Diesel PM Collection for Marine Emissions Using Double Cylinder Type Electrostatic Precipitator

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Abstract

Collection of low resistive particulate matter (PM) generated from marine engines or diesel generators have been known to be difficult by the conventional electrostatic precipitators (ESP). In this study, the double cylinder type ESP was developed to remove the low resistive diesel exhaust particles. Two(W=C ESPs, namely, the conventional single cylinder type ESP (S-Cylinder ESP) and W-Cylinder ESP were investigated using a 6728-cc engine. The particle size-dependent collection efficiency was obtained using a Scanning Mobility Particle Sizer with particle size in the range of 40 - 500 nm and a aerosol spectrometer with particle size in the range of 300-17,000 nm. The particle mass collection efficiency was obtained using a Low Volume Air Sampler. The effectiveness of re-entrainment or collection efficiency for two ESPs was compared. As a result, the conventional S-Cylinder ESP showed good collection efficiency for particle sizes less than 300 nm but showed severe re-entrainment for particle size greater than 1000 nm. W-Cylinder ESP also showed good collection efficiency for particle size less than 300 nm. However, the collection efficiency for particle size greater than 1000 nm was significantly improved due to suppression of particle re-entrainment. This result was also supported by the particle mass measurement and the filter color determined by the LVS. (Spell out).

1 Introduction

Electrostatic precipitators (ESPs) have been extensively used to decontaminate polluted gases exhausted from industrial plants and to clean air in buildings, etc., because of high collection efficiency. However, the collection of these low resistivity particles by the conventional ESPs is known to be difficult. These particles are generated from various emissions such as diesel automobiles, marine engines and power generation engines. The low resistivity particles cause particle detachment from a collection plate by an induction charge, i.e., dust re-entrainment, resulting in a poor collection efficiency.

Several attempts that had been proposed to surpress re-entrainment are as follows;

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

However, these concepts have limited success for minimizing the re-entrainment in the high dust loading and the high gas temperature. The electrohydrodynamically assisted ESP is suggested in this condition [8]-[9].

The new double cylinder type ESP (W-Cylinder ESP) was developed to overcome the re-entrainment [10]. In the previous report, the effect of the W-Cylinder ESP investigated by numerical simulation [ref]. The W-Cylinder ESP utilizes differential pressure to transport the re-entrained particles effectively into the low gas velocity space from the high gas velocity space. The captured particles are trapped on the electrode in the low gas velocity space, so that hydrodynamic shear stress was decreased.

In this paper, two ESPs, namely, the conventional single cylinder type ESP (S-Cylinder ESP) and W-Cylinder ESP were investigated using a 6728-cc engine. The particle size-dependent collection efficiency was obtained using a Scanning Mobility Particle Sizer (SMPS, TSI) with particle size in the range of 40 - 500 nm and a aerosol spectrometer (Welas 2000, Palas) with particle size in the range of 300-17,000 nm. The particle mass collection efficiency was obtained using a Low Volume Air Sampler (Model 2000, R&P). The effectiveness of re-entrainment or collection efficiency for the two ESPs was compared.

2 Experimental Setup

The schematic diagram of experimental system was shown in Fig.1. Emissions from a diesel engine compressor (Denyo, DIS-685SB, displacement volume of 6,278 cc, output of 140 kW) using heavy oil A (Exxon Mobile Corporation, FOA 01) with 1200 rpm were used to achieve a high gas velocity, high gas temperature in the ESP. In order to determine the number particle density in the ESP, the flue gas was diluted approximately 10 times by the dilution system (KHG-2010, Palas) and the particle size-dependent number densities before and after the ESPs were determined by the Scanning Mobility Particle Sizer (SMPS, Model3936L76-N, TSI) for the particle size ranged 40 - 500 nm and the aerosol spectrometer (Welas 2000, Palas) for the particle size of 300 - 17000 nm, respectively. The particle mass concentrations were determined by the Low Volume Air Sampler (LVS, Model 2000, R&P). The exhaust gas temperature was 220 - 334 ℃。 The gas velocity in the ESP was approximately 10 m/s. 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 ESP upstream particle concentration, N_d was the downstream ESP particle concentration.

The W-Cylinder ESP configuration was shown in Fig. 2. W-Cylinder ESP consisted of discharge electrode, grounded hole-punched electrode and grounding case. The upper and lower portions between the grounded hole-punched electrode and the grounded case were closed. Therefore, the flue gas was connected to upper portion between the discharge electrode and the grounded hole-punched electrode.

The S-Cylinder ESP consisted of the discharge electrode and the grounded electrode substituted for the grounded hole-punched electrode in Fig.2.

Negative DC high voltage with -4.8 ～ -6.1 kV was applied to the discharge electrode.

