The Characteristics of Mini-Cylindrical Electrostatic Precipitator

By Takayoshi ADACHI*, Shundo SUYAMA* and Makoto SHIMODA**

Abstract

It is known that both positive and negative corona discharge are accompanied with Ionic Wind (*IW*) in air at atmospheric pressure. Ions are accelerated toward the collecting electrode by the electric field and collide with many neutral molecules. As the result, the neutral molecules dragging by ions move toward the collecting electrode, too. *IW* is caused such a way and its velocity is almost equal to gas velocity in the Electrostatic Precipitator (*EP*).

Then, Mini-Cylindrical *EP*, utlizing *IW* for the purpose of dust collection positively, was produced by way of experiment. Authors call this apparatus Mini-Cylindrical *EP* so that the scale of this *EP* is about one tenth as large as an industrial *EP*. In this paper it is described that Mini-Cylindrical *EP* is useful for cleaning air from the results of experiments.

Introduction

It was shown experimentally in a wark[1] that Ionic Wind (*IW*) had blown from discharging wire to collecting electrode. Therefore, it can be considered that *IW* has important effects upon the dust collection of Electrostatic Precipitator (*EP*). The principles of Mini-Cylindrical *EP* are as follows. Needle and cylinder are used as discharging and collecting electrode, respectively. A positive high voltage is applied on needle electrode. Most of the dust at the field are charged by the positive ions and are driven to the cylindrical electrode by two forces of electric field strength and *IW*. The dust, whether these are charged or not, are driven by *IW*. Then the dust are collected by the Coulomb force etc. at the inside of cylinder.

This *EP* is small and may be used for cleaning air. Harmful gases as ozone are generated at the negative corona. Positive corona has bad characteristics as low collection efficiency and low spark voltage. Air conditioning *EP*, however, needs low-ozone generation, so positive corona is used. In the case of increasing gas flow rate, the demerit of low collection efficiency is covered sufficiently by increasing number of cylinder.

This *EP*, as compared with two-stage type *EP*, can do without two power sources. *IW* drives the dust so that a blower is not necessary. As it is the same place where dust are driven and charged, it has an advantage to be small.

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* Department of Electrical Engineering

** The Postgraduate Course of Electrical Engineering

Experimental Apparatus and Procedure

Apparatus:

Fig. 1 and Fig. 2 show the schematic diagram of the experimental circuit and the arrangement for measurement of collection efficiency, respectively. In Fig. 1, *Tr* is a neon transformer, *SR* is a full-wave rectifire, *R* is a protection resister, *SV* is a static voltmeter and *A* is an ammeter. The part of *EP* is the corona discharge field.

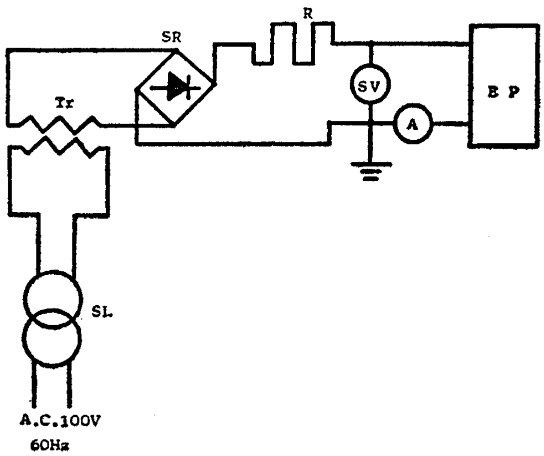

Fig. 1 Schematic diagram of experimental circuit.

In Fig. 2, discharging needle electrode had a diameter of 6.1 mm and tip angle of $\alpha°$. Cylindrical electrode which was made of iron and faced the needle at the distance of D_1 mm had a inside diameter of d mm, thickness of Δd mm, length of L mm and tip angle of $\beta°$. A bakelite plate (20·20 cm) was furnished at the tip of the cylindrical electrode perpendicularly so that *IW* could flow only through the cylinder.

