Performance of High Velocity Electrostatic Precipitator for Road Tunnel

Yoshiyasu Ehara
Tokyo City University
Japan
yehara@tcu.ac.jp

Ryouske Nakano
Tokyo City University
Japan
g0981317@tcu.ac.jp

Toshiaki Yamamoto
Tokyo City University
Japan
yama-t@tcu.ac.jp

Akinori Zukeran
Kanagawa Institute of Technology
Japan
zukeran-akinori@ele.kanagawa-it.ac.jp

Takashi Inui
Fuji Electric Systems Co., Ltd.
Japan
inui-takashi@fujielectric.co.jp

Hitomi Kawakami
Fuji Electric Systems Co., Ltd.
Japan
kawakami-hitomi@fujielectric.co.jp

1. Abstract:

The particles emitted from diesel engine exhaust have low resistivity and extremely small in the range of 70-120nm. An electrostatic precipitator (ESP) has been extensively used for the collection of these particles. A two-stage ESP using charging section and collection section has been installed for the collection of diesel particles and improving the visibility index in road tunnels. The characteristics of ESP in road tunnels are demanded to process in high gas flow velocity, miniaturization and high collection efficiency. In this study, the underlying data of ESP performance was extracted in condition of high gas flow velocity. The gas flow velocity was in the range of 10 to 25 m/s. The collection efficiency for experiment and the simulation were compared.

2. Introduction

Diesel Exhaust Particles (DEPs) are the problem of air pollution in high concentration the closing space such as long-distance tunnels of highway. Electrostatic precipitators (ESPs) is installed in a tunnel to collect particulates that principally involve DEP. They are suitable for decontaminating polluted gases and improving the visibility index in road tunnels, thereby saving drivers and improving the air environment around the tunnels.

In recently, some research of ESP for road tunnel is reported. To use an ESP in a road tunnel, it is necessary to prevent particles from depositing onto walls away from the ESP. Particles deposited onto cameras, lights, walls and so on in a tunnel will lower the noticeable performance of drivers and the monitoring devices at the tunnel. The causes for the particle deposition are the charged particles [1]. ESPs under AC operating mode (AC-ESP) [2] and parallel constitution of plus and minus discharge electrode [3] were proposed for inhibition of particle accumulation on the surface of the wall as a neutralization method of the charged particles.

ESP collects the particle by the corona discharge. Therefore, ESP generates harmful ozone in the human body and the environment without fail. Ozone oxidizes NO contained in the diesel exhaust gas, and increases the NO_2 concentration included in the atmosphere. For this reason, the researches for electrode geometry and polarity of corona discharge on ozone generation were reported [4, 5, 6].

The particles in road tunnels usually have a low resistivity and are easy to be re-entrained [7, 8]. The low resistive particles cause particle detachment from the collection plate by induction charge, i.e. dust re-entrainment, resulting in poor collection efficiency. Therefore, it is very important to prevent the particles from being re-entrained.

Authors have been studying the technology of the re-entrainment inhibition in ESP. The particle re-entrainment was prevented by AC-ESP [9]. AC-ESP with hole-punched electrode was suggested to improve the nano particle collection efficiency and suppress particle re-entrainment [10].

In Japan, the first standard specifications of ESP for road tunnels is determined to remove SPM (Suspended Particulate Matter) is over 70%, 7m/s air flow velocity. The latest one is determined to remove over 80%, 9m/s.

Metropolitan Expressway at Tokyo has many ventilation stations on the expressway. SPM in an exhaust gas is removed by ESP. Clean air is ventilated to the ground from underground road tunnel. The long-distance underground tunnel of the expressway of the metropolitan area increases, and installation of ESP is needed. The characteristics of ESP in underground tunnels are also demanded to process in high gas flow velocity, miniaturization and high collection efficiency.

In this study, the underlying data of ESP performance was extracted in condition of high gas flow velocity. The gas flow velocity was in the range of 10 to 25 m/s. The experimental ESP was two-stage-type which composed of a precharger, followed by the collection section. The high voltage electrode in the charging section was saw-tooth type. The collection efficiency for experiment and the simulation were compared. The constitution of the ESP units to a collection efficiency was considered.