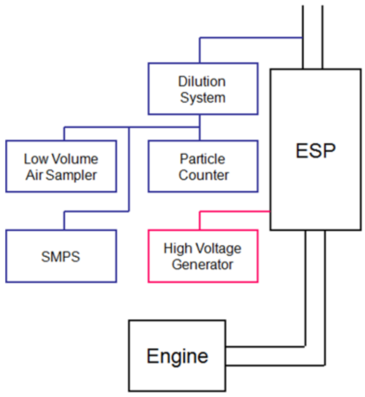

Fig.1 Schematic diagram of the experimental system.

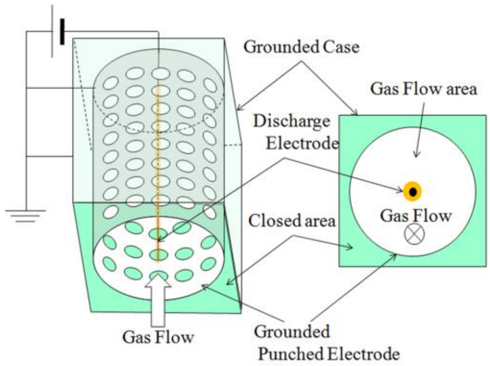

Fig.2 W-Cylinder ESP cofiguration

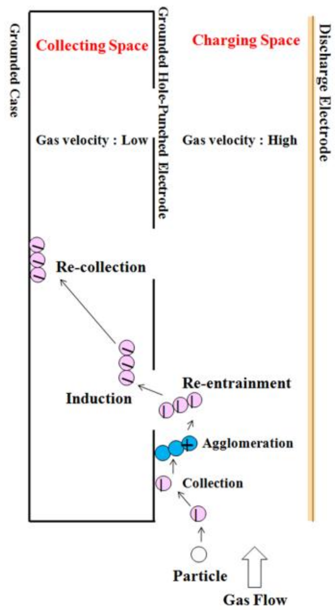

fig.3 Concept of the W-Cylinder ESP for particle collection

Concept of the W-Cylinder ESP for collection was shown in Fig. 3. The space between the discharge electrode and the grounded hole-punched electrode was called "charging space" and the space between the grounded hole-punched electrode and the grounded case was called "collecting space". Particles in the flue gas were introduced to the charging space and negatively charged by corona discharge. The charged particles were collected on the grounded hole-punched electrode. The collected particles positively charged by induction charge, so that the collected particles glow large particles by agglomeration [11]. The large particles were re-entrained by hydrodynamic repulsion force and are introduced into the collecting space by differential pressure. The gas velocity in the collection space was 1/3 or less of the charging space, so that re-entrained particles were re-collected on surface of the grounded hole-punched electrode and the grounded case in the collecting space.

3 Results and Discussion

3.1 Collection for Fine Particles

The particle size distributions in the range of 40 ～500 nm in the S-Cylinder ESP and the W-Cylinder ESP were shown in Fig. 4 and 5. The flue gas temperature was 250 ～ 275 ℃ .A maximum value of the inlet distribution was at approximately 100 nm in diameter. The outlet particle density decreased compared with inlet, respectively.

The particle size-dependent collection efficiency in the range of 40～300 nm for various ESPs was shown in Fig.6. The minimum efficiency occurred at 150nm, respectively. This was attributed to the lower charge on submicronmeter particles, which falls in between diffusion and field charging theory. The collection efficiency at approximately 100 nm in W-Cylinder ESP was less than that in S-Cylinder ESP. This cause was that the area in the hole-punched electrode was less than that on the electrode in the S-Cylinder ESP. However, we need more investigation for the fine particle collection. The collection efficiencies smaller than 80 nm and larger than 200nm in W-Cylinder ESP were greater than that in the S-Cylinder ESP due to the suppression the particle re-entrainment.

3.2 Collection for Large Particles

The particle size distribution in the range of 300 ～1700nm in the S-Cylinder ESP and the W-Cylinder ESP were shown in Fig.7 and 8. The flue gas temperature was 250～275℃.The particle concentration decreased with increasing the particle diameter, respectively. The outlet particle concentration larger than 600 nm increased compared with inlet due to the particle re-entrainment [11]. Negative

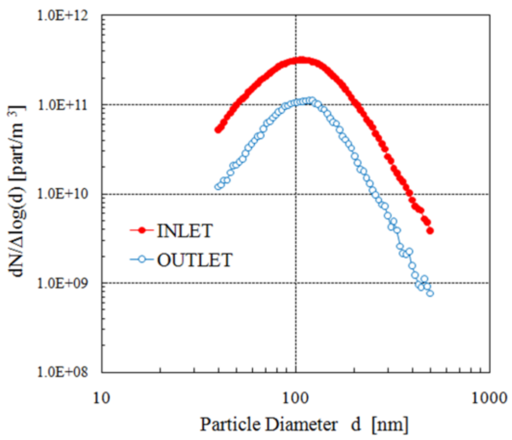

Fig.4 Particle size distibution in the range of 40 - 500 nm in the S-Cylinder ESP.