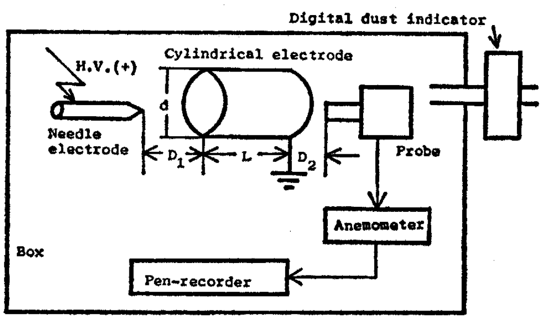

Fig. 2 Schematic diagram of experimental apparatus.

Detector (dia. 2 mmϕ) of Thermistor-anemometer was placed at the distance of D_2 mm at the rear of cylinder. Velocity of *IW* passing through the cylinder is the average of measured value which was recorded by a pen-recorder for one minute. Probe of anemometer could be slide across the diameter horizontally and was earthed lest it should be charged.

Apparatus for experiment of collection efficiency is shown in Fig. 2. A smoke of an incense stick was used as collected dust. The initial density of the smoke was done to be 60 mg/cm³. The decreasing density was measured by a digital dust indicator, which was set outside of the box. The tube was inserted in the box for entrance of the dust to the indicator.

The measuring time of the indicator was decided one minute every three minutes taking into consideration of decreasing density. The volume of the box was decided on about 0.30 m³ (60·60·83 cm) taking into consideration of scale of *EP*, measuring time and applied voltage.

Determination of tip angle $\alpha°$, $\beta°$:

The tip angle of electrodes are shown in Table 1. According as the angle of two electrodes are large, the corona current is small and *IW* velocity is slow. When the angle of $\beta°$ is small, it is not desirable because much ozone is generated by negative corona from the tip of cylindrical electrode. Therefore, the experiment was done at the combination of b-B (45°) in Table 1.

Table 1 Tip angles $\alpha°$, $\beta°$ of electrodes

Needle:	$\alpha°$	Cylinder:	$\beta°$
a	20°	A	15°
b	45°	B	45°
c	70°	C	75°

The corona discharging characteristic in this case is shown in Fig. 3 at the thickness of cylinder $\Delta d = 2$ mm. The range from 10 kV to 15 kV is good discharging condition judging from the average electric field strength ($4 \sim 7$ kV/cm)[2] of an industrial *EP*.

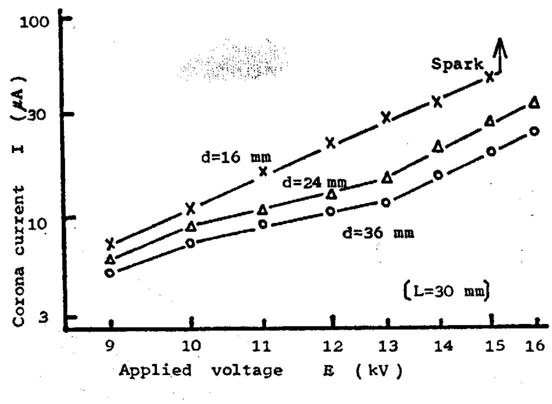

Fig. 3 Characteristics of corona discharge.

Determination of parameter:

In Fig. 1, the parameter D_1 was decided on the distance of 15 mm, at which spark did not occur if 15 kV was applied, D_2 was decided on the distance of 5 mm as *IW* velocity was not defferent so much at range from 3 mm to 12 mm.

IW of Mini Cylindrical *EP*

IW velocity was measured by Thermistor-anemometer across the center of cylinder and the distribution of *IW* velocity is shown in Fig. 4. It is shown that its curve is mountaneous and its center is a maximum value. The slope of that distribution is steeper with the inside diameter of the cylinder. *IW* flow rate Q (cm^3/sec) calculated from Fig. 4 and Eq. 1.

