Electrostatic precipitator installed with ceramic foam on a collection plate

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Abstract

An electrostatic precipitator (ESP) has been widely used for gas treatment such as flue gas cleaning and room air cleaning. Collection of particle matter (PM) in diesel exhaust is a new application of ESP. It shows very high collection efficiency for the PM in diesel exhaust, which includes fine particles ranging from some nanometer to some micrometer in diameter. Low pressure drop is another advantage of the ESP against conventional PM collection technologies like diesel particulate filter (DPF). However, PM slip due to abnormal reentrainment sometimes takes place because electric conductivity of the PM is high enough to lose charges on the collection plate.

In this study, to cope with this problem, porous ceramic foam consisting of many fine holes is used to suppress the reentrainment. The ceramic foam placed on a collecting plate of an ESP is expected to enhance capacity to keep the PM. It is also expected to reduce the velocity of the gas flow in the vicinity of the collection plate. Wire-plate type ESP was constructed and collection efficiency was measured and particle / gas flow in the ESP was measured.

As a result, ESP with the ceramic foam showed slightly higher diesel PM collection efficiency whereas discharge current was smaller than that of conventional ESP when the applied voltage and discharge gas were same. As a result of particle flow visualization in the ESP using carbon black fine particles to simulate diesel PM, smaller number of particles was observed when wet ceramic foam was used while both conventional ESP and ESP with dry ceramic foam resulted in similar particle density. The difference was more significant in the area downstream of the collection plate, where no electrostatic force acts on the particles. These results suggest that porous ceramic foam, especially when it is wet, effectively suppresses the reentrainment of the fine particles.

1. Introduction

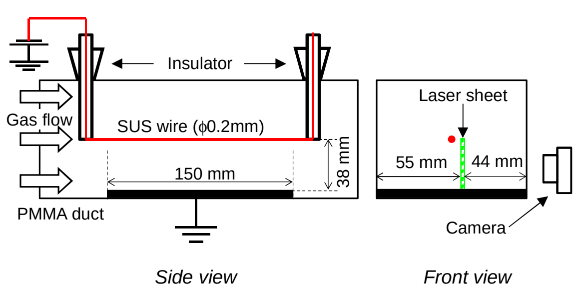
An electrostatic precipitator (ESP) has been widely used for gas treatment such as flue gas cleaning and room air cleaning. Collection of particle matter (PM) in diesel exhaust is a new application of ESP. It shows very high collection efficiency for the PM in diesel exhaust, which includes fine particles ranging from some nanometer to some micrometer in diameter. Low pressure drop is another advantage of the ESP against conventional PM collection technologies like diesel particulate filter (DPF). However, PM slip due to abnormal reentrainment sometimes takes place because electric conductivity of the PM is high enough to lose charges on the collection plate. Therefore, it is necessary to suppress abnormal reentrainment on the collection plate so that the ESP can be used for collection of PM in the diesel exhaust. To address this problem, studies on optimization of applied voltage[1-3], modification of the collection plate of ESP[4-6], and an “electrohydrodynamically-assisted ESP”[7-9] were reported. In this study, a novel approach for suppression of PM from an ESP utilizing a newly developed collection plate equipped with ceramic foam was examined.

2. Experimental

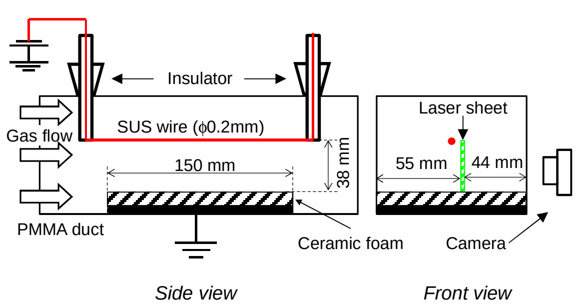
In this study, to cope with the problem, porous ceramic foam consisting of many fine holes is used to suppress the reentrainment. The ceramic foam placed on a collecting plate of an ESP is expected to enhance capacity to keep the PM owing to its large surface area. It is also expected to reduce the velocity of the gas flow in the vicinity of the collection plate. Wire-plate type ESP was constructed and collection efficiency was measured and particle / gas flow in the ESP was measured.