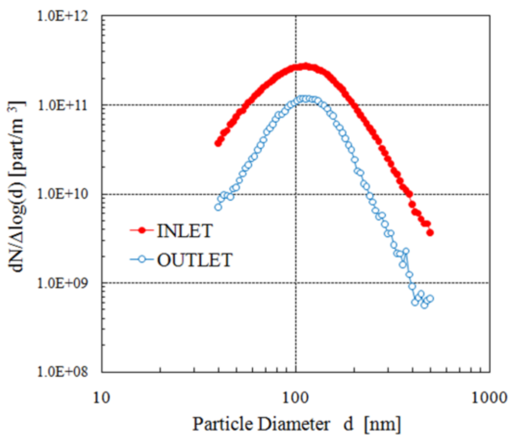

Fig.5 Particle size distibution in the range of 40 - 500 nm in the W-Cylinder ESP.

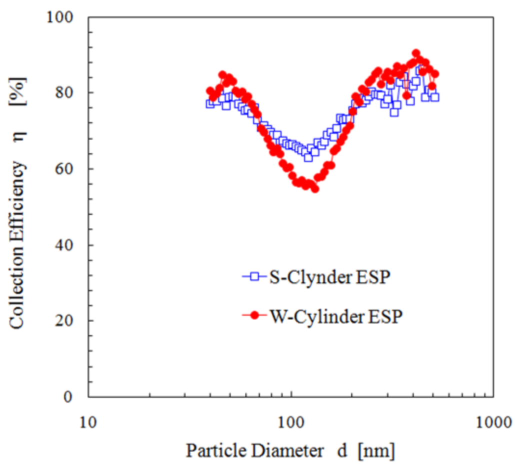

Fig.6 Particle size-dependent collection efficiency in the range of 40-500 nm for various ESPs.

collection efficiency indicated that the agglomerated large particles captured at the

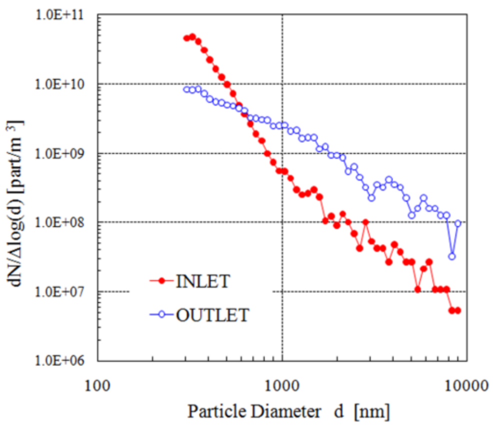

Fig.7 Particle size distribution in the range of 300 - 10000 nm in the S-Cylinder ESP.

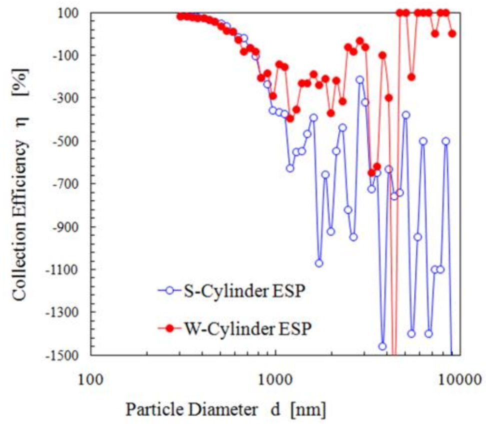

Fig.9 Particle size-depnedent collection efficiency in the range of 300 - 10000 nm for various ESPs.

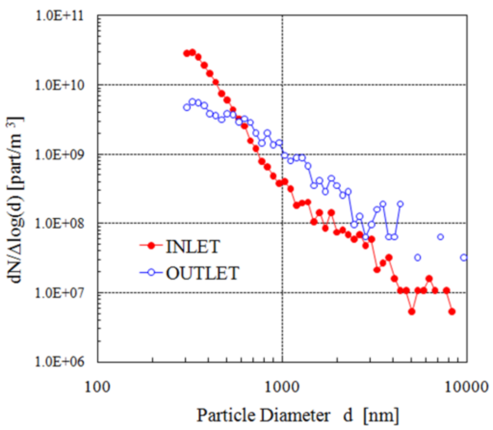

Fig.8 Particle size distribution in the range of 300 - 10000 nm in the W-Cylinder ESP.

