

Electrostatic Precipitator Using Weak Corona Discharge Generated by Carbon Fiber Flocking Electrodes

Atsushi Katatani

Dept. of Business Development & Promotion
Panasonic Environmental Systems & Engineering Co.,Ltd.
phone: +81-90-5973-6929
e-mail: katatani.atsushi@jp.panasonic.com

Hiroshi Hosono

Engineering Department of Tunnel Ventilation Systems
Panasonic Ecology Systems Co.,Ltd.

Hikaru Murata

Engineering Department of Tunnel Ventilation Systems
Panasonic Ecology Systems Co.,Ltd.

Yuki Iizuka

Engineering Department of Tunnel Ventilation Systems
Panasonic Ecology Systems Co.,Ltd.

Hiroshi Yahata

Engineering Department of Tunnel Ventilation Systems
Panasonic Ecology Systems Co.,Ltd.

Akira Mizuno

Department of Environmental and Life Sciences
Toyohashi University of Technology

Abstract—The authors have been studying the electrostatic precipitator (ESP) which can charge particles without using corona discharge. In this method, we have tried to use “induction charging.” DC high-voltage lower than the corona-starting-voltage is applied to the electrostatic-flocked electrodes with carbon fibers. Particles are attracted to the fibers due to gradient force. When the particles are attached to the fibers, induction-charging takes place. Then these particles eventually re-entrain with the induction charge. Because of the

strengthened electric field by converged electric-field-lines at the tip of the carbon fibers, the particles should acquire larger induction charge compared to the case of flat plate electrodes without flocked fibers. After these particles detach from the fibers, they are collected by the following parallel plate electrode assembly. Even without corona discharge, the experimental results in the last study showed that a certain value of particle collection efficiency was observed. The observed collection efficiency was stable for smaller particles (from 0.3 to 1.0 μm), however, was unstable for larger particles (from 1.0 to 5.0 μm). In this study, when a weak corona discharge was generated in the flocked electrodes with carbon fibers to drive the suspended particles towards the tip of the fibers, the collection efficiency of 80% or higher, equivalent to conventional ESPs, was obtained in all the diameter ranges using only 10% of the electric power consumption compared with conventional ESPs.

I. INTRODUCTION

In our previous study, published as the reference [1], the two stage electrostatic precipitator (ESP, hereafter) was used, composed of a front stage “Charger” and a rear stage “Collector”. The outline and subjects of this previous study are shown as follows. Carbon Fibers (CF, hereafter) were planted on flat metal-plates by electrostatic flocking. Those electrostatic flocked-plates (ESFP, hereafter) were arranged parallel in the charger. The dc high voltage applied to the charger was set carefully below the corona starting voltage. This is to use gradient force to attract suspended particles to the converged intense electric field region at the tip of the fibers of the charger. Once the suspended particles attach to the tip of the conductive fiber, they are charged by induction. If they re-entrain to the space, they should carry the induction charge, and they should be precipitated in the following collector. The collection efficiency of this process was stable within the range of particle-diameters between 0.3 and 1.0 μm . On the other hand, the collection efficiency was not stable for larger particles with diameter-range between 1.0 and 5.0 μm .

In ref.[2], we used a corona charger in the two stage ESP. The collection efficiency with the corona discharge was approx. 20% for 0.3 and 0.5 μm diameter particles, and 86% for the diameter-range of 2.0 and 5.0 μm . In this case the efficiency was more stable. We thought a weak corona discharge is necessary to realize our idea of using induction charging. In a weak corona discharge, suspended particles are driven by Coulombic force to the tip of the fibers, then are driven by gradient force to be collected at the tip. When the collected particles re-entrain, they should carry the charge acquired by the induction charging. In this study, by utilizing the induction charging, we have set a new target to reduce the power consumption to 10 % compare to the conventional 2-stage ESPs.

II. METHODOLOGY

In this study, a two-stage-ESP which can generate weak corona-discharge at ESFP in the charger is used. The details are as follows.

A. Manufacturing ESFP

We described the method to manufacture ESFP in ref. [1]. Outline is as follows.

The electro-conductive glue (Three-Bond 3303G), which is mainly made from silver-paste and silicon-resin, was applied on one side of the stainless-steel-plates (Stainless steel 304, 36 x 40 mm, thickness 0.4 mm). These base-plates were arranged in an electrostatic-flocking device with a fan for generating circulation-wind. Carbon fiber (CF, production code CO6343 made by TORAY, fiber diameter : from 5 to 10 μm) was cut with the length from approx. 0.1 to 3 mm by using scissors to make CF piles. The CF piles were thrown into the device for electrostatic flocking. The voltage of dc

-5 kV was applied to the arranged base-plates with gap 25 mm in the device, under the condition of generating circulation-wind. Then, some CF piles contacted to the adhesive glue on the plate-surface by the effect of circulation-wind in the device, and were finally fixed to form the flocked-plates. The base-plates took out from the device were set in an incubator where the temperature was approx. 200 deg. C for 1 h. After that, the base-plates were naturally cooled, to realize the electrostatic flocked-plates as shown in Fig. 1 (a). Fig.1(c) is a photo of ESFP with applying dc -7 kV. In the photo, light spots from corona discharge can be observed at edges of ESFP. Side view of the ESFP is shown in Fig. 1 (b), whose magnified figure is (d). In (e) the CFs on the edge of the ESFP were cut. With CFs on the edge, as shown in (d), the electric lines converge more than (e) and corona discharge easily takes place. In this study, we cut the CFs on the edge to try to generate corona more evenly.