3. Experimental Methods

A sample gas was used the exhaust gas of the diesel engine. A schematic of experimental apparatus is shown in Figure 1. The gases exhausted from the diesel engine were diluted with air and introduced into ESP. Gas flow velocity was controlled by the inverter fans at the upstream and downstream of ESP. The flow meter (HFA Höntzsch) of vane type was used. The SMPS (Scanning Mobility Particle Sizer, Model 3034) for the particle size ranged 20-800 nm and the particle counter (Rion KC-01C) for the particle size larger than 0.3 μ m were used to measure the number of particles for particle sizes, respectively. The numbers of particles were measured at upstream and downstream of ESP. The collection efficiency of ESP was obtained from the difference of the particle concentration of the upstream and downstream in ESP. The elapsed time in ESP was 20 minutes.

The experiment is conducted by two-stage-type ESP composed a charging section and collection section. The ESP used for the

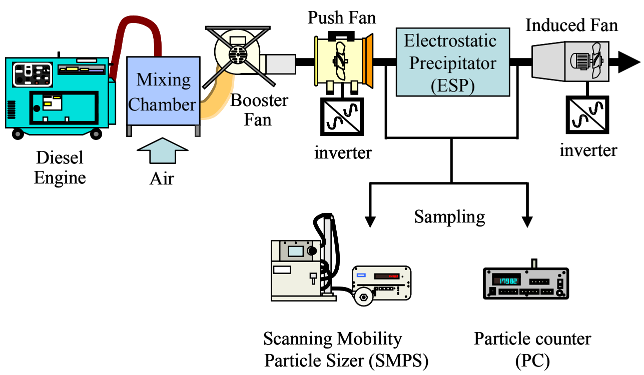

Figure.1 Experimental setup for ESP

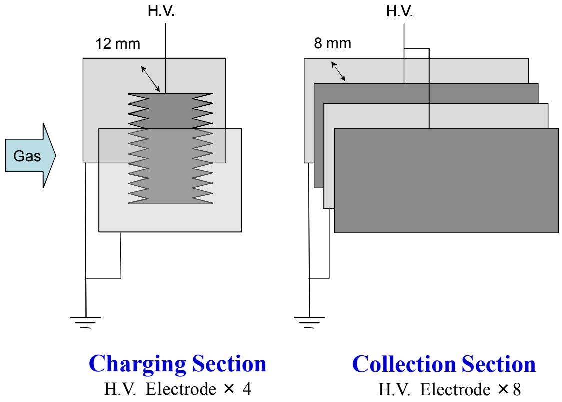

Figure.2 ESP configuration

account of a theoretical collection efficiency and this experiment was shown in Figure 2. In the charging section, 4 high voltage electrode of a saw-tooth was used to experiment. The discharge gap was 12mm. Each ground electrode used a plate. Negative DC voltage was applied to high voltage electrode in the charging section. The collection section had parallel-plates configuration. The length between electrodes is 8mm, it had 6 high voltage electrode. DC -7.0kV was applied to high voltage electrode in the collection section.

4. Results and Discussion

4.1 Influence of gas flow velocity on collection efficiency

The theoretical collection efficiency was investigated based on the fundamental Deutsch formula. Charged particles in electrical field transfer with the migration velocity W_{th} towards the collecting electrodes. The theoretical migration velocity W_{th} is

$$W_{th} = \frac{qE}{6\pi\mu d} C_m \quad (1)$$

Where q is the particle charge, E is electric field, μ is the dynamic gas viscosity, d is particle diameter and C_m is Cunningham correction factor depending on the mean free path λ for air molecules.

Deutsch formula is as follows;

$$\eta = 1 - \exp\left(- \mathrm{W_{th}} \frac{l}{v_g g} \right) \quad (2)$$

Where l stands for the length of the electric field, V_g denotes gas flow velocity and g is distance between the electrodes.

The collection efficiency η is so high that W_{th} is large, it is so low that the gas flow velocity V_g. Figure 3 shows the particle-diameter dependent the theoretical collection efficiency as a function of gas flow velocity for the two-stage-type ESP shown in Figure 2 when the applied voltage of collecting electrode was -7.0 kV. The gas flow velocity was at 10 m/s, 15 m/s, 20 m/s and 25 m/s. The theoretical collection efficiency has the minimum value near particle diameter of 200 nm in any gas flow velocity.

Subsequently, the influence of gas flow velocity on the collection efficiency was experimentally verified. The discharge current was 2.5 mA and the applied voltage of collecting electrode was -7.0 kV. Figure 4 shows the particle-diameter dependent number density at the ESP upstream as a function of gas flow velocity. The particle size was in the range of 20 nm and 3000 nm in diameter with the peak number density at near 100 nm with at the ESP upstream in any gas flow velocity. The number density decrease slightly with increasing the gas flow velocity because the amount of the air to dilute increases.