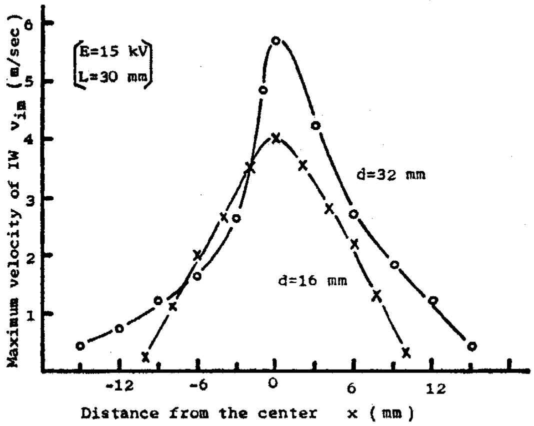

Fig. 4 Relation between the maximum velocity of *IW* and the distance from the center.

$$Q=\sum_i((2\pi x_i)\cdot\Delta x)\cdot v_i, \qquad \cdots\cdots\cdots(1)$$

where x_i (cm) is the distance between the measuring point and the center of cylinder, Δx is the narrow range at x_i and v_i (cm/sec) is the mean value of *IW* velocity within Δx.

The relation between the maximum velocity v_{im} of *IW* and applied voltage E is shown in Fig. 5, where the length of cylindrical electrode L is a parameter. These characteristics are straight and the corona discharge is stable at the region from 8 kV to 15 kV. From Fig. 5, the relation between v_{im} and L are obtained. According to this result, v_{im} is small at the length of 10 mm and is a maximum

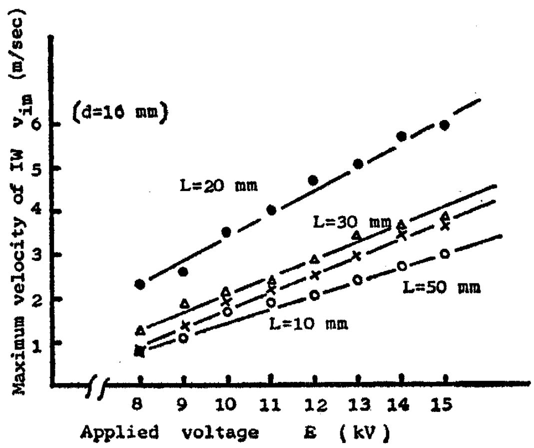

Fig. 5 Relation between maximum velocity of ionic wind and applied voltage.

at the length of 20 mm. v_{im} has a tendency to reduce with increasing L because of increasing of the frictional resistance in the cylinder. The cylinder of the length of 30 mm is mainly used because it is used for a long time.

The corona current I, *IW* flow rate Q and the maximum velocity v_{im} of *IW* are plotted in Fig. 6 as a function of inside diameter d of cylinder. At the range of the measurement, v_{im} and I decrease with d at a constant applied voltage. Because the distance between two electrodes increases and the electric field strength weakens. Thereby ions being generated at the corona region are lessen and Coulomb force which accelerates ions is weakened. For these reasons, v_{im} and I depending on the ions are decreased. However Q has a tendency to increase straightly until $d=28$ mm. The experimental equation in Fig. 6 is shown by

$$Q=45d-160 \text{ (cm}^3\text{/sec)}. \qquad \cdots\cdots\cdots(2)$$

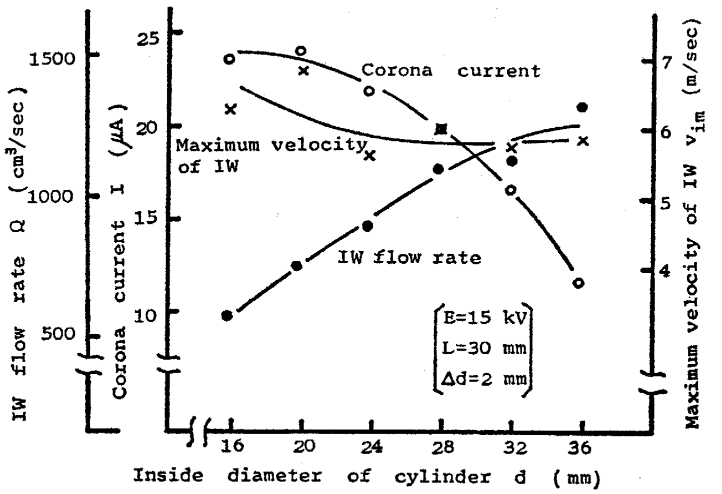

Fig. 6 Relation between inside diameter and *IW* flow rate, corona current and maximum value of *IW* velocity.