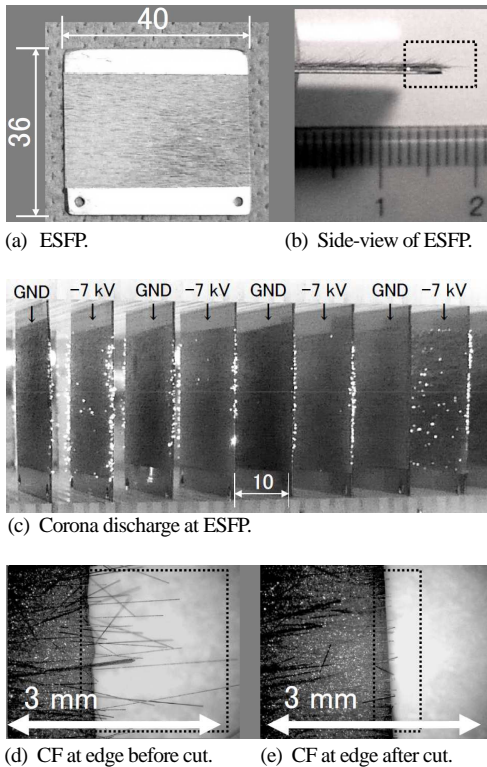


Fig. 1. Pole-plate with electrostatic-flocking. (ESFP: Electrostatic-flocked plate)

B. Layout of ESFP in the charger

The layout/electric-circuit of the flocked-plates in the charger is shown in Fig. 2 (the same as that in [1]). Twenty-four flocked-plates were set parallel with 10 mm gaps. Two plates at the end points were not flocked. In addition, the surfaces of twelve flocked-plates at leeward of the gas flow were facing to the opposite direction of the flocked surfaces at windward. Although the distance between the windward plate and the leeward plate on a line was 40 mm, the two plates on the same line were electrically connected, which means those two stood on the same voltage. The electric circuit was composed of the manner that each negative voltage line exists on the center position between the next two grounded plates.

In the previous study in [1], the authors noticed that the emitted light by the corona discharge weakened gradually with time transition of operation. We did not investigate the reason at that time because we selected the condition with “no corona discharge.” In this study, we used corona discharge, therefore, the corona V-I characteristics of the ESFP was studied to understand the causes of the time transition of the current change.

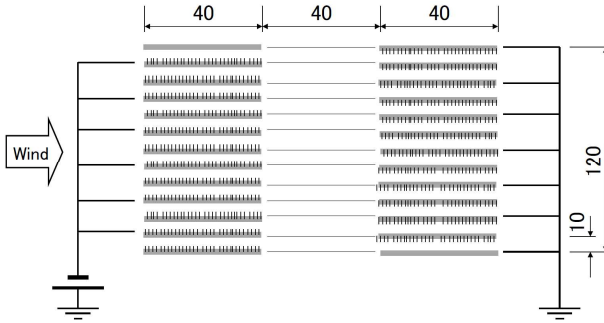


Fig. 2. Layout of electrode-plates with electrostatic flocking in the charger.

C. Wind velocity in the charger

In the test, the wind velocity in charger was fixed at 2 m/s. Cross section area of the charger was 121 mm x 32 mm, therefore, the air flow rate was 0.46 m³/min .

D. Determination of target power consumption for corona discharge

The determined air flow value was almost the same air-flow level of air cleaners with ESP in home electric appliances. The target power consumption of the corona discharge in this test, therefore, was to be determined by patent-information about those air cleaners.

An air cleaner whose air flow and power consumption are 0.3 m³/min and 3,500 mW respectively is shown in [3]. The discharge current is estimated as 500 μ A because the applied voltage is 7 kV. Ref. [4] describes an air cleaner with the discharge current of 500 μ A and the air flow of 3 m³/min. Although the applied voltage is not shown, the authors notice that the discharge current in [4] is the same as the current in [3] whereas the air flow in [4] is ten times larger than the air flow in [3].