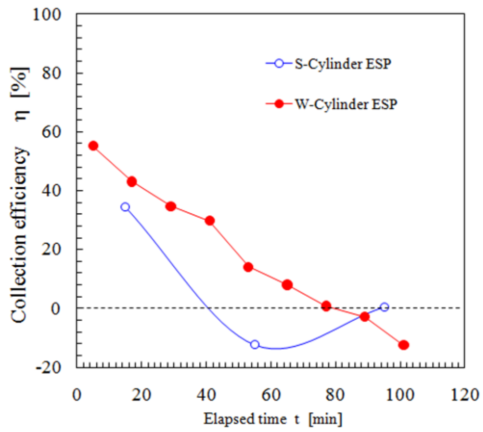

Fig.10 Collection efficiency as a function of elapsed time for various ESPs.

electrostatic field exposed were detached and re-entrained by the repulsion force caused by the fluid dynamic shear stress.

The particle size-dependent collection efficiency in the range of 300 ～17000nm for various ESPs was shown in Fig.9. The collection efficiency decreased with increasing the particle diameter. However, the collection efficiency larger than 1000 nm in W-Cylinder ESP improved compared with S-Cylinder ESP. These results indicated the effect of the W-Cylinder ESP on the suppression particle re-entrainment.

3.3 Mass Collection Efficiency

The collection efficiency was not estimated only the particle number density, but also the particle mass density. The particle mass collection efficiency as a function of elapsed time for various ESP was shown in Fig.10. The flue gas temperature was 220～282℃. The particle mass collection efficiency in S-Cylinder ESP was 34% at 15minutes after the start of operation. However, the collection efficiency significantly decreased with increasing elapsed time due to particle re-entrainment. On the other hand, the collection efficiency in W-Cylinder ESP improved compared with S-Cylinder ESP, although the collection efficiency decreased with increasing elapsed time.

The filter color of LVS indicated particle concentration in 500 litters flue gas, as shown in Fig. 11. The particle concentration before treatment was higher than after treatment as indicated by lighter color of filter in the W-Cylinder ESP. However, this tendency was not clear in the S-Cylinder ESP.

4 Conclusion

The collection of particles generated from marine and automobile engines was investigated using two types of ESPs, namely, the conventional single cylinder type ESP (S-Cylinder ESP) and the double cylinder type

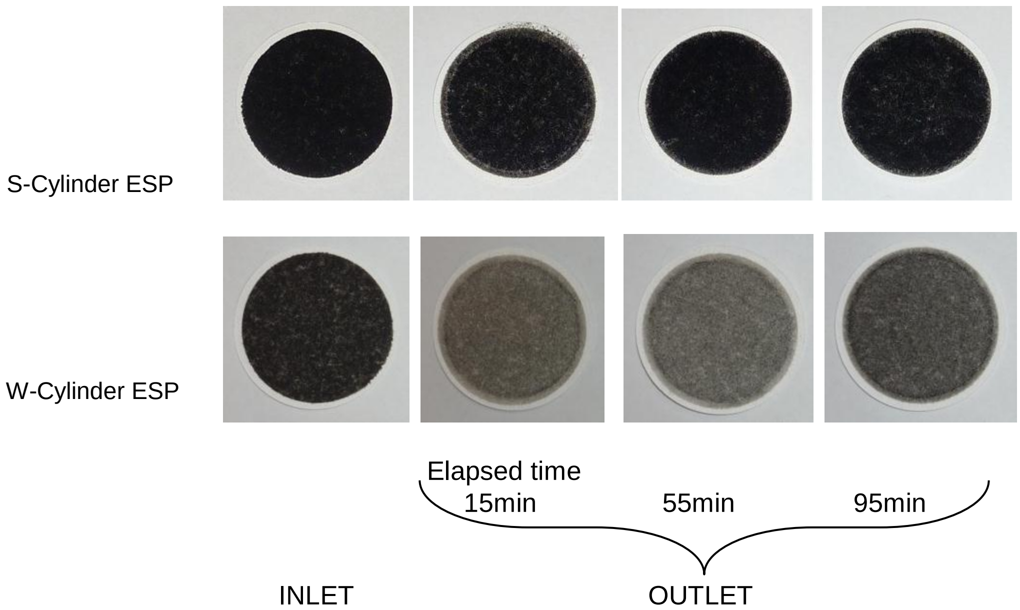

Fig.11 Color of filter paper after used to take particle sample

ESP (W-Cylinder ESP). The conventional S-Cylinder ESP showed good collection efficiency for particle sizes less than 300 nm but showed severe re-entrainment for particle size greater than 1000 nm. The W-Cylinder ESP also showed good collection efficiency for particle size less than 300 nm. Furthermore, the collection efficiency for particle size greater than 1000 nm was improved due to suppression of particle re-entrainment. This result was also supported by the particle mass measurement and the filter color determined by the LVS.

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