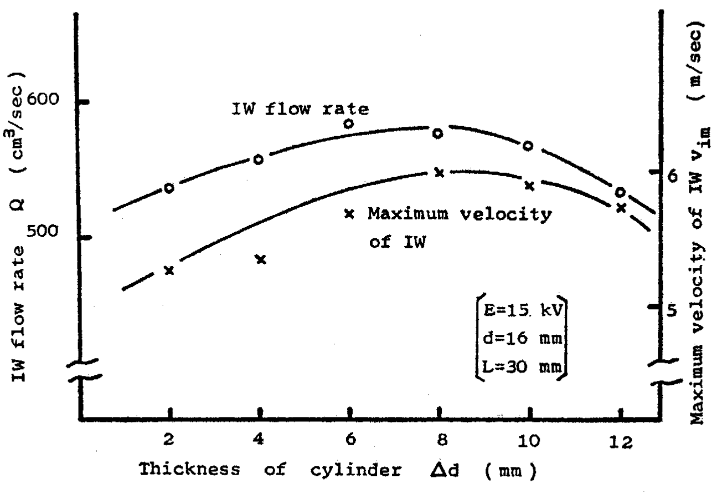

Fig. 7 Characteristics of *IW* flow rate and maximum velocity of *IW* versus thickness of cylinder.

As *IW* could flow only through the cylinder for the bakelite plate, Q increases with d. Where inside diameter is larger than 28 mm, *IW* flow rate Q is saturated for the reason of less ions.

IW flow rate Q and the maximum velocity v_{im} of *IW* are plotted in Fig. 7 as a function of the thickness Δd of the cylinder at the constant inside diameter $d=16$ mm. There are not very much change on these characteristics. If the declination of *IW* flow rate Q is calculated, it is within $\pm 5\%$ and that of v_{im} is the same. From these results, the thickness Δd being changed, Q and v_i are not change particulary. Accordingly, the ready-made iron tube ($\Delta d=$ 2 mm) was used because it was taken easily.

The Characteristics of Particle Collection of Mini-Cylindrical *EP*

The characteristics of particle collection of Mini-Cylindrical *EP* was obtained by using the experimental apparatus in Fig. 2. The changing density of aerosol with time is shown in Fig. 8 in the case of initial density 60 mg/m^3. According to Fig. 8, the spontaneous decrease of aerosol is not remarkable. The reason of this tendency is considered that the particles sticked to the wall of box due to its motion and settled naturaly because of the increase of diameter of particle due to collision between particles.

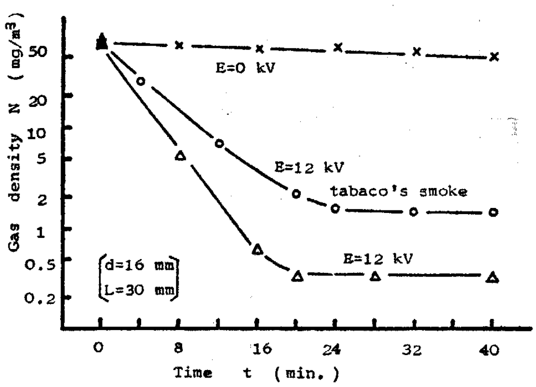

Fig. 8 Relation between gas density and time.

After high voltage is applied, corona discharge occured and *IW* arise. The density of aerosol decreases with time at this condition rapidly and straightly in Fig. 8. Using tabaco's smoke (spontaneous combution) as the aerosol, the rate of decrease is less than in case of using incense-stick's smoke. As an optical dust indicator was used, these results were not maked direct comparison. Since the diameter of usual tabaco's smoke is nearly two times as large as non-smoked smoke, the collection efficiency is better than that in Fig. 8. After the density of aerosol using incense-stick's smoke becomes nearly 0.5 mg/m^3, the variation of density cannot be measured because of the characteristics of the sensitivity of the dust indicator.

