Collection performance of an electrostatic precipitator using bipolar corona discharges

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Abstract— Two-stage-type ESPs (electrostatic precipitators) are composed of ionizers and collectors. DC high voltage is applied to the discharge electrodes in the front stage ionizers. Particles passing through the ionizers with either positive or negative corona are charged. The rear stage collectors with uniform dc electric field catch the charged particles. The spike-type discharger electrodes are widely adopted. In this test, the spikes are assembled not only in the energized-plates but also in the grounded-plates of the ionizer. The test result shows that the particles are collected with the generation of both positive-corona and negative-corona discharges in the ionizer. The discharge in the grounded-plates generates ions of opposite polarity to those of the energized-plates. This bipolar collection method, simultaneously using positive and negative discharges, shows that the particles are caught not only on the grounded-plates but also on the energized-plates in the collector. The results of this study imply the suppression of re-entrainment and longer wash-interval of ESPs.

Keywords—Electrostatic precipitator, DC corona, positive discharge, negative discharge, bipolar, spike

I. Introduction

Two-stage-type ESPs (electrostatic precipitators) are composed of both ionizers and collectors to which DC high voltages are applied. Since these ESPs can collect particles under the condition of relatively high wind-velocity such as 9 m/s, they are widely adopted for purifying tunnel-exhaust from motor-vehicles in which concentration of diesel-particles is high [1].

In order to decrease the phenomenon of re-entrainment from the ESPs, the authors have been studying the two-stage type ESP with “bipolar corona discharge” in which both positive corona and negative corona are simultaneously generated in the front-stage ionizer for charging particles in positive and/or negative and collecting particles in the rear-stage collector [2-4].

The principle is shown in Fig. 1. Each double-circle in the ionizer represents a spike-tip at which corona-discharge is generated. The image shows that particles are charged in both polarities, and they are collected not only on the grounded-plate but also on the energized-plate.

The authors have reported that the case of the positive corona at windward and the negative corona at leeward realizes higher collection-efficiency η than the case of the negative corona located at windward and the positive corona [2-4]. The reports also have implied that the reason of better η might be attributed to the “γ effect” at the negative spikes that could be enhanced by collision of positive ions from the windward.

However, the following items have not been reported in the above-mentioned studies on the bipolar discharge ESPs.

1) Evaluation of the collection performance using the air with diesel particles at a typical concentration of the tunnel air of 0.5 mg/m^3.
2) The evidence that particles are collected well not only on the grounded-plates but also on the energized-plates in the collector.
3) Characteristics of the abnormal re-entrainment.

The purpose of this study is to clarify those points, and to compare the performance of the bipolar ESP and a conventional mono-polar ESP.

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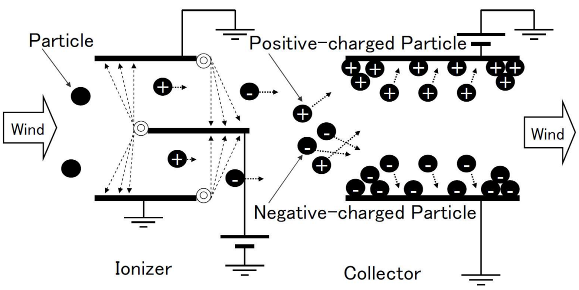


Fig. 1. Principle of ESP with bipolar corona discharge.

II. METHODOLOGY

The ionizer-plates are shown in Fig. 2 (a) and (b). Fig. 2 (a) indicates a plate with spikes for discharge. In case of bipolar corona discharge, spike-plates are used for energized-plates and grounded-plates. In case of mono-polar corona discharge, spike-plates are used only for energized-plates. Fig. 2 (b) shows a plate without spikes which is only for the use of grounded-plates in case of mono-polar discharge.

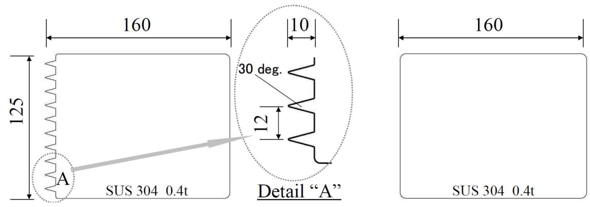
The structure of the ionizers is shown in Fig. 3 (a) and (b). The case of bipolar discharge is in Fig. 3 (a) and the case of mono-polar discharge is in Fig. 3 (b).

The test equipment is depicted in Fig. 4. The specifications for the test equipment are shown in Table I.

Diesel particles generated by the diesel engine #1 are introduced into two duct-systems. Duct #3 to duct #7 (#3, #4, #5, #6, #7) form the first duct system which is for a bipolar ESP. Duct #10 to duct #14 (#10, #11, #12, #13, #14) form the second duct system which is for a mono-polar ESP. The two parallel duct systems can be operated simultaneously by using the same gas. The inner gas velocity in both ESPs is 9 m/s (the same). Concentration of diesel-particle at the inlet of each ESPs is 0.5 mg/m^3 (the same). Two ESPs are continuously operated in parallel for 16 h.

