ranging in 20 to 5,000 nm was measured using a scanning mobility particle sizer (SMPS) and a particle counter (PC). The collected particles on electrodes were observed usign a scanning electron microscope (SEM). The collection efficiencies as a function of the electrode length and the particle diameter were estimated. As results, the particle re-entrainment was suppressed with increasingn the number of discharge electrode in the one-stage type ESP and increasing the collection electrode length of the collection section in two-stage type ESP.

1 INTRODUCTION

Electrostatic precipitators (ESPs) have been extensively used for the cleaning of industrial process flue gases, combustion flue gases, and ventilation flue gases of road tunnels, etc.. Conventional ESPs has high collection efficiency but still has a problem in that collection efficiency decreases due to particle re-entrainment. The collection of low resisitive particles are detached from the collection plate where the electrostatic repulsion force due to induction charge exceeds particle adhesion force and electrohydrodynamic shear stress on the collection electrode. This phenomenon has been known as particle re-entrainment. These particles are generated from various emissions such as diesel automobiles, marine engines, power generation engines, and tunnel or underground parking. Therefore, it is very important to suppress the re-entrainment.

Fujimura et. al measured the relation between the particle size distribution and the optical density. They studied the influence of the re-entrainment on the visibility in road tunnels[1]. Takahashi studied the influence of the re-entrainamet on the particle deposition on the wall[2]. Re-entrained particle charging polarity and the particle behavior after re-entrainment were investigated [3]. H.Masuda, et.al suggested that charged particles re-entrained easily compared with uncharged particles [4] and the frequency of the re-entrainment depended on the structure of the electrode surface, the gas velocity and the particle size [5]. Felder et. al noted that collection electrodes covered by particles exhibited higher efficiency than uncovered collection electrodes. They concluded that this is due to the decrease re-entrainment [6]. Several attempts that had been proposed to surpress re-entrainment are as follows;

1) collection electrode coated with a dielectric sheet [7].
2) mixing water mist with gases[8].
3) using an ESP as an agglomerator [9-10]
4) Silent discharge type ESP [11]
5) Application of gradient force [12]
6) ESP by low frequency AC field [13]

However, these concepts have limited success for minimizing the re-entrainment and the fundamental collection characteristic for low resistivity particles was not investigated in the high dust loading and the high gas temperature. The electrohydrodynamically assisted ESP was suggested in this condition [14].

In this paper, the fundamental collection characteristics under high dust loading and high gas temperature were investigated in the one-stage and the two-stage ESP. The influences of the number of the discharge electrode, the collection electrode length and the engine load on the particle size–dependent collection efficiency were investigated using a 199-cc engine. The particle concentration for the particle size ranging in 20 to 5,000 nm was measured using a scanning mobility particle sizer (SMPS) and a particle counter (PC). The collected particles on the electrodes were observed usign a scanning electron microscope (SEM).

2 EXPERIMENTAL SETUP

The schematic diagram of experimental system was shown in Fig.1. Emissions from a small diesel engine generator (Yammer Co., Ltd., YDG200A-5E, direct injection type for a single cylinder, displacement volume of 199 cc, maximum electric power output of 1.7 kW) using light oil with 3000 rpm were used to achieve a high dust loading, high gas temperature in the ESP. In order to determine the number particle density in the ESP, the flue gas was diluted approximately 100 times by the dilution system (MD19-3E, Matter) and the particle size-dependent number densities before and after the ESPs were determined by the Scanning Mobility Particle Sizer (SMPS, Model3080, TSI) for the particle size ranged 20 - 300 nm and the Particle Counter (KC01-E, RION) for the particle size of 300 – 5,000 nm, respectively. The collected particles on the collection electrode were observed usign a scanning electron microscope (SEM). The exhaust gas temperature was 130 - 200 ℃. The gas velocity in the ESP was approximately 1.3 m/s. The engine load was varied from 30, 60 and 90 %. The collection efficiency η was calculated by equation (1).

$$\eta = \left(1 - \frac{N_u}{N_d}\right) \times 100 \quad [\%] \qquad (1)$$

where, N_u was the upstream ESP particle concentration, N_d was the downstream ESP particle concentration.

