The Characteristics of Ionic Wind Velocity for the Model Electrostatic Precipitator

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Abstract

It is estimated that the collecting characteristics of particles for an electrostatic precipitator (*EP*) is influenced by the ionic wind (*IW*) which caused by the corona discharge. In order to study this influences, *IW* velocity at the model *EP* which has the corona discharging field was measured by a Thermistor-anemometer. The characteristics of the maximum of *IW* velocity and the modes of *IW* velocity distribution were obtained through these measurements. In this measurement two types of *EP* were used; wire to net type electrode and needle to net type electrode.

The results of these experiments are as follows. The *IW* velocity is influenced by the form of discharging electrode, the polarity of discharging electrode and the temperature of environmental gas. The *IW* velocity is comparably high as the gas velocity in *EP* and through this fact it is said that *IW* influences on the phenomena of collecting particle for *EP*.

1 Introduction

It is known that the ionic stream so called *IW* in the corona discharging field consists of many unipolar ions of high speed some 60 m/sec-100 m/sec. Also it may be said *IW* is caused by these ions collided with and dragging through viscosity of these ions on the neutral molecules of the atomospheric gases. Hence, *IW* is similar to "ion drag-pumping phenomena"[1] in a liquid as one of the electrohydrodynamics (EHD) phenomena occurs and a ring formed dust-figure[2] is made by *IW* at the front of needle electrode on the plate electrode. How to be influenced on the phenomena of dust collection in *EP* by *IW* has presented problems. Therefore, we have decided to study the behavior of *IW* in a corona discharging field in the hope that this study will shed some light on the cause for difficulty in precipitating phenomena. According to the studies done so far, some nature of *IW* have been investigated[3~7].

In order to study the nature of *IW* more quantitatively, wire to net electorde and needle to net electrode were used, and the *IW* velocity at these model *EP* was measured by Thermistor-anemometer respectively. As a result, those facts were become clear that the maximum *IW* velocity and the distribution of *IW* velocity are influenced by the condition of gas, the form and the polarity of discharging electorde.

In this paper, the *IW* due to negative or positive corona discharge is called

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as "negative *IW*" or "positive *IW*" respectively.

2 Experimental apparatus

Fig. 1 shows the schematic diagram of the corona discharging field and measurement device for *IW* velocity. In Fig. 1, A is a micro-ammeter. The discharging wire is 0.052 cm in diameter. The net electrode face size is 21 cm × 10 cm and the each edge of the net electrode is rounded so as to eliminate the Edge-Effect of corona discharge. *IW* blows from discharging electrode to net electrode regardless of the polarity of discharging electrode. The measured values of *IW* velocity are substancially equal for the anemometer probe distance behind the net electrode ranging from 0.3 cm to 1.2 cm. Where the size of the anemometer probe is 0.15 cm in diameter. Therefore, it was decided to keep the distance as 0.5 cm constant. The anemometer probe was traveled from one side to the other side along the net electrode, holding this distance. From measured value at each point, the characteristics of *IW* velocity distribution were obtained. The distance between both electrodes D (see Fig. 1) was decided as 2 cm taking into consideration of the diameter of discharging wire, the maximum voltage of electric source and the average electric field strength ranging 4 kV/cm–7 kV/cm[8] for an industrial *EP*.

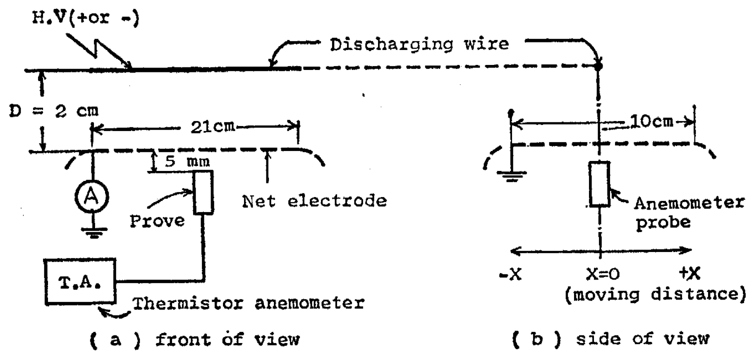


Fig. 1 Schematic diagram of the measurement.

