Effects of Pressure and Temperature of Airflow on Performance of Nozzle-type Electrostatic Eliminator

Kwang-Seok CHOI† , Tomofumi MOGAMI* and Teruo SUZUKI*

Abstract - The effects of the pressure and temperature of airflow were experimentally investigated to improve the performance of a nozzle-type electrostatic eliminator. The pressure (A_P) and the temperature (A_T) of the airflow toward the needle electrode were controlled in the ranges of 0 Mpa to 0.3 Mpa and of 25°C to 125°C, respectively. It was confirmed that the ion-generation ability was increased depending on the magnitude of the A_P and the A_T of the airflow provided to the surrounding region of the needle electrode in the nozzle-type electrostatic eliminator. In addition, it was clear that the mixed effect of the A_P and the A_T of the airflow was large. These results were attributed mainly to (1) the activation of the corona discharge by the A_T, (2) the change of the decomposition and production of a suppression gas by the A_T, (3) the blow-off of the suppression gas near the needle electrode by the A_P, and (4) the change of the distribution of the current densities on the needle electrode by the A_P.

Keywords: airflow, corona discharge, electrostatic eliminator, pressure, temperature

1. Introduction

When transferring powders using a compressed airflow, and when loading and storing powders and dusts within a specific section, powders are usually tribo-charged by the friction and collision of pipe-particles and inter-particles [1]. Since such a charging phenomenon may cause an explosion and/or fire of fine powders and dusts when fine powder is present at a concentration higher than the lower explosion limit, electrostatic elimination technologies for the prevention of such accidents are essential to avoid discharge sparks [2]. Accordingly, various new types of electrostatic eliminators that can neutralize much more efficiently have been produced and studied. In particular, we have developed a new nozzle-type electrostatic eliminator using high voltage [3]. Conversely, test results have demonstrated that the corona discharge occurring at the wire electrode is affected by the airflow and the temperature [4, 5]. These facts are also of interest in connection with the improvement of the eliminating performance of a nozzle-type electrostatic eliminator.

This study reports the results of an experiment to improve the ion-generation ability of a new nozzle-type electrostatic eliminator by providing an airflow having the ability to control the pressure and temperature synchronously.

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2. Experimental

2.1 Brief review of the nozzle-type neutralizer using high voltage [6]

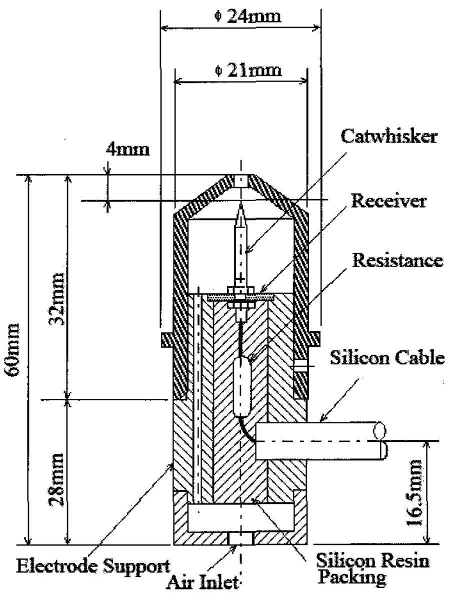
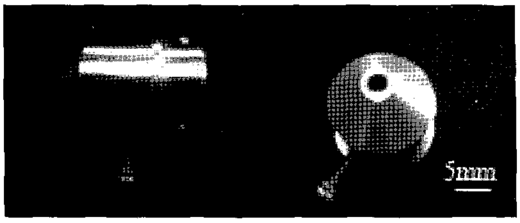


Fig. 1 Structure of a nozzle-type electrostatic neutralizer

The actual structure, including the dimensions of the nozzle-type of neutralizer, is shown in Fig. 1. It consists of a needle electrode (diameter: 2 mm) situated within a grounded shield (stainless steel; length, 32 mm; inner diameter, 21 mm; opening diameter, 3 mm, Fig. 2) for a corona discharge, an electrode support, and a slender tube 3 mm in diameter for air supply. Compressed air with a pressure of 0.1 to 0.3 MPa was supplied to the nozzle to protect the needle electrode from the deposition of powder as well as to blow ionized air toward the charged powder within the pipe wall. The neutralizer was generally driven with an AC (50Hz) or a DC high-voltage power source. For the needle material, Ni-Cr composite was used to prevent corrosion and erosion.



(a) side view (b) top view

Fig. 2 Photograph showing the cylindrical shape of the nozzle of the electrostatic eliminator used in this study

2.2 Apparatus and method

The overall structure of the experimental apparatus is shown in Fig. 3. It consists of a nozzle-type electrostatic eliminator as mentioned above, a high-voltage dc power source (Trek, Model No. 663A), an amplifier (Trek, Model No. 662), an air compressor (Hitachi, 250 ℓ, 10.4 kgf/cm), a fully automatic air dryer (CKD, RD-2008), controllers for the air pressure (A_P) and the temperature (A_T), an electrometer (Keithley-6512), and other auxiliary devices.

The A_P and A_T of the airflow were maintained in the ranges of 0 Mpa to 0.3 Mpa and of 25 ± 2 °C to 125 ± 2 °C, respectively. The voltage applied to the needle electrode and the corona current I_c were controlled and recorded automatically by a computer through GP-IB. The space d between the opening of the electrostatic eliminator and the metal plate (0.1 m × 0.1 m) was 0.05 m. The I_c was measured with an electrometer connected between a metal plate impressed with both high voltage and the ground. The edge of the plate electrode was covered with an insulator film (Teflon) to prevent any leakage of current. In this study, the experimental value represents an average of ten measurements performed under the same conditions; the scatter limits for the ten measurements are given in each Fig.. All the test conditions were 23 ± 3°C and 35 ± 5% RH

3. Results and discussion

The I_c as a function of the charging voltage on the metal plate with various A_P was compared, as shown in Fig. 4. The rates (v_f) of the airflow at the centre of the opening of the nozzle measured with an airflow meter (Hiyoshi Electric Manufacturing, Model No. DP 70 D) were 7 m/s at 0.1 Mpa, 12 m/s at 0.2 Mpa, and 16.5 m/s at 0.3 Mpa. DC 5 kV (in bipolar) was applied to the needle electrode in the electrostatic eliminator. As a result, I_c at 0.3 Mpa had the largest value, but this value decreased at 0.2 Mpa, 0.1 Mpa, and 0 Mpa; that is, the I_c was shown to increase depending significantly on the A_P provided to the surrounding region of the needle electrode.

On the other hand, we experimentally investigated the corona onset voltage V_{onset} under various conditions. The