The one-stage type ESP configuration was shown in Fig. 2. The one-stage type ESP consisted of grounded plate electrodes and saw tooth form discharge electrodes. The length of the grounded plate electrode was 150, 300 and 450 mm. The saw tooth from arrangement was upstream and downstream discharge electrode edges. The length of discharge electrode is 130 mm. The spacing between the adjacent plates is 9mm. -7.5 kV DC was applied to the one-stage type ESP. The Aluminium foils were attached to electrode to observe collected particles using SEM as shown in Fig. 2 (b).

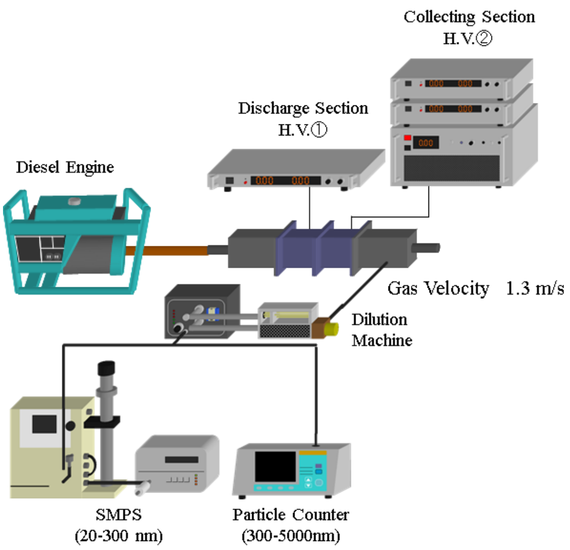
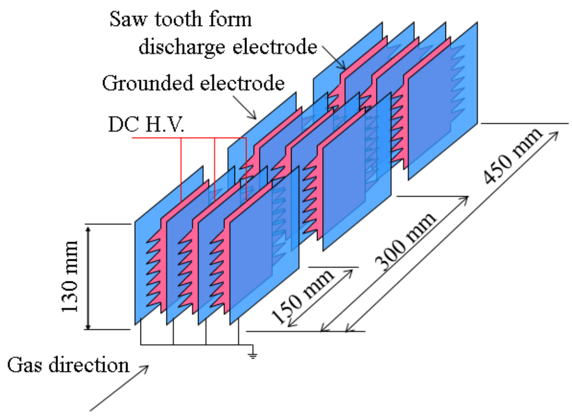
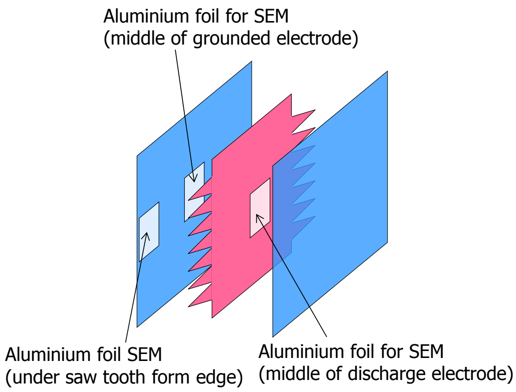


Fig. 1 Schematic diagram of experimental system.



a) Configulation.



b) Sampling location for SEM

Fig. 2 One-stage type ESP cofiguration

The two-stage type ESP configuration was Fig. 3. The two-stage type ESP consisted of the pre-charger and the collecting section. The pre-charger was same with the one-stage type ESP as shown in Fig. 2. However, the length of the grounded plate electrode was 150mm. The collecting section was parallel plate configuration and the spacing between each plate was 9mm. The length of the electrode was 150, 300 and 450 mm. -7.5 kV DC was applied to the pre-charger and -8 kV DC was applied to the collecting section. The aluminium foils were attached on the grounded electrode in the collecting section to observe collected particles by SEM.

The particle-size dependent number density upstream ESP for various engine loads was shown in Fig.4. A maximum value at particle diameter approximately 70 nm was observed in the engine load of 30 %. The peak of number density was shifted to larger particle size with increasing the engine load. The maximum value also increased with increased the engine load.