Some details of net electrodes used in this experiment are shown in Table 1. As for these electrode arrangements, the discharging characteristics are almost the same each other. Therefore, the net electrode of No. 1 condition in Table 1 was used through following experiments. As it is, when the mesh size

Table 1 Net electrode (See Fig. 1)

	mesh size (mm)	Dia. of mesh wire (mm)
No. 1	1.00×1.06	0.74
No. 2	2.08×2.41	0.61
No. 3	2.93×3.07	1.14

is changed larger than that of Table 1, there is very different in the discharging characteristics. Therefore, further these experiments will be made in the future.

The discharging characteristics of wire to this net electode are shwon in Fig. 2. These discharging characteristics are practically equal to those of wire to plate electrode[2], the quantity of *IW* which caused by the corona discharge of wire to net electrode is analogous to the case of wire to plate electorde. However, *IW* velocity in the space between wire and plate electrode should be less than that in the space between wire and net electrode, because *IW* collides against the plate electrode and some reaction from the plate electrode is exist in the latter case. As the applied voltage in Fig. 2 increases, the discharging characteristics of heated wire (heating current; 5A) approach to that of non heated wire because of the increase of cooling effect by *IW*.

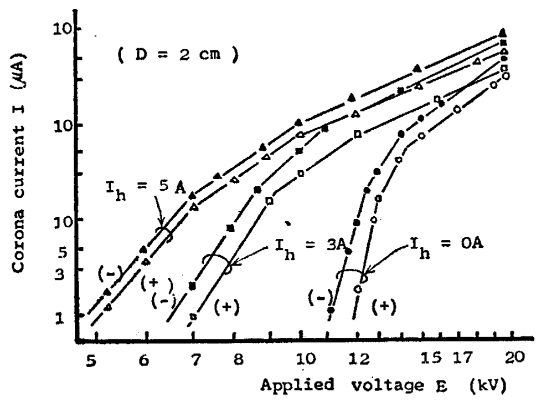


Fig. 2 Corona discharging characteristics for wire to net electrode

For the experiment on needle to plate electrode, the needle electrode of which diameter is 5 mm and the tip angle is 18° was used. The relations between the discharging characteristics of needle to plate electorde[2] and that of needle to plate electrode were almost the same as the results described for wire electrode.

3 *IW* velocity distribution

IW velocity distribution described here is concerned about that of one section of three-dimensional distribution of *IW* velocity. Fig. 3 and 4 show *IW* velocity distribution in negative and positive corona discharge field of wire to net electrode system, respectively. As for these characteristic curves, *IW* velocity decreases with the increase of X cm and its mode is shown as the normal distribution function[9] and *IW* velocity distribution is similar to the ionic current density distribution on the plate electrode.

The mode of *IW* velocity distribution in negative corona field are almost the same as that of positive corona. Because it is thought that, in the moment of electron passes through the outer radius r_0 of the glow region near the negative wire electrode, it adheres to a neutral molecule of air and is turned into

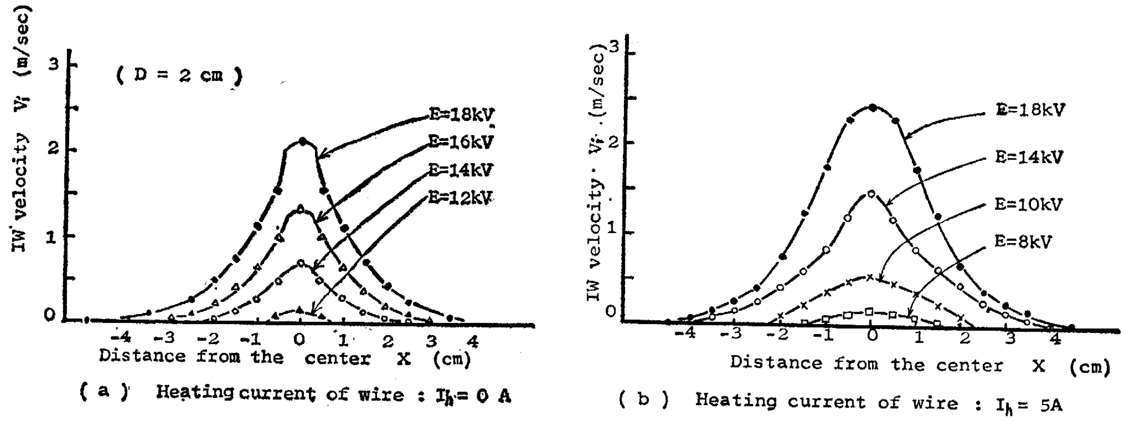


Fig. 3 Distributions of negative *IW* velocity for wire to net electrode (See Fig. 1)