In order to determine a specification of a hypothetical conventional-air-cleaner (hereafter, hypothetical-air-cleaner), the severer (lower) power consumption is to be selected from [3] and [4]. Then, “the specification of applied voltage 7 kV, discharge current 50 μ A, and power consumption 350 mW under the condition of air flow 0.3 m³/min” can be estimated by taking both [3] and [4] into consideration. In order to match the air flow 0.46 m³/min of the ESP in this test, the abovementioned specification can be transformed into “applied voltage 7 kV, discharge current 76 μ A, and power consumption 532 mW under the condition of air flow 0.46 m³/min” as the specification of the hypothetical-air-cleaner.

In addition, the reference [5] indicates that collection efficiency of air cleaners are around 80%. Then, the collection efficiency of the abovementioned hypothetical-air-cleaner is determined as 80%. (Although this collection efficiency stands on the condition of including not only charger but also collector, it is natural that the collector is not to consume electric power.)

E. Composition of the collector

The layout and electric-circuit of the collector is shown in Fig. 3. The collector used 13 electrode-plates with rectangular shape of 94 x 280 mm (thickness 0.4 mm) made of stainless-steel 304. There was no discharge-spike on these plates. Seven grounded-plates and six energized plates were alternately arranged parallel with 10 mm separation. The applied voltage to the energized-collector plates was -9 kV which did not generate corona-discharge. Therefore, the power consumption in the collector was neglected.

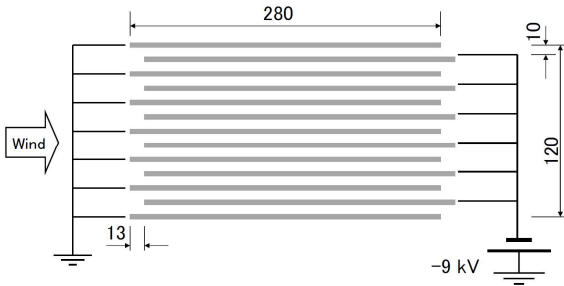


Fig. 3. Layout of electrode-plates in the collector.

F. Composition of the test equipment and test method

Schematic diagram and specification of the test equipment are shown in Fig. 4 and Table I, respectively. The particles to be collected in this study were those suspended in the air of the laboratory room. The inlet duct and the connection duct are indicated as #1 and #2, respectively. The charger duct, the connection duct, the collector duct, the connection duct, the outlet duct and the variable-speed fan are shown as #3, #4, #5, #6, #7 and #8, respectively. All the ducts were made of acrylic resin.

The ESP used in this test was composed by making #1 to #8 be serially connected. The air containing room-air particles were ventilated through this ESP. The high voltage power supplies (dc) are indicated as #9 and #10, which were connected to the charger duct and the collector duct, respectively. The current and voltage in both high voltage circuits were measured by using the voltage meters #13 and the current meters #14. Wind velocity meter #12 was used at the inlet of the inlet duct. The wind velocity in the charger duct was adjusted to 2 m/s with a fan-speed-controller.

The number-concentration of particles in the room-air was measured using the particle counter #11, whose two sampling tubes at the inlet-duct and the outlet-duct were alternately switched to calculate the collection efficiency as shown in (1).

$$\text{Collection efficiency} = [1 - (\text{outlet count} / \text{inlet count})] \times 100\% \quad (1)$$

This particle counter can measure number-concentration for each diameter-range from 0.3 to 0.5 μm , 0.5 to 1.0 μm , 1.0 to 2.0 μm , 2.0 to 5.0 μm and particles larger than 0.3 μm at one time. Particle concentration at the inlet and the outlet was measured five times for each condition, and the obtained five pairs of data were used to calculate the averaged collection efficiency. A series of this measurement was to be implemented in one day. Before starting the measurement, the test equipment with ESP was operated for 180 minutes with the maximum applied voltage. Then after confirming the collection efficiency being relatively stable, the measurement for this study was started.

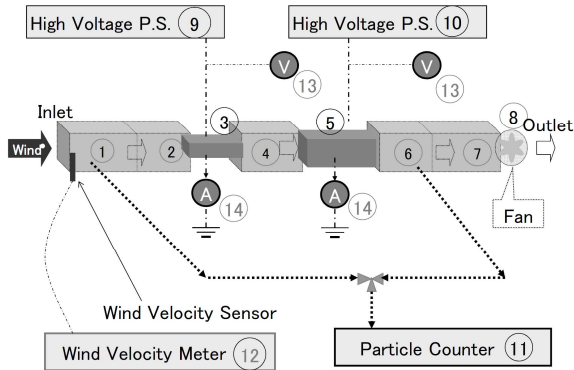


Fig. 4. Schematic diagram of test equipment.