Figure 1 shows a schematic illustration of two types of electrostatic precipitator used in the experiment. Conventional ESP without ceramic foam and newly proposed one with ceramic foam were shown in (a) and (b), respectively. Both of them consist of a PMMA duct having rectangular intersection, corona electrode made of a stainless steel wire (0.2mm in diameter), and a collection plate made of a stainless steel plate. The collection plate was placed only on the bottom surface of the duct. Length of the collection plate was 150mm. The corona electrode was supported by two insulators 38mm above the collection plate at the center of the duct. The length of the corona electrode was longer than that of the collection plate.

Figure 2 shows a schematic illustration of the experimental setup for visualization of particle flow and for measuring particle collection efficiency. A frequency-doubled YAG laser (λ=532nm) was used to visualize the particle flow in the ESP. Cylindrical lenses were used to generate a laser sheet of which height and thickness was 38mm and 1 mm respectively. The laser sheet was introduced in the ESP parallel to the main gas flow as shown in figure 1. It covers the area between the corona electrode and the collection plate so that motion of the particles can be traced by monitoring the scattered light due to particles in the gas stream. The laser sheet was offset by 5 mm from the corona electrode in order to avoid intense light scattering due to the corona electrode. A video camera was set perpendicular to the gas flow so that particle motion in the whole area was recorded. Carbon black fine powder, of which diameter was $5\mu m$ was used to simulate diesel particulate matter. Performance of the ESP was investigated by measuring of the collection efficiency using a particle counter (Shibata Science LD-1). This experiment was made using the same simulated diesel exhaust as above.



(a) Conventional ESP



(b) ESP with ceramic foam

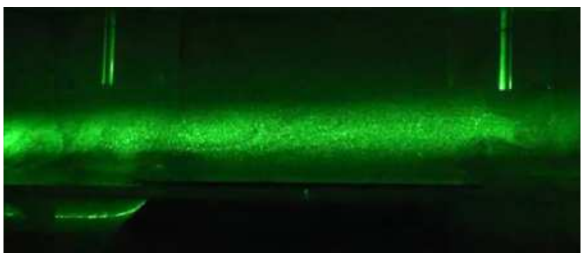
Fig. 1: Schematic illustration of electrostatic precipitators examined

Ceramic foam was placed on the collection plate as shown in figure 1 (b). In this case, position of the corona electrode was placed a few mm upward to adjust the gap between the corona electrode and the ceramic foam was 28mm, which is the same gap as conventional ESP.

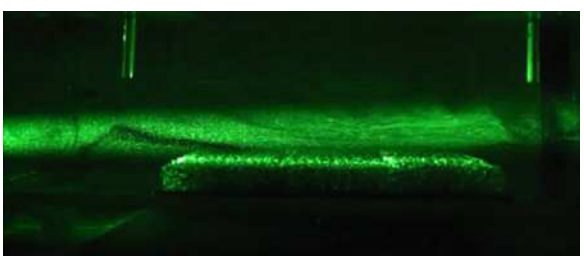
3. Results and discussion

Figure 3 shows the results of the particle/gas flow visualization. Photographs of the scattered light from conventional ESP, one equipped with dry ceramic foam, and one with humid ceramic foam were shown in figures (a), (b) and (c), respectively. ESP was off in all cases. These results show that two dimensional particle concentration distribution was successfully obtained. It was found that the ceramic foam placed on the collection plate induced no perturbation to the gas flow at least near the ceramic foam (the collection plate) suggesting that the ceramic foam can be used with ESP.

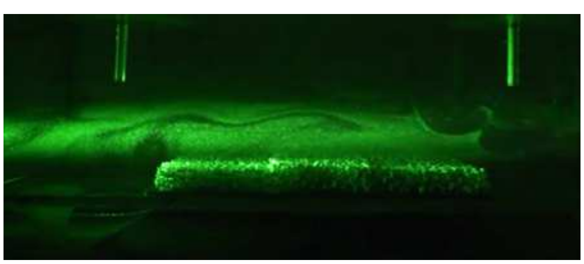
Figure 4 (a) – (c) show the results of the particle/gas flow visualization when the ESP was on. Figures (a), (b) and (c) represent the results of conventional ESP, one equipped with dry ceramic foam, and one with humid ceramic foam, respectively. DC high voltage of -15kV was applied to the ESP and corona discharge took place in all cases. Smaller corona current (about 1/3) was observed when the dry ceramic foam was used compared with