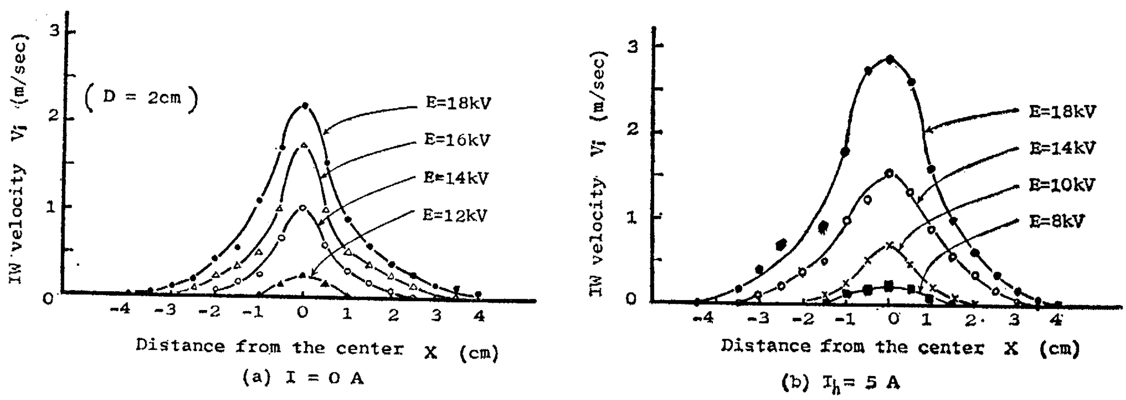


Fig. 4 Distribution of positive *IW* velocity for wire to net electrode.

negative ion. The value of r_0 is somewhat indefinite but is roughly equal to the radius of the visible glow region, which is usually several times as large as the wire radius.

In Fig. 3 and 4, the characteristics of Fig. (b) become more gentle than that of Fig. (a), respectively. *IW* velocity for heated electrode includes some error, because the error is due to anemometer which is indicated by cooling effect of *IW*. Moreover, the characteristics is gentle as shown in Fig. (b), because they are due to the coefficient of air viscosity increased by a heat in air near the wire electrode. The heating current of the wire electrode is 5A and the temperature of the wire elctrode is measured as 720°C by optical pyrometer at non-applied voltage. That is necessary condition to apply the Schlieren method well.

The coefficient of viscosity for air[10] is given by

$$k = k_0 \frac{273.1 + C}{T + C} \left(\frac{T}{273.1} \right) \qquad (\mu \text{ Poise}). \qquad (1)$$

Where, k_0 is the coefficient of viscosity for air at 0°C and normal atmospheric pressure 760 mm of mercury column, and is 171 μ Poise; T is the absolute temperature of air namely $t+273.1$, where t is actual temperature in °C; and C is a constant.

Equation (1) for k is shown graphically in Fig. 5, as a function of t. In Fig. 5, k saturates a constant value above certain value of t and it will no more

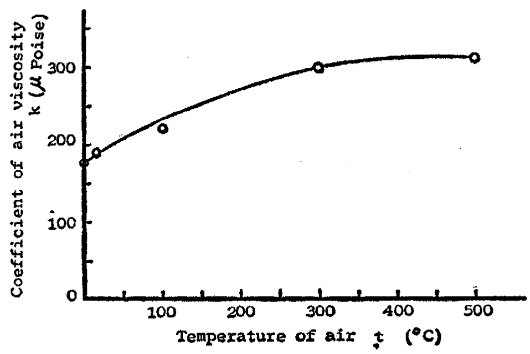


Fig. 5 Relation between the temperature of air and the coefficient of viscosity (See equation 1).