TABLE 1: SPECIFICATION OF TEST EQUIPMENT

Items	Details
Duct(#1,2,4,6,7)	W 121, H 140, L 200 mm (Inside)
Charger duct (#3)	Duct ; W 121, H 32, L 180 mm (Inside) with slots for fixing electrode-plates
Collector duct(#5)	Duct ; W 121, H 90, L 300 mm (Inside) with slots for fixing electrode-plates
Fan (#8)	MU1238A-11B (Oriental Motor Co., Ltd.) Quantity ; 2 (tandem coupled) With a variable frequency controller
High voltage power supply (#9)	HV α -10K10N/OLTS/100 (Maxelec Co.,Ltd.) Max output voltage ; DC-10 kV Max current ; 10mA Ripple ; 0.01%
High voltage power supply (#10)	APH-10K5N (Maxelec Co.,Ltd.) Max output voltage ; DC-10 kV Max current ; 30mA Ripple ; 0.02%
Particle counter (#11)	KC-01E (RION), Light scattering method Range ; 0.3, 0.5, 1, 2, 5 over μm Sampling volume for individual measurement ; sample-mode of 283 mL (per 34 s)
Wind velocity Meter (#12)	Climomaster MODEL6531 (Kanomax) Mode;1 s measuring & 10 times ave.
Voltage meter & Probe (#13)	Digital multi meter type73303 (Yokogawa) Ratio;1/1000 (FLUKE), For high voltage
Current meter (#14)	Type 201133 (Yokogawa) Range; 0.1, 0.3, 1, 3 mA

III. RESULTS AND DISCUSSION

A. Characteristics of discharge current in the charger

Characteristics of the discharge current were measured with applying high voltage to ESFP in the charger. A transition of the discharge-current characteristic (short time) when -7.3 kV was applied to ESFP is shown in Fig. 5. The ESFP was exposed in the room-air for 3 months without applying high voltage until this measurement. As soon as applying high voltage, the initial discharge current of approx. $1,000$ μA quickly decreased to 38 μA at 30 minutes after the voltage application.

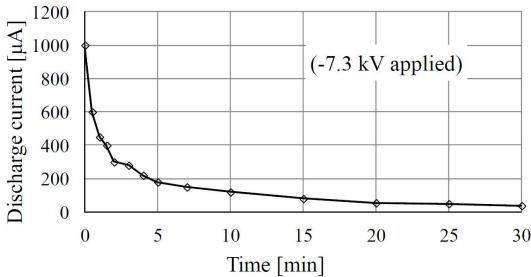


Fig. 5. Short time characteristic of discharge current. (in case of ESFP of applying no-voltage for 3 months)

The further transition of the current (long time) after 30 minutes is shown in Fig. 6. At around 120 min, the current reached a stable value of approx. 17 μA . When the applied voltage was reduced from -7.3 to -7.0 kV at the time of 180 min, the current was approx. 5 μA . The power was therefore approx. 35 mW, less than the target power consumption of 53 mW as described in section D.

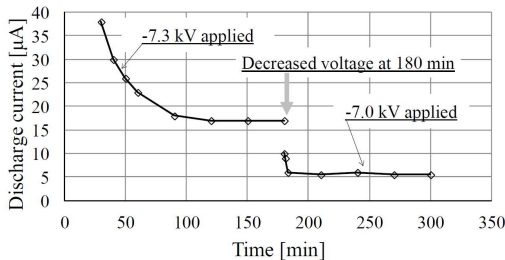


Fig. 6. Long time characteristic of discharge current. (in case of ESFP of applying no-voltage for 3 months)

As the result of the abovementioned test, the high voltage -7 kV was applied to the ESFP several times to investigate the time transition of discharge current. The discharge-current characteristics are shown in Fig. 7 and Fig. 8. The discharge current decreased to a stable value of approx. 5 μA after 180 minutes from the voltage application. The same voltage of -7 kV was applied to the ESFP on different days as indicated in Fig. 7 and Fig. 8. Similar tendency was obtained. Cause of the decrease in the current with time might be absorption of moisture by CF from the room-air. Judging from these observations, although the current of ESFP fluctuate in the beginning of the voltage application, it became a stable value of several μA after approx. 180 minutes.

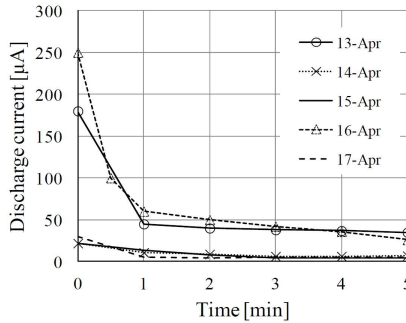


Fig. 7. Short time characteristics of discharge current. (applied voltage -7 kV)

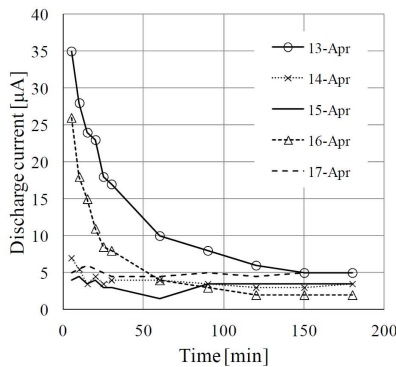


Fig. 8. Long time characteristics of discharge current. (applied voltage -7 kV)