The particle-diameter dependent the experimental collection efficiency as a function of gas flow velocity is shown in Figure 5. The experimental collection efficiency has the minimum value near particle diameter of 100nm. The collection efficiency decrease with increasing the gas flow velocity. This result is mostly in agreement with the theoretical collection efficiency shown in Figure 3. In the gas flow velocity of 25 m/s, the collection efficiency at 30-300 nm was less than 60%. However, the experimental collection efficiency is higher than the theoretical collection efficiency in any gas flow velocity. This reason is considered that the collection in the charging section is not added to the account of a theoretical collection efficiency.

4.2 Method to collection efficiency improvement

Here, the methods for the improvement in the collection efficiency are described. First, it investigated about the effect of an charging section. The gas flow velocity was at 25 m/s, the applied voltage of collecting electrode was -7.0 kV, the charging section and the collection section were used one unit, respectively. Figure 6 shows the particle-diameter

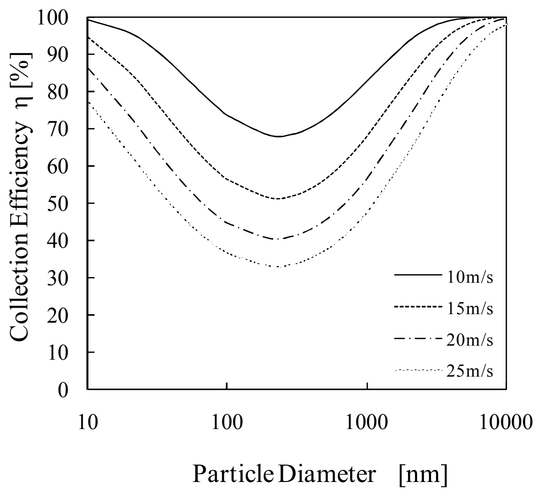

Figure 3 The particle-diameter dependent the theoretical collection efficiency as a function of gas flow velocity

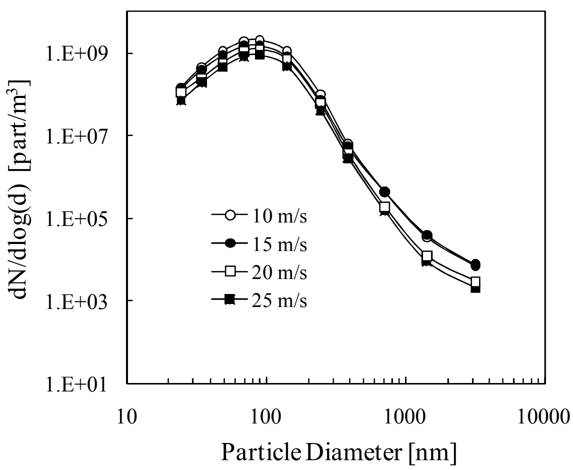

Figure 4 The particle- diameter dependent number density at the ESP upstream as a function of gas flow velocity

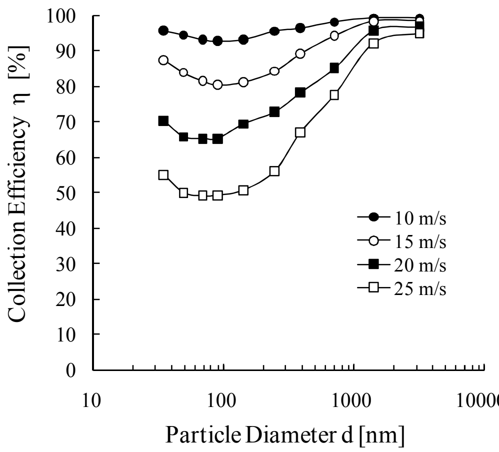

Figure 5 The particle- diameter dependent the experimental collection efficiency as a function of gas flow velocity

dependent collection efficiency as a function of discharge current at the chargeing section. The collection efficiency increase with increasing discharge current. At the discharge current of 0.5 mA, the collection efficiency falls greatly. The collection efficiency at the charging section with 2.5 mA is about 30 %. The collection efficiency in more than 1000 nm is high. It is considered that the larger particle diameter has the larger charging amount, and it is easy to be collected.