The relation between applied voltage E (kV) and collection time T (min.) when the collection efficiency is 99%, is shown in Fig. 9 on semilog coordinates. In any case of the diameter of cylindrical electrode d (mm), T decrease straightly. An experimental equation becomes

$$\log T = -3.3 \log E + C, \qquad \cdots\cdots\cdots(3)$$

where C is the constant of d function. The larger d is, the more Q (cm^3/sec) increases and the better the collection efficiency becomes.

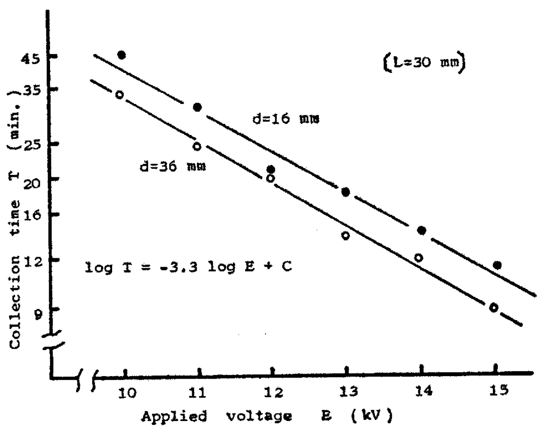

Fig. 9 Relation between collection time at $\eta = 99\%$ and applied voltage.

The relation between the diameter of cylindrical electrode d (mm) and the collection time T (min) when the collection efficiency is 99% is shown in Fig. 10. T decreases as increasing with d in Fig. 10. This decreasing tendency is remarkable at $E = 10$ kV. This reason is that Q increases with d as shown in Fig. 6 and plenty of aerosol was carried into the cylinder. IW flow rate through the cylinder for ten-minutes periods is 0.33 m^3, where the applied voltage $E = 15$ kV and the inside diameter of cylindrical electrode $d = 16$ mm. This value is nearly equal to the volume of the box for experiment. From these results of Fig. 9 and Fig. 10, collection time T is short when the applied voltage is high and inside diameter is large at the range of measurement.

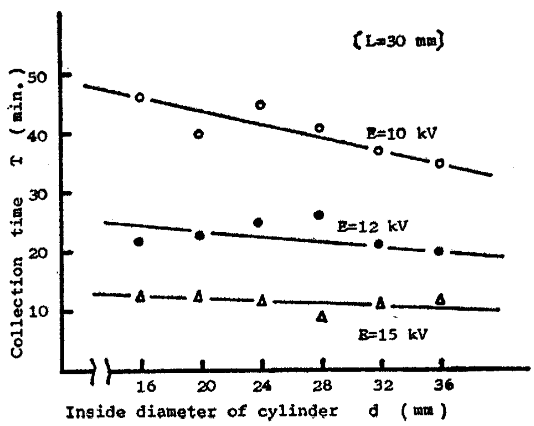

Fig. 10 Relation between collection time at $\eta = 99\%$ and inside diameter of cylinder.

The relation between the inside diameter of cylindrical electrode d (mm) and the collection efficiency η at ten minutes past is shown in Fig. 11. If the applied voltage E is constant, η is in proportion to d.

If d is large, the distance between electrodes become large, and the electric field strength between electrodes is weaken and IW velocity is small. However, IW flow rate Q through the cylinder is increase in Fig. 6. As increasing with the applied voltage E (kV), η increases rapidly and approaches 100% in Fig. 11.

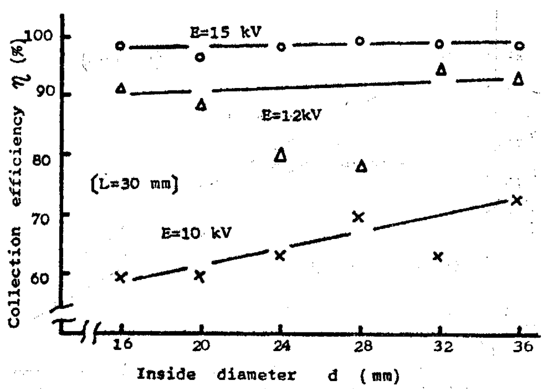

Fig. 11 Relation between colletion efficiency and inside diameter.