We implemented a test of how the discharge-characteristics change by measuring discharge current after making ESFP adsorb moisture intentionally. The test method was as follows. As soon as the measurement of discharge current of “15-Apr” was completed, all ESFP in the charger were taken out. Those ESFP were immersed in a vessel filled with tap-water for 1 h. Then, those ESFP were taken out and were naturally dried in the room-atmosphere (humidity approx. 40% Rh). After approx. 16 h passed, the visual check that the water on the surfaces of ESFP disappeared was implemented. Then, the dried ESFP were inserted into the charger again to apply voltage for measuring discharge current. The characteristics of ESFP after natural dryness process through immersion process are shown as “16-Apr” in Fig. 7 and Fig. 8. The initial discharge current immediately after the voltage application was large (approx. 250 μA), as indicated by “16-Apr” in Fig. 7. This resembles the ESFP characteristic of “13-Apr” whose voltage had not been applied for 11 days. Further current measurement was made as shown by “17-Apr”. The authors found that this characteristic resembled to those of “14-Apr” and “15-Apr” in which the voltages were applied “one day after large current discharge” and “two days after large current discharge.”

The authors described that the cause of the change of the discharge current lay in the absorbed water on (in) CF. On the other hand, the ref. [6] reports that tips of CF are particularly worn out in case of generating corona discharge with large current. Since the flocked CFs were not uniformly distributed (planted), current tends to be converged only in limited tips. This could lead the large initial-current and lead to worn the tip, causing gradual decrease in current.

The authors determined the applied-voltage to the charger on measuring the collection efficiency of the ESP, judging from the abovementioned results of the discharge-current measurement. The

key-points for determining the applied voltage were described as follows.

- 1) The target value for power consumption of the charger is less than 53 mW.
- 2) In case of applying -7 kV to the charger, “180 minutes” is sufficient to reach the current to a stable value.
- 3) At -7 kV, lowest current value was between 2 and 5 μA .
- 4) With the current of 5 μA , the power consumption is 35 mW. This is less than the target value of 53 mW.

B. Collection efficiency of the two-stage-ESP

Although the applied voltage to the charger was determined as -7 kV, other lower voltages were also to be applied to grasp the effect of the voltage on collection efficiency. i.e., the voltage of -7 kV was applied at first for 180 minutes. Then after confirming that the discharge current was kept at the lowest current value, the collection efficiency was measured. Then the voltage was reduced step by step (-6, -5, -4, -3 and 0 kV). All the measurement of the collection efficiency (totally 5 times) was implemented in April. Ambient temperature of each measurement was in the range between 18 and 24 deg. C, and the humidity was between 36 and 55% Rh. As the concentration, counted particle number which indicated the particle number in 1 L gas was used. As the concentration of particles in room air (measured 5 times), size distribution of the number concentration and the ratio to the center value were used in TABLE 2.

Since very few particles were measured for “all the particle-diameters of larger than 5 μm ”, the authors did not evaluate the collection efficiency on this diameter-range.

TABLE 2: THE RANGE OF COUNTED PARTICLE NUMBER (ABOUT THE MEASUREMENT FIVE TIMES)

Size of particle [μm]	Range of counted particle-number per 1 L (Range-ratio [%] to the center value of range)				
	1 st measurement	2 nd measurement	3 rd measurement	4 th measurement	5 th measurement
2.0 to 5.0	22 – 55 (± 42.9)	121 – 172 (± 17.4)	8 – 35 (± 62.8)	5 – 18 (± 56.5)	13 – 42 (± 52.7)
1.0 to 2.0	95 – 182 (± 31.4)	319 – 400 (± 11.3)	62 – 88 (± 17.3)	26 – 57 (± 37.3)	113 – 155 (± 15.7)
0.5 to 1.0	682 – 830 (± 9.8)	759 – 885 (± 7.7)	434 – 708 (± 24.0)	125 – 216 (± 26.7)	868 – 1,031 (± 8.6)
0.3 to 0.5	13,192–17,216 (± 13.2)	9,284–9,705 (± 2.2)	10,266–15,080 (± 19.0)	1,666 – 3,109 (± 30.2)	15,547–17,891 (± 7.0)
All over 0.3	14,152–18,183 (± 12.5)	10,589–11,128 (± 2.5)	10,824–15,894 (± 19.0)	1,831 – 3,370 (± 29.6)	16,605–18,979 (± 6.7)

C. Collection efficiency for particles of all the diameters of “larger than 0.3 μm ”

The collection efficiency for particles of all the diameters of “larger than 0.3 μm ” on changing voltage of the charger under the constant condition of applied voltage -9 kV to the collector and wind velocity 2 m/s is shown in Fig. 9. The collection efficiency between 0 and -4 kV is almost constant at 30% without showing the rise of efficiency with increasing the voltage.