The particle-size dependent mass density upstream ESP for various engine loads was shown in Fig.5. The peak of mass density was shifted to larger particle size in comparison with the particle number density as shown in Fig.4. The total mass densities were 1.5 mg/m^3 at the engine load of 30 %, 15.4 mg/m^3 at 60 % and 85 mg/m^3 at 90 %.

3 RESULTS and DISCUSSOION

3.1 Collection for One-Stage ESP

The particle-size dependent collection efficiency for various electrode lengths in the one-stage type ESP was shown in Fig.6 when the engine load was 90 %. The collection efficiency at the particle size of 20-300 nm was greater than almost 90 % for all electrode lengths. The collection efficiency at the particle size of 300-5,000 nm for the electrode length of 150 mm decreased with increased the particle size. The collection efficiency greater than 2,000 nm was negative value. The negative collection efficiency indicated that the downstream particle density was greater than upstream particle density due to particle re-entrainment. The collection efficiency at the particle size of 300-5,000 nm increased with increased the electrode length. The collection efficiency at the electrode length greater than 300 mm was positive value due to suppressing particle re-entrainment.

The collected particles on the surface of electrodes were observed to investigate the mechanism of suppressing particle re-entrainment. Pieces of aluminium foil were attached on the grounded electrode surfaces to sample particles as shown in Fig. 2. The pieces were prepared for the SEM. The typical SEM images of collected particles for various sampling locations were shown in Fig. 7. Many large agglomeration particles were observed at the electrode surface under saw tooth form

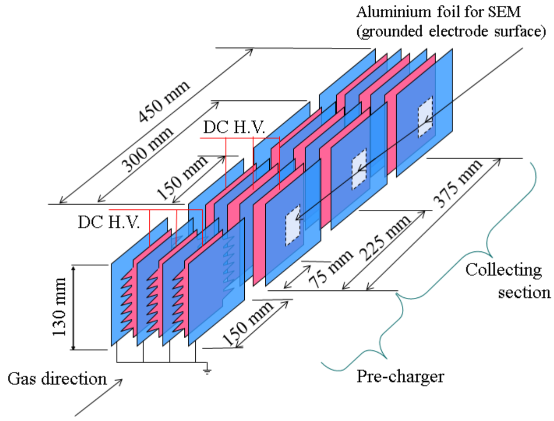


Fig.3 Two-stage type ESP cofigration

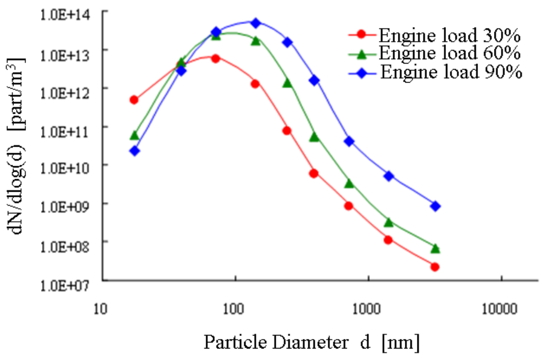


Fig.4 Particle-size dependent number density upstream ESP for various engine loads.

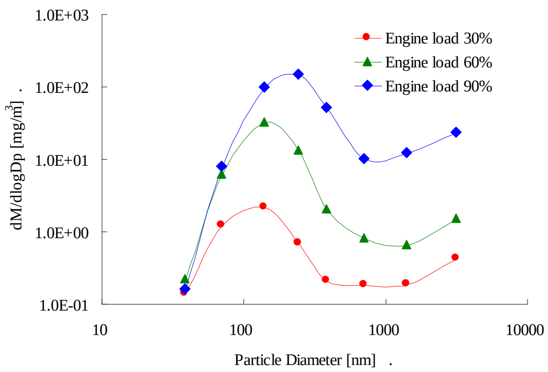


Fig. 5 Paritcle-size dependent mass density upstream ESP for various engine loads.

edge as shown in Fig. 7(a). The particles were pressed down by corona discharge. Therefore, the particles were spherical shape which was difficult to re-entrain due to increasing contact area between particles and electrodes. The particles at the middle position of the grounded electrode formed dendrite due to agglomeration in electrostatic field as shown in Fig. 7 (b). The charges on particles were drained off to the grounded electrode and the positive charges were accumulated on the