The collection efficiency η at ten-minutes past and the collection time T at 99% are plotted in Fig. 12 as a function of the length of cylindrical electrode L (mm). As increasing with L, η decreases and T increases. This fact shows that L has better be short. This is the reason that the decrease of Q caused by viscocity is more influent than the increase of collection area due to increasing L. Therefore, in this EP, dust was collected in the area where the distance is nearly equal to 10 mm from the tip of the cylinder. This fact is obtained experimentally. However, in practical, in order to use long time, L is required to some length because the collection area have need to be wide, and the demerit of the characteristics of T and η is covered sufficiently.

The collection efficiency η versus IW flow rate Q (cm^3/sec) is plotted in Fig. 13 on log-log coordinates for a range of parameters d. It is evident that

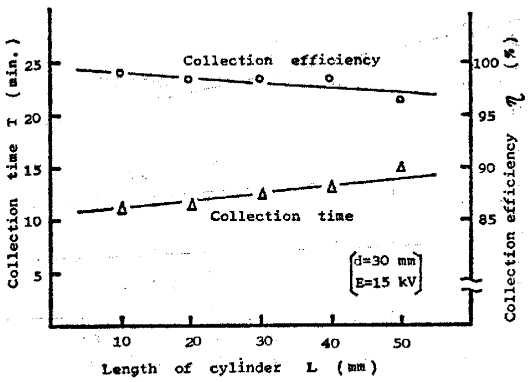

Fig. 12 Collection time at $\eta=99\%$ and collection efficiency at ten minutes past versus length of cylinder.

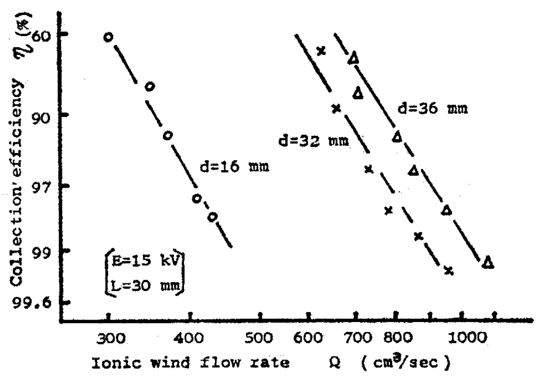

Fig. 13 Relation between collection efficiency at ten minutes past and ionic wind flow rate.

η increases with Q and each straight lines are roughly parallel. In order to obtain the same collection efficiency, *IW* flow rate in case of $d=32$ mm is almost twice as much as that of $d=16$ mm. This is due to proportion of *IW* flow rate versus inside diameter d in Fig. 6.

In Fig. 14, collection efficiency is in proportion to average electric field strength G that is applied voltage divided by distance from needle to tip of cylinder on log-log coordinates. Improvement of the collection efficiency η due to the increase of G depends on the charging quality of particles and the increase of *IW* flow rate.

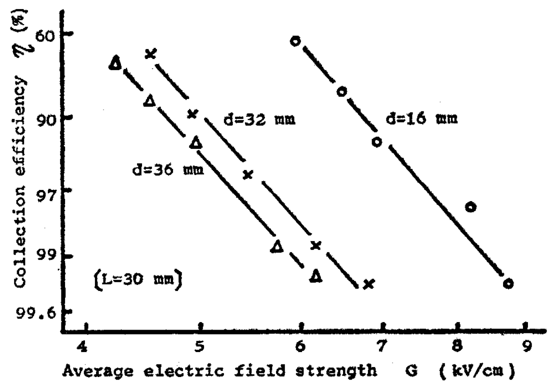

Fig. 14 Relation between collection efficiency at ten minutes past and average electric field strength.