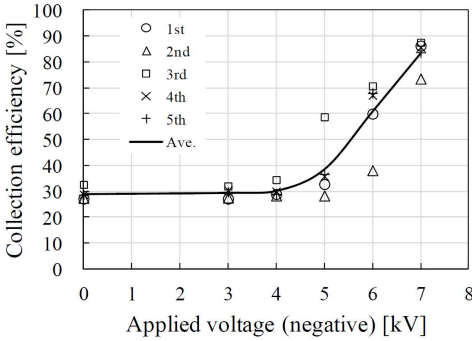


Fig. 9. Collection efficiency. (all the diameters larger than 0.3 μm)

Fig. 9 shows that the collection efficiency increased in accordance with the voltage rise beyond -4 kV to attain approx. 85 % at -7 kV. The discharge current was recorded during the measurement for collection efficiency with changing voltage as shown in Fig. 10 which indicates the current rise beyond -5 kV. Since the smallest scale of the current meter was 1 μA , some fluctuation might exist. Furthermore, the dispersion of collection efficiency at -5 and -6 kV in Fig. 9 was remarkable. This could be due to unstable corona characteristics at lower voltages.

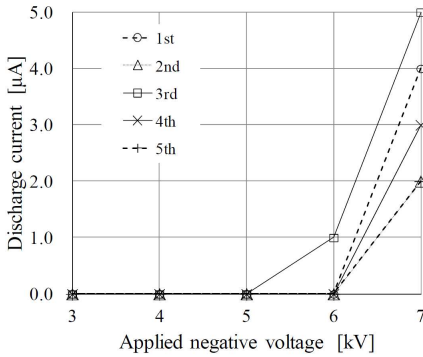


Fig. 10. V-I characteristics of the charger.

The relation between the discharge current (on applying -7 kV) and humidity of the room air for each measurement is shown in Fig. 11. The humidity at the second measurement was 36% Rh (the minimum value). The humidity values at the third and the fourth measurement were 50% Rh and 55% Rh (relatively high). The solid line in the figure was obtained from linear approximation. As indicated, the discharge current increased in accordance with the humidity. The authors understand that there might be humidity change as a factor for the dispersed values of discharge-current mentioned above.

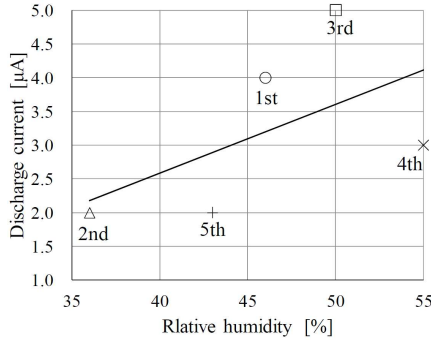


Fig. 11. Characteristic of “humidity - current.”

The relation between the collection-efficiency and the humidity for each voltage is shown in Fig. 12. At the voltages of 0, -3 and -4 kV, the collection efficiency was shown as “almost-flat characteristics” of approx. 30% even in the case that the humidity changed within the range from 36 to 55% Rh. Although it was natural that corona discharge was not generated at 0 kV, the three voltages of 0, -3 and -4 kV indicated the same kind of flat characteristics, which implies that corona discharge also might not be generated at -3 and -4 kV.

On the other hand, the tendency that the collection efficiency increased in accordance with the rise of humidity was seen in case of -7 kV. The cause of the increased collection efficiency might lie in the rise of discharge current. However, the collection efficiency was slightly reduced in case of humidity 55% Rh. The cause for this is unclear.

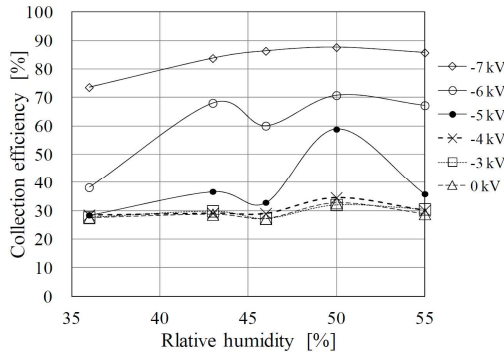


Fig. 12. Characteristics of “humidity - collection efficiency.”

The relation between the discharge current and the collection-efficiency at -7 kV is shown in Fig. 13. The relation between the power consumption and the collection efficiency is shown in Fig. 14. From Fig. 13 and/or 14, the collection efficiency increased in accordance with the discharge current or the power consumption. However, this tendency showed slightly-saturated. Judging from Fig. 14, the collection efficiency of 84% was attained under the condition of 14 mW power consumption which was smaller than the target value of 53 mW.