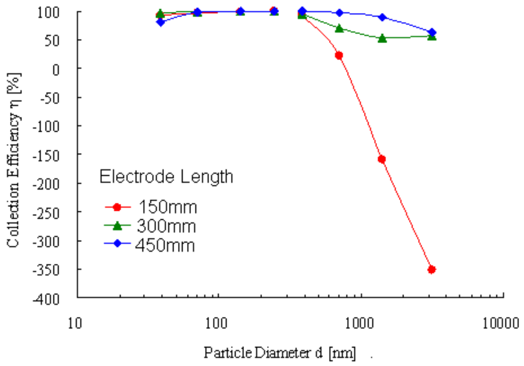


Fig. 6 Particle-size dependent collection efficiency for various electrode length in the one-state type ESP. (Engine load: 90%)

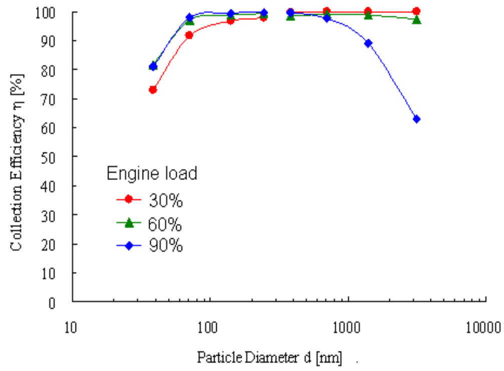
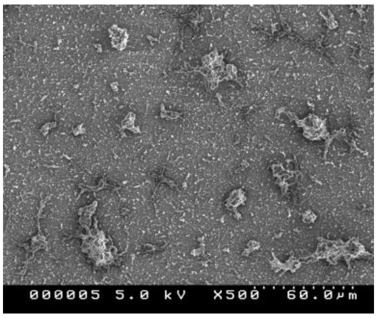
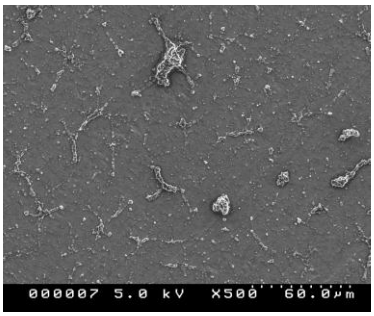


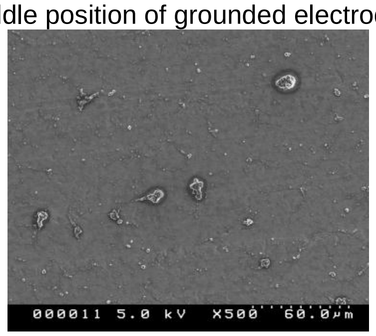
Fig. 8 Particle-size dependent collection efficiency for various engine loads in the one stage-type ESP. (Electrode length: 450mm)



a) Grounded electrode Under saw tooth form electrode



b) Middle position of grounded electrode



c) Middle position of discharge electrode

Fig. 7 The typical SEM images of collected particles for various sampling locations in one stage type ESP

particle due to the induction charge, resulting in dendrite form. The dendrite agglomeration particle was easy to re-entrain due to the aerodynamic force exposed to the gas stream.

The particles at the middle position of the discharge electrode were spherical shape. The area under the saw tooth form edge, where was difficult to re-entrain, increased with increased the discharge electrode length, resulting in further reduction of re-entrainment.

The particle-size dependent collection efficiency for various engine loads when the electrode length was 450 mm was shown in Fig.8. The collection efficiency lager than 1,000 nm increased with decreased the engine load. This was attributed to higher adhesion force due to higher oil mist.

3.2 Collection for Two-Stage ESP

Fig.9 shows the particle-size dependent collection efficiency for various collecting electrode lengths for the two-stage type ESP when the electrode length of the pre-charger was 150 mm and the engine load was 60 %. The collection efficiency at the particle size of 20-300 nm was greater than 90 % for all electrode lengths. The collection efficiency at the particle size of 300-5,000 nm for the electrode length of 130 mm decreased with increased the particle size. The collection efficiency greater than 2,000 nm was negative value due to particle re-entrainment. The collection efficiency at the particle size of 300-5,000 nm increased with increased the electrode length. The collection efficiency at the electrode length of 450 mm was positive value due to suppressing re-entrainment.