The power consumption of the ionizer for bipolar discharge #4 and the ionizer for mono-polar discharge #11 are 5.1 W. The power consumption was adjusted by the applied voltages, and consequently the discharge currents, so that the power consumption of both ESPs was kept to be the same. In case of the bipolar discharge, the discharge current is 525 μA at dc +9.8 kV. In case of the mono-polar discharge, the discharge current is 425 μA at dc +12.1 kV.

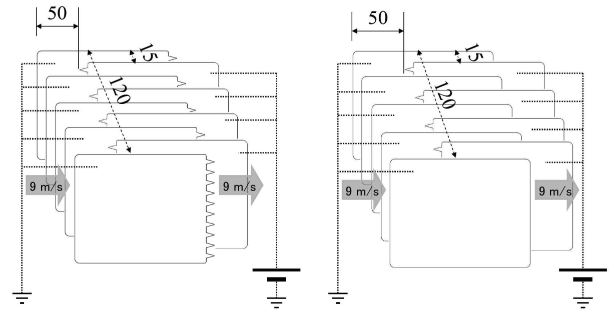
The specifications, the structure and the applied-voltages to both collectors, #6 in the bipolar ESP and #13 in the mono-polar ESP, are the same. Size of a collector-plate made of stainless steel 304 is 125 mm (H), 370 mm (L) and 0.4 mm (t). This plate is used for grounded-plates and/or energized-plates in both collectors. The parallel gap distance between the grounded-plate and the energized-plate in both collectors is 10 mm (the same). The voltage applied to both collectors is dc +8 kV (the same).



(a) Spike-plate for bipolar and mono-polar use.

(b) Grounded-plate for mono-polar use only.

Fig. 2. Ionizer-plates.



(a) Bipolar-discharge type.

(b) Mono-polar-discharge type.

Fig. 3. Two cases of ionizers.

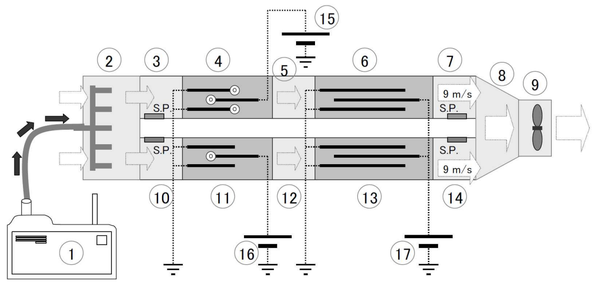


Fig. 4. Schematic diagram of test equipment.

TABLE I

SPECIFICATIONS OF TEST EQIPMENT

Items	Details
Diesel engine #1	ISUZU 4BD1-1, 1200 rpm, fuel: diesel oil
Chamber duct #2	Total length; 4 m (approx.) Accessory; pipe with exhaust-distribution-nozzles
Connection duct (#3,5,7,10,12,14)	W 121, H 140, L 150 mm (Inside) Material; ABS resin
Ionizer of bipolar discharge #4	Duct ; W 121, H 120, L 300 mm (Inside) Material; ABS resin
	Type ; Parallel-flat-plates type Gap length; 15 mm (between adjacent plates) Plates shape; shown in fig. 2 4 plates with spikes at windward and 5 plates with spikes at leeward.
Collector #6	Duct ; W 121, H 120, L 400 mm (Inside) Material; ABS resin
	Type ; Parallel-flat-plates type Gap length; 10 mm (between adjacent plates) Plate ; H 125, L 370 mm, thickness 0.4 Material; SUS 304 6 plates with voltage and 7 plates to ground
Ionizer of mono-polar #11	4 plates with spikes and 5 plates without spikes. Other items are the same as #4.
Collector #13	All specifications are the same as #6.
Chamber duct #8	Total length; 4 m (approx.)
Fan #9	Axial flow fan with inverter-control
High voltage power supply #15	Type-SWEP (Origin Electric) Max. output ; DC +11 kV , 500 mA Ripple; from -3 to +3 %
High voltage power supply #16, #17	Tunnel-ESP power supply (Origin Electric) Max. output ; DC +13 kV , 150 mA and Max. output ; DC +9 kV , 20 mA Ripple; 5 % or less
Microscope (Optical)	Digital microscope VHX-100F (KEYENCE) Lens 1; VH-Z25 (25-175 times), Lens 2; VH-Z100 (100-1000 times)
Sample pieces to check soot-stain	Gypsum board of JIS A5430 (Chu-etsu Advan) Color; white color; cut-size; W 50, H 50, D 5 mm Sample pieces (S.P.) are attached to the inside walls in the connection duct of #3, #7, #10 and #14.