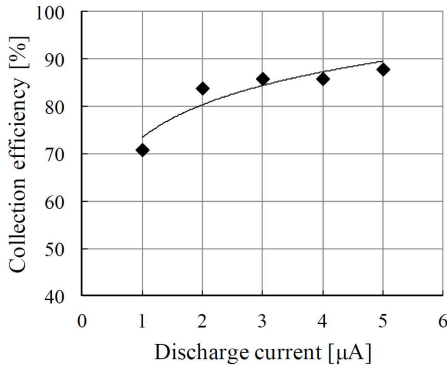


Fig. 13. Characteristic of “current - collection efficiency.”

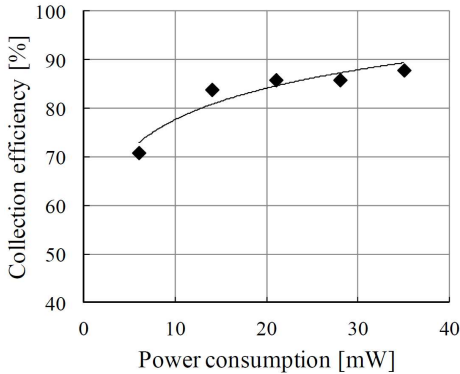


Fig. 14. Characteristic of “power consumption - collection efficiency.”

D. Collection efficiency for particle diameters from 0.3 to 0.5 μm

The collection efficiency for particle diameters from 0.3 to 0.5 μm is shown in Fig. 15. Since the counted number of particles in this diameter-range occupied approx. 90% of all the counted number in all the ranges, Fig. 15 indicated similar characteristic to the one for “particles of all the diameters of larger than 0.3 μm ” shown in Fig. 9.

The dispersion on the collection efficiency of the applied voltage range from 0 to -4 kV was small. The authors think that the small dispersion at 0 kV meant that the dispersion was small even in case of no voltage to the charger (no operation of the charger) due to the stable collection efficiency of “the collector only.” With -3 or -4 kV to the charger, no big difference was seen compared to the case of 0 kV. The authors think that the collection efficiency for -3 or -4 kV was almost governed by the efficiency of “the collector only.” The collection efficiency for -5, -6 and -7 kV in the second measurement indicated the minimum values, which can be understood with the fact that the humidity during the second measurement was the lowest 36% Rh as shown in Fig. 11 (low humidity might make electric-discharge “throttle down”).

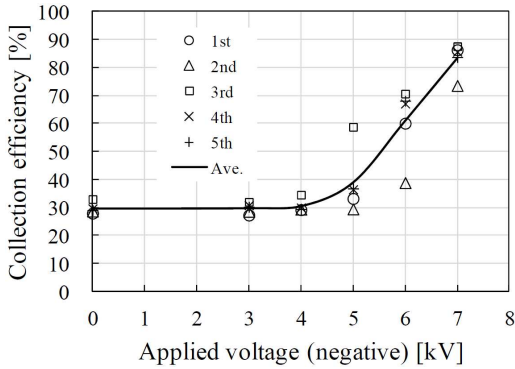


Fig. 15. Collection efficiency. (diameters 0.3 - 0.5 μm)

E. Collection efficiency for “particle diameters from 0.5 to 1.0 μm”

The collection efficiency for “particle diameters from 0.5 to 1.0 μm” is shown in Fig. 16. Although Fig. 16 indicated similar characteristic to the one for “particle diameters from 0.3 to 0.5 μm” shown in Fig. 15, the collection efficiency of the applied voltage range between 0 and -4 kV slightly increased in accordance with the rise of applied voltage. The cause for the increasing collection efficiency might lie in the possibility that some parts of the passing particles through the charger were induction-charged and collected at the collector.

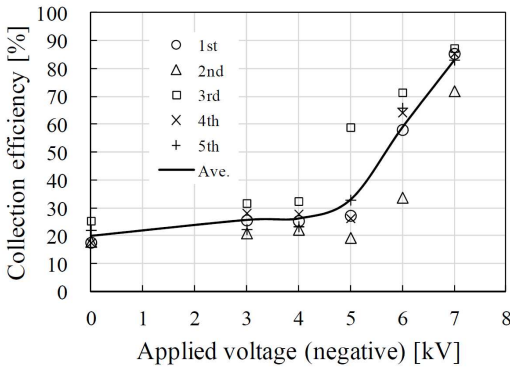


Fig. 16. Collection efficiency. (diameters 0.5 - 1.0 μm)

F. Collection efficiency for “particle diameters from 1.0 to 2.0 μm”

The collection efficiency for “particle diameters from 1.0 to 2.0 μm” is shown in Fig. 17. The figure 17 indicated similar characteristic to the one for “particle diameters from 0.5 to 1.0 μm” shown in Fig. 16. The authors think that the voltage application of -7 kV which made the current be activated might lead to the relatively-stable collection efficiency by considering the relatively-small dispersion at the voltage, even in case of the larger diameters of particles from 1.0 to 2.0 μm.