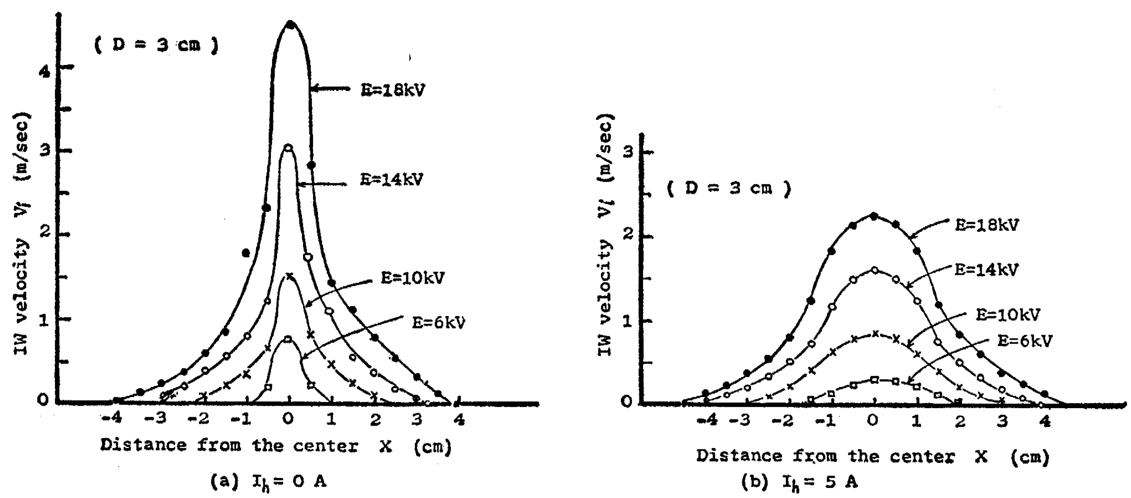


Fig. 6 Distribution of negative *IW* velocity for needle to net electrode.

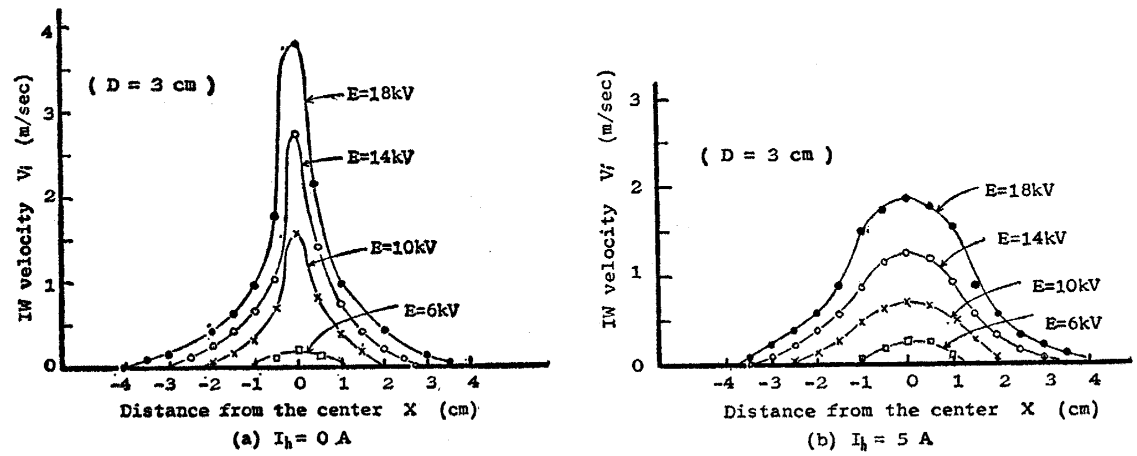


Fig. 7 Distribution of positive *IW* velocity for needle to net electrode.

increase substancially even if t increases. Nevertheless, the rate of increase of k is a little at Fig. 5, *IW* velocity distribution is influenced considerably with this rate of increase as Fig. 3 (b) or 4 (b).

According to the Fig. 1 of reference (8), when the temperature of air changes from 20°C to 720°C, negative or positive ion movility become about 2.9 or 3.3 times as large as ion movility at 20°C, respectively. The temperature of the air in the space between the both electrodes would be considerably lower than 720°C and then the ion movility must not so increase as considered above. As the results, *IW* velocity distribution is more influenced by the coefficient of viscosity than the inon movility as the temperature change.

Fig. 6 and 7 show *IW* velocity distribution in the negative and positive corona field on needle to net electrode system, respectively. As the corona starting voltage for needle electrode is lower than that for wire electrode, it is decided that the distance between needle electrode and net electrode is 3 cm. The characteristics of positive *IW* is almost the same in mode as that of negative *IW*. In Fig. 6(b) or 7 (b), the mode of the characteristics that the discharging electrode is heated becomes gentle as that of a bell, and the maximum velocity of *IW* in Fig. 6 (b) is smaller than that in Fig. 6(a). The calorific value of heated wire around needle electrode is 66 watts and the heated air is concentrated in the neighborhood of the extreme point of the needle electrode by *IW*, so that the cause of the gentle characteristics is due to the coefficient of viscosity[9] of the heated air.