The only difference between the two ESPs is the discharge mode of the ionizers. Aim of the microscopic observation is how the different ionizers influence the collection performance and pattern of soot on the collector plates. The sample pieces made of gypsum board (50 mm square) are stuck on the inner walls of the connection duct #3, #7, #10 and #14. Collected particles on the sample pieces are observed after 16 h operation.

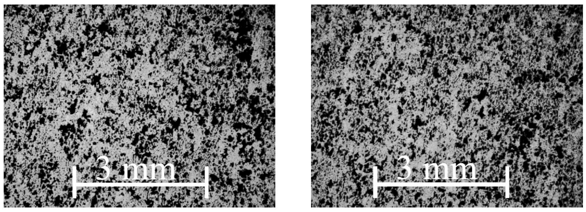
III. RESULTS AND DISCUSSION

After 16 h operation, each plate in both collectors was observed by using an optical microscope (50 times).

In case of the bipolar ESP, the test result of the grounded plate is shown in Fig. 5 (a) and the energized-plate in Fig. 5 (b). Banks or accumulated particles of soot-vestiges seem deep-black and the part between the banks seems gray due to attached fine particles of soot. Collected particles on the plates (a) and (b) are almost the same.

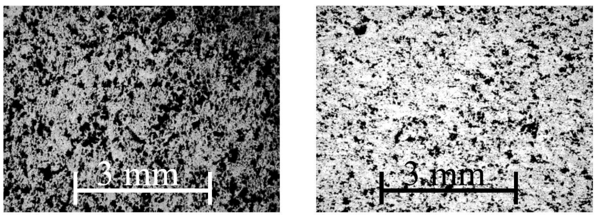
In case of mono-polar ESP, the result of the grounded plate is indicated in Fig. 6 (a) and the energized-plate in Fig. 6 (b). Banks of particles also seem deep-black and the part between banks seems gray in Fig. 6 (a) of the grounded-plate, which resembles Fig. 5 (a) and (b) of the bipolar case. On the other hand, in Fig. 6 (b) of the energized-plate, the part between banks seems white as if without attached fine particles of soot. The vestige of the energized-plate in the mono-polar ESP obviously differs from that in the bipolar ESP. Although fewer banks of particles seem deep-black in the energized-plate in the mono-polar ESP, this is because the re-entrained particles from grounded-plates are electrified in the opposite polarity and as a result fewer particles are attached on the energized-plate, which has been reported in the reference [5].

By using the binalization software of “Photo Filter”, the microscope-photos of Fig. 5 and Fig. 6 are converted into the black-and-white images of Fig. 7 and Fig. 8. The threshold level of black or white is *Level 100* in total 256 levels. Black parts in the binalized-images represent the collected particles on the plate.



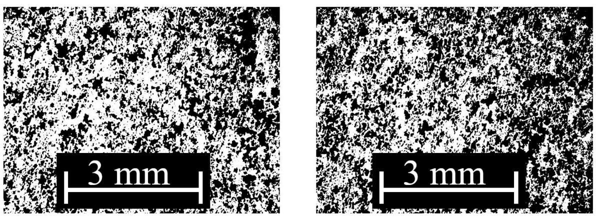
(a) Grounded-plate. (b) Energized-plate.

Fig. 5. Observation on collector-plates in bipolar ESP.



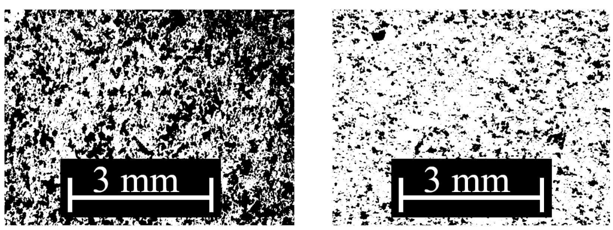
(a) Grounded-plate. (b) Energized-plate.

Fig. 6. Observation on collector-plates in mono-polar ESP.



(a) Grounded-plate. Black-area-ratio = 42.3 % (b) Energized-plate. Black-area-ratio = 52.1 %

Fig. 7. Binarized-image of collector-plates in bipolar ESP.



(a) Grounded-plate. Black-area-ratio = 50.0 % (b) Energized-plate. Black-area-ratio = 17.8 %

Fig. 8. Binarized-image of collector-plates in mono-polar ESP.

The software “Pixel Counter” for analyzing binalized-images is used for calculating areas of the black parts. The “black-area-ratio” is defined as the ratio of “black area to total area” in a binalized-image. A calculated value of black-area-ratio accompanies each binalized-image in Fig. 7 and Fig. 8.