(a) Conventional ESP

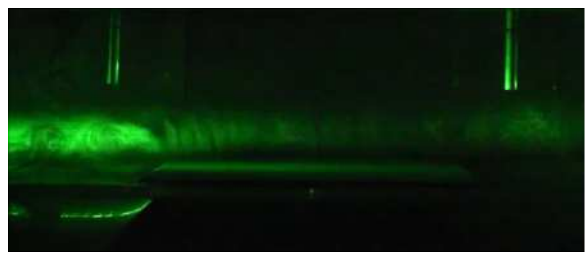


(b) ESP with dry ceramic foam

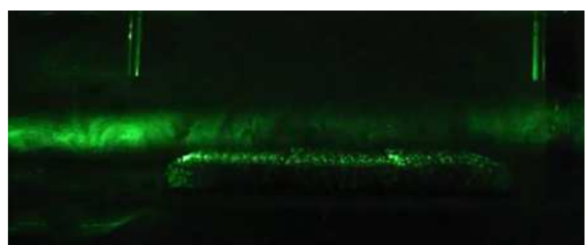


(c) ESP with humid ceramic foam

Fig. 3: Effect of ceramic foam on particle / gas flow in ESPs when the applied voltage was 0.



(a) Conventional ESP



(b) ESP with dry ceramic foam

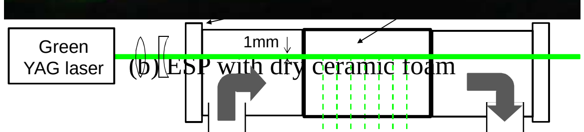


Fig. 2: Schematic illustration of experimental setup for particle / air flow visualization and collection efficiency measurement

(c) ESP with humid ceramic foam

Fig. 4: Effect of ceramic foam on particle / gas flow in ESPs when the applied voltage was -15kV.

other two cases.

It is clearly shown that particle concentration in the ESPs and downstream was smaller compared with that of upstream when the ESP was on. These results suggest that the ESP works although strong perturbation of the air flow was found. Comparison between conventional one and dry type shows results, in spite of smaller corona current when dry ceramic foam was used. It suggests that the ceramic foam is effective to improve collection efficiency. Comparison between conventional one and humid type shows that particle concentration was smaller when humid ceramic foam was installed on the collection plate. Taking into account the result that corona current was nearly same in these cases, humid ceramic foam is effective. From these results, it is speculated that ceramic foam enhances the particle collection efficiency due to high PM storage capacity and that humid ceramic foam can provide adhesive surface. It was also found that ceramic foam on the collection plate reduces vertical air flow velocity on the collection plate (data not shown). Therefore, it is probable that lower particle concentration in the ESP with a ceramic form was brought about by these effects.

Figures 5 shows the comparison of time course of collection efficiency between conventional ESP and ones with dry and humid ceramic foam. Transient characteristics when the ESP was turned on/off were obtained. ESP with humid ceramic foam resulted in the highest collection efficiency among the three cases. It was also found that humid ceramic foam showed high collection efficiency immediately after turning on the power, while others took longer time. It is also notable that collection efficiency was not deteriorated with time when humid ceramic foam was employed, which was clearly different from others.

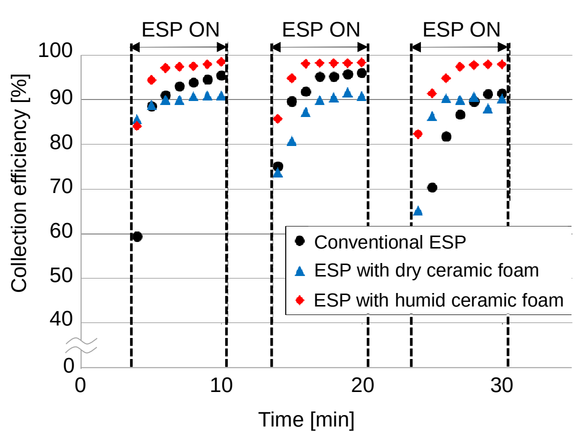


Fig. 5: Schematic illustration of experimental setup for particle / air flow visualization and collection efficiency measurement

4. Conclusion

Electrostatic precipitator equipped with ceramic foam was experimentally investigated. As a result, ceramic foam placed on a collection plate, especially when it is humid, significantly enhance particle collection efficiency. The high particle collection efficiency was maintained for a long duration when humid ceramic foam was employed.

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