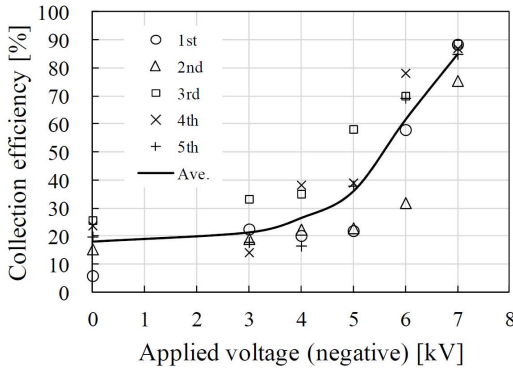


Fig. 17. Collection efficiency. (diameters 1.0 - 2.0 μm)

G. Collection efficiency for “particle diameters from 2.0 to 5.0 μm”

The collection efficiency for “particle diameters from 2.0 to 5.0 μm” is shown in Fig. 18. Although the figure 18 indicated similar characteristic to the one for “particle diameters from 1.0 to 2.0 μm” shown in Fig. 17, the collection efficiency at -4 kV showed the “segmental bottom.” The diameters of CF are from 5 to 10 μm, and the particle diameters are almost half to the CF diameters. When the discharge from CF starts, the “discharge just-points” might be the particles having been attached on the surfaces of CF. As a result, the re-entrainment might be accelerated. However, the details for this are unclear.

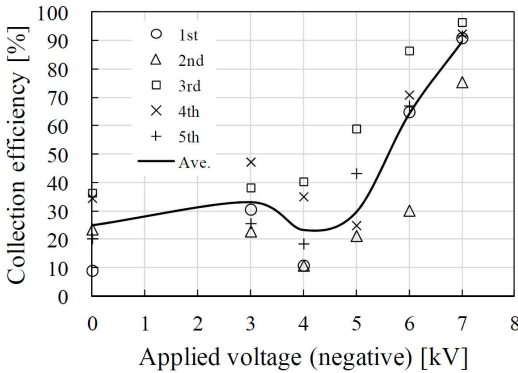


Fig. 18. Collection efficiency. (diameters 2.0 - 5.0 μm)

H. The summarization of collection efficiency (Closing)

In case of applying -7 kV, the discharge current was approximately 5 μA, i.e., the power consumption was 35 mW which was less than the target power consumption 53 mW. At this condition, the collection efficiency of 80% was attained in all the diameter ranges. The power consumption of 35 mW means “less than 10%” compared to the power consumption of a typical ESP used in air cleaners in market. This experimental result shows that the power consumption for generating

charged particles can be reduced using the electrostatic-flocked electrode with CF. The assumed factors are as follows.

(a) There is possibility that number of particles touched to the extremely-fine CF (especially the tips of CF) may increase with the help of charging effect to the particles by weak corona-discharge.

(b) Since diameter of each CF is approx. 7 μm , electric field converges intensively and gradient force is induced when particles close to the tips.

(c) As a result, the particles are driven towards the tips of the CF with the help of charging due to weak corona-discharge, and then they are attracted to the tips of CF with strong gradient force to contact to CF or be collected on CF.

(d) In case that the particles which contact to CF (or were collected on CF) with strong electric field re-entrain, the particles may be induction-charged strongly. This could be more effective compare to the corona charging, and these charged particles could be collected effectively at the following parallel plate collector.

IV. CONCLUSION

Metal plates on which electrostatic flocking was processed with fine carbon fibers were prepared. These plates were arranged in parallel with spacing of 10 mm to compose the charger to which dc -7 kV to generate weak corona-discharge was applied. The collector, placed after the charger, was composed of parallel flat plates made of metal (gap 10 mm, applied voltage dc -9 kV and no corona discharge). Using this two-stage-ESP, room-air containing particles was measured for the test with the air flow velocity of 2 m/s. The collection efficiency was measured, and the following results were obtained.

(1) The collection efficiency of 80% was attained in all the diameter ranges from 0.3 to 5.0 μm with the power consumption of "less than approx. 10%" of that for typical ESPs used for conventional air cleaners in the market. Suspended particles are sufficiently-charged by induction charging to be collected finally, even though the corona discharge was weak. However, the detailed charging mechanism with electrostatic-flocked plates is unclear, and further investigation is necessary.

(2) When the humidity was within the range between 36 and 55% Rh, the collection efficiency did not increase so much at the voltages of -3 and -4 kV where discharge current hardly flowed in the charger, even in the case of humidity-rise.

(3) On the other hand, the tendency that the collection efficiency increased in accordance with humidity-rise was seen in case of -7 kV where small discharge current flowed in the charger. The cause of the increased collection efficiency might lie in the rise of discharge current in accordance with the humidity-rise, i.e., the charge-effect to particles might increase.

(4) As for the electrodes being electrostatic-flocked with CF, the electrodes adsorbed water in the air. On making corona-discharge generate under this adsorption condition, large initial discharge current flowed at first. However, the current decreased in the course of time transition to reach a constant value finally.

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