The Empirical Equation for the Collection Efficiency

In Fig. 13 and Fig. 14 plotted on logarithmic graph paper, it was found that the collection efficiency η versus *IW* flow rate Q and the average electric field strength G lay almost on a straight. In spite of changing the inside diameter of cylinder those gradient are nearly equal to -3. Those empirical formula are obtained as follows;

$$\log(1-\eta)=-3\log Q+A_1. \qquad \cdots\cdots\cdots(4)$$

$$\log(1-\eta)=-3\log G+B_1. \qquad \cdots\cdots\cdots(5)$$

Rearranging the expression,

$$\eta=1-A_2Q^{-3}. \qquad \cdots\cdots\cdots(6)$$

$$\eta=1-B_2G^{-3}. \qquad \cdots\cdots\cdots(7)$$

Where, A_1, A_2, B_1 and B_2 are empirical constant numbers. Asuming that Q is independent on G each other and constant number k_1 takes place in two equations,

$$\eta=1-k_1(QG)^{-3}. \qquad \cdots\cdots\cdots(8)$$

In practical problem, Q is depend on G each other. Both Q and G is based on applied voltage E and inside diameter d of cylinder.

The following relation were obtained in the experimental apparatus of Fig. 1.

$$Q=\pi(d/2)^2\bar{v}_i, \qquad \cdots\cdots\cdots(9)$$

$$G=\frac{E}{((d/2)^2+D_1^2)^{1/2}}, \qquad \cdots\cdots\cdots(10)$$

where $\bar{v}_i$ is the mean velocity of *IW*, and D_1 is the distance between two electrodes. Rearranging Eq. (8) by substituting Eq. (9) and Eq. (10) into Eq. (8), this is approximated by Eq. (11).

$$\eta=1-k_2(\bar{v}_i\cdot d\cdot E)^{-3}, \qquad \cdots\cdots\cdots(11)$$

where k_2 is a constant number.

The experimental values agree approximately with the calculated value of an empirical equation (11) which is applicable in the experimental regions as follows;

$$16<d<36 \text{ (mm)},$$

$$10<E<15 \text{ (kV)}.$$

Judging from experimental error, Eq. (11) is appropriate practically.

Conclusion

The summary of the result is as follows;

(1) The distribution of *IW* velocity at the exit of cylindrical electrode is a mountainous curve. As increasing with the inside diameter of cylindrical electrode d, its slope is steeper.

(2) According as the inside diameter d of cylindrical electrode is increased at its thickness $\Delta d=2$ mm, the maximum velocity of *IW* v_{im} and corona current I have a tendency to decrease. But, *IW* flow rate increase strongly with d.

(3) When the thickness of cylindrical electrode is changed at its inside diameter $d=16$ mm, *IW* flow rate and the maximum velocity of *IW* show slightly a mountainous curve. However, because both declination are within $\pm 5\%$

respetively, the variation of Δd is negligible.

(4) Setting the initial density of the smoke of incense-stick 60 mg/m^3 in the box, the density reduces little by little in nature. When Mini-Cylindrical *EP* is operated in this box, its density reduces untill near 0%. This fact is shown obviously that the usefulness of this *EP* is excellent.

(5) The collection time T when the collection efficiency is 99% decreases in proportion to applied voltage E at the constant of d, and with the inside diameter of cylindrical electrode at the constant of E. The latter reduces few at the region of measurement. When the length of cylindrical electrode is large, a bad result that T is large slightly was obtained.

(6) At a ten-minutes past after high voltage applied, the collection efficiency η increased with the length and diameter of cylindrical electrode. These causes are that *IW* flow rate increases with diameter and the collection area increases with length.

(7) According as *IW* flow rate and the average electric field strength increase, the collection efficiency η of ten-minutes past becomes good. This is caused by increasing d in the latter and increasing Q in the other.

(8) In the above-mentioned results, the characteristics of $(1-\eta)$ versus Q and G is a straight line each other after plotting of logarithmic graph paper. Therefore, an approximate criterion derived by the use of these empirical equations becomes as follow;

$$\eta = 1 - k_2(\bar{v}_i \cdot d \cdot E)^{-3},$$

where k_2 is a constant number, $\bar{v}_i$ is the mean velocity of *IW*, d is the inside diameter of cylindrical electrode and E is a applied voltge. It is noted in this criterion that η is $\bar{v}_i$ function.

Aknowledgement

The authers would like to aknowledge the continuing guidance and encouragement of Dr. K. Hashimoto, and were favored to have the assistance of Mr. Y. Ikeda, Mr. M. Kunitake, Mr. T. Miki and Mr. T. Matsuzaki.

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