Fig. 7 (a) is the binalized-image of the grounded-plate of the bipolar ESP and Fig. 7 (b) is from the energized-plate. As the black-area-ratios are 42.3% on the grounded-plate and 52.1% on the energized-plate, the vestiges of the attached diesel-particles are nearly the same between both plates.

Fig. 8 (a) is the binalized-image of the grounded-plate of the mono-polar ESP and Fig. 8 (b) is from the energized-plate. The black-area-ratios are 50.0% on the grounded-plate and 17.8% on the energized-plate. The vestiges of the attached particles differ significantly between both plates.

Fig. 9 (a), (b), (c) and (d) indicate the sample pieces of gypsum board which have been exposed in the air with diesel particles for 16 h except (c). Fig. 9 (a) has been installed on the wall at an inlet duct of both ESPs. Fig. 9 (b) shows the piece installed on the wall at the outlet of the bipolar ESP. Fig. 9 (d) on the wall at the outlet of the mono-polar ESP. Fig. 9 (c) of “Before-use” has not been exposed at all. “(a) Inlet at ESPs” is slightly darker by soot particles than “(c) Before-use”. “(b) Outlet at bipolar ESP” is not darker than “(d) Outlet at mono-polar ESP”.

The magnified photos of these four pieces are taken by an optical microscope (100 times). Those are converted into the binalized-image. As the soot-vestiges on each sample-piece are not constant, the photos are taken at three points of windward, center and leeward for each piece. The effect is shown in Table II as black-area-ratios. The marks of (a), (b), (c) and (d) in Table II correspond to those in Fig. 9.

The black-area-ratio of 9.8% average on “(b) Outlet at bipolar ESP” is slightly higher than the one of 8.0% on “(a) Inlet at ESPs”. The black-area-ratio of 9.8% on “(b) Outlet at bipolar ESP” is approximately 40% smaller than the one of 15.1% on “(d) Outlet at mono-polar ESP”.

According to the test, the energized-plate of the bipolar ESP collects more particles than the energized-plate of the mono-polar ESP. In addition, the re-entrainment of the bipolar ESP is depressed in comparison with that of the mono-polar ESP. For the reason, further studies are necessary.

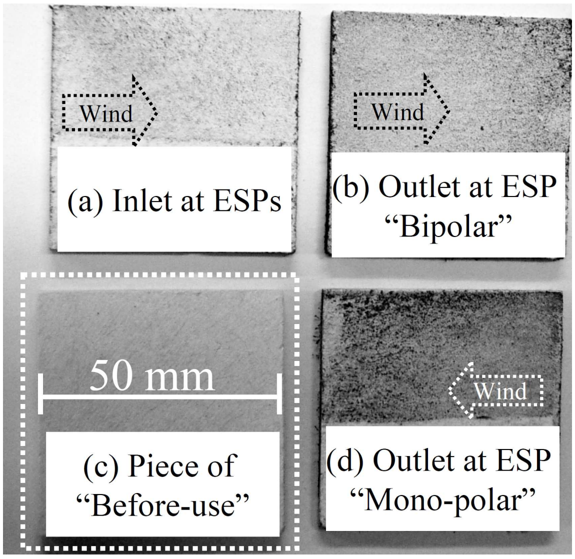


Fig. 9. Sample pieces to check soot-vestiges on walls in ducts.

Table II

SPECIFICATIONS OF TEST EQIPMENT

(a) Inlet at ESPs.

Piece-location	Ratio[%]
Windward	8.5
Center	6.8
Leeward	6.9
(Average)	8.0

(b) Outlet at ESP “Bipolar”

Piece-location	Ratio[%]
Windward	7.5
Center	7.5
Leeward	11.7
(Average)	9.8

(c) Piece of “Before-use”

Piece-location	Ratio[%]
Windward	0.9
Center	0.9
Leeward	0.9
(Average)	0.9

(d) Outlet at ESP “Mono-polar”

Piece-location	Ratio[%]
Windward	9.4
Center	12.8
Leeward	17.1
(Average)	15.1

IV. CONCLUSION

The bipolar ESP and the mono-polar ESP are simultaneously operated in parallel with ventilating the air with diesel particles under the condition of the same power consumption of 5.1 W. After 16 h operation, the electrode plates in the collectors of both ESPs and the sample pieces attached on the duct walls have been observed to evaluate the degree of vestige by soot-particles. The test results can be summarized as follows.

(1) In the mono-polar ESP, many particles are collected on the grounded-plate and fewer particles are attached on the energized-plate. In the bipolar ESP, many particles are captured not only on the grounded-plate but also on the energized-plate.

(2) The comparison of the degree of vestige on the sample pieces located at the outlets of both ESPs showed that the degree of vestige of the bipolar ESP is approximately two thirds of that of the mono-polar ESP.

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