4 The maximum velocity of *IW*

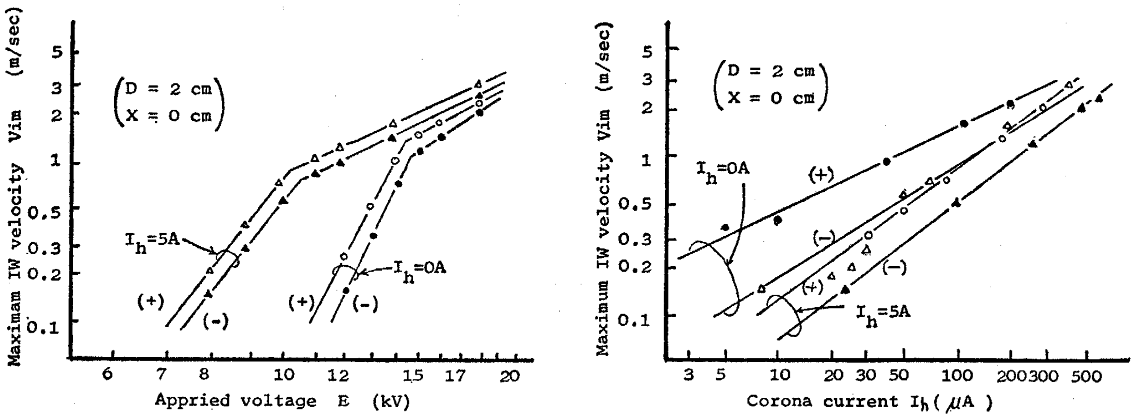
The maximum velocity of *IW* (Vim) is the maximum value of *IW* velocity distribution. Fig. 8 (a) and (b) show the characteristics of Vim versus the applied voltage E (kV) and Vim versus the corona current I (μA) for wire to net electrode, respectively. Fig. 9 (a) and (b) show the characteristics corresponding above case respectively for needle to net electrode.

On the logarithmic graph paper, any characteristics of Vim versus I is represented with one straight line and that of Vim versus E is represented with two straight lines holding brake point, but the characteristics of $Ih=5A$ in Fig. 9 (a) is another question. However, according to the practically used region of the average electric field strength for the industrial *EP*, the latter case is considered to be one line. Therefore, the empirical formulas for these characteristics are given as follows:

$$\log \mathrm{Vim} = A_1 \log E + B_1 \ , \tag{2}$$

$$\log \mathrm{Vim} = A_2 \log I + B_2 \ , \tag{3}$$

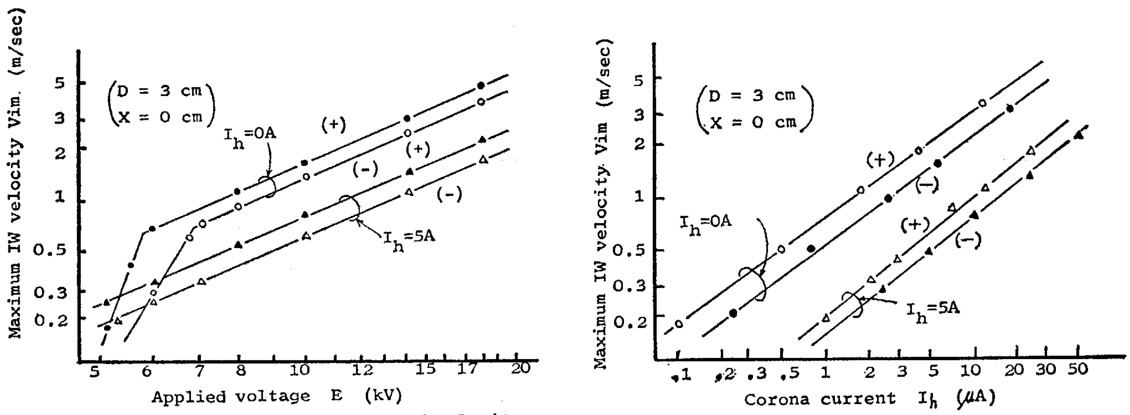
where, the constants of A_1, A_2, B_1 and B_2 depend on the constraction of discharging electrode and plate electrode, the polarity of discharging electrode



(a) Relation between Maximum IW velocity and applied voltage

(b) Relation between maximum IW velocity and corona current

Fig. 8 Characteristics of maximum *IW* velocity for wire to net electrode.