The collected particles on the surface of electrodes were observed to investigate the mechanism of suppressed re-entrainment for the two-stage type ESP. Pieces of aluminium foil were attached on the grounded electrode surfaces to sample particles as shown in Fig. 3. The typical SEM images of collected particles for various sampling locations for two-stage type ESP were shown in Fig. 10. Many large agglomeration particles were observed at the electrode surface, where was the position of 75 mm and 225 mm as shown in Fig.10 (a) and (b). The agglomeration particles formed dendrite which was easy to re-entrain. The spherical agglomeration particles, which were difficult to re-entrain, were observed on the electrode surface of 375 mm as shown in Fig. 10 (c). The positively charged re-entrainment particle from the grounded electrode was re-collected on the negatively high voltage electrode. The re-collected particle on the negatively high voltage electrode was charged positively due to induction charge and re-entrained again. These processes were repeated and the particle was changed to spherical shape which was difficult to re-entrain.

4 SUMMARY

The effect of the electrode configuration on the collection performance of deisel particulates was investigated using the one-stage and the two-stage ESP.

The collection efficiency for the electrode length of 150 mm decreased with increased the particle size in the one-stage type ESP due to particle re-entrainment. The particle re-entrainment suppressed with increased the number of the discharge electrode due to particle transformation to spherical form.

The collection efficiency for the collection electrode length of 130 mm decreased with increased the particle size in the two-stage type ESP due to re-entrainment. The particle re-entrainment suppressed with increased the collection electrode length.

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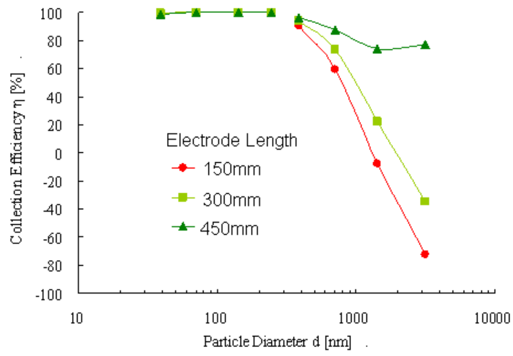
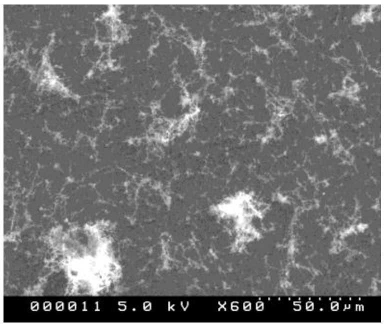
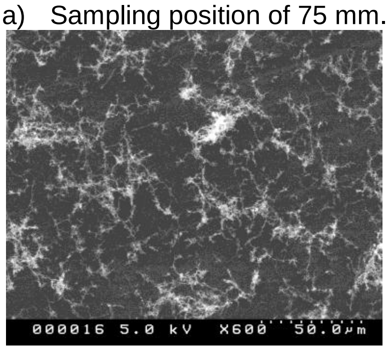


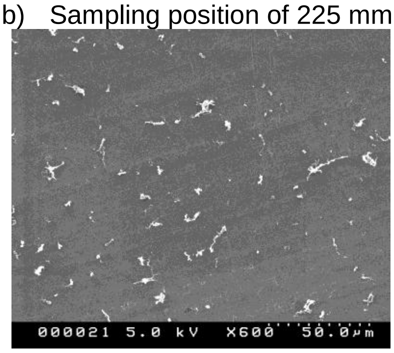
Fig. 9 Particle-size dependent collection efficiency for various collecting electrode length in the two-stage type ESP. (Electrode length of the precharger: 150mm, Engine load: 60%)



a) Sampling position of 75 mm.



b) Sampling position of 225 mm.



c) Sampling position of 375 mm.

Fig. 10 Typical SEM images of collected particles for various sampling locations for two-stage type ESP.

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