It is attention was paid to the number of units of a charging section. The gas flow velocity was at 25 m/s, the applied voltage of collecting electrode was -7.0 kV. Figure 7 shows the particle-diameter dependent collection efficiency as a function of the number of units of the charging section. D means one unit, DD means two units and DDD means three units. Discharge current is 2.5 mA per one D unit. The collection efficiency increase with increasing the number of units of the charging section. From the above-mentioned, it is effective in the improvement in the collection efficiency to make discharge current increase by increasing the number of units etc.

Secondly, appreciation in a charging section was compared with appreciation in a collection section, and which investgated in effect. The number of units of the charging section and collection section was changed. The gas flow velocity was at 25 m/s, the applied voltage of collecting electrode was -7.0 kV, the discharge current is 2.5 mA per one D unit. The particle-diameter dependent collection efficiency as a function of the unit configuration is shown in Figure 8. DCCC means one charging section and three collection sections. The collection efficiency is high in order of he unit configuration of DDDC, DDCC and DCCC. The collection efficiency increase with increasing D unit. The collection efficiency of DDDC was 70% or more, and it was excellent up to 30-3,000 nm. Therefore, it is suggested that the appreciation in the charging section is more effective than the appreciation in the collection section.

5. Conclusion

The collection efficiency for diesel exhaust particles in condition of high gas flow velocity was investigated using the two stage ESP. The gas flow velocity performance of a theoretical collection efficiency and an experimental collection efficiency was well in agreement. As for one unit or the number of units, the

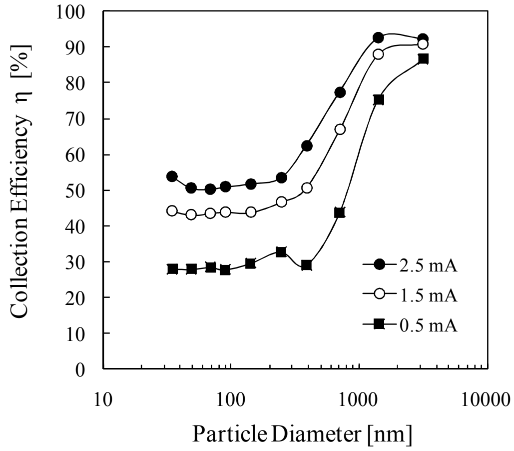

Figure 6 the particle-diameter dependent collection efficiency as a function of discharge current at the chargeing section

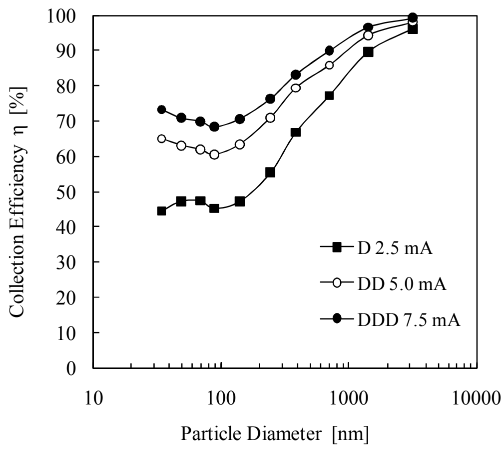

Figure 7 The particle-diameter dependent collection efficiency as a function of the number of units of the charging section

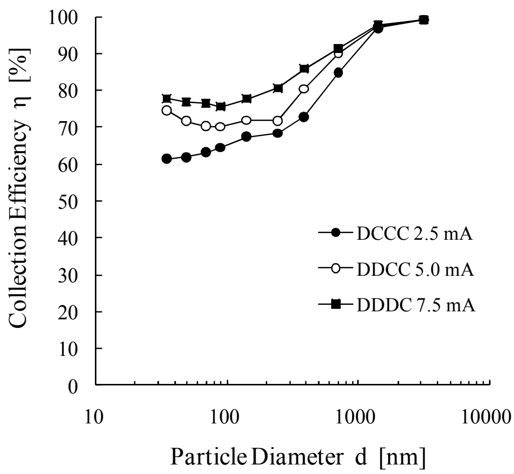

Figure 8 The particle-diameter dependent collection efficiency as a function of the unit configuration

collection efficiency increase with increasing discharge current. Moreover, the appreciation in the charging section is more effective than the appreciation in the collection section at the gas flow velocity of 25 m/s.

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