(a) Relation between maximum IW velocity and applied voltage

(b) Relation between maximum IW velocity and corona current

Fig. 9 Characteristics of maximum *IW* velocity for needle to net electrode.

and the temperature of air. The following equaton is obtained by eliminating Vim from above two empirical formulas (2) and (3).

$$\log I = A_3 \log E + B_3, \qquad (4)$$

where, A_3 and B_3 are constants depending on above similar conditions. The equation (4) is recognized as so far by many researchers[11,12] from the physical point of view. Therefor, it may be said that the empirical formulas (2) and (3) should be appropriate for practice.

The gas velocity in *EP* is less than 2 m/sec usualy. Because, at the gas velocity above 2 m/sec, the reentrainment phenomena of the particles precipitated on the surface of a plate electrode may occur in a dry type *EP*. While *IW* velocity in the electric field of 4 kV/cm —7 kV/cm[7] for an industrial *EP* is known as 1 m/sec through the authers experiments. Therefore, *IW* velocity in *EP* is comparable to the gas velocity. These two components of velocity meet at right angles each other on the basic consideration. Moreover, the migration velocity of charged particles due to Coulomb force in *EP* can be estimated through some trial calculation as about one-tenth of *IW* velocity. As theoretical concideration on collecting of particles in *EP*, it is mainly considerable result that the particles are charged, carried away to the plate electrode by Coulomb force and adhere there. In addition to this fact, the collecting force due to *IW* velocity that is superior than that due to Coulomb force takes side with the Coulomb force.

Through these consideration, it may also said that *IW* makes the gas flow turbulent and occur some reentrainment phenomena of particles at the face of the plate electrode. Nevertheless, the turbulent gas flow act to bring the particles in weak field to stronger field. Consequentially, more charged particles are carried to the plate electrode by the force due to *IW* velocity. It is important problem that they meet as the effects of same side on the phenomena of particle collection in *EP*.

5 Conclusion

These experimental results may be summerized as follows.

1) Through the experiments on wire to net electrode, the distribution of *IW* velocity is shown as the form of normal function when the wire electrode do not heated by electric current. This distribution is similar to the distribution mode of the electric field intensity on the plate electrode. While, when the wire electrode heated by electric current at 5*A* the characteristics of *IW* velocity distribution become more gentle form than the preceding characteristics. As the cuase of this, it is said that the gentle characseristics is due to the increased coefficient of air viscosity by the electric heating of wire electrode.

2) Through the experiments on needle to net electrode, the mode of distribution of *IW* velocity as one section of three-dimensional distribution is similar to that of wire to net electrode.

3) According to the practically used region of the avarage electric field strength for an industrial *EP*, the characteristics of Vim versus E and Vim versus I is considered to be a linear relation on logarithmic graph paper. Therefore, the empirical formula of this relation may be shown as follows:

$$\log \mathrm{Vim} = A_1 \log E + B_1,$$

$$\log \mathrm{Vim} = A_2 \log I + B_2,$$

where, the constants of A_1, A_2, B_1 and B_2 are due to the constraction of electrode, the polality of discharging electrode and the temperature of air. These equations should be recognized from the physical point of view.

4) *IW* velocity in *EP* is comparable with the gas velocity, and these two conponents of velocity meet at right angles each other in *EP*. While, the charged particle velocity driven by Coulomb force in *EP* is about one-tenth of *IW*

velocity.

5) The effect of *IW* velocity on the phenomena of particle collection in *EP* may be said as follows. *IW* velocity make the gas flow to the turbulent flow and occurs the reentrainment phenomena of particles at the face of the plate electrode, and the charged particles are carried away to the plate electrode by *IW* velocity.

Acknowledgement

The author would like to acknowledge the continuing guidance and encouragement of Dr. K. Hashimoto and Dr. S. Masuda. The author is also deeply indebted to Mr. M. Kawasaki, Mr. S. Suyama and Mr. T. Ikeda for their considerable assistance with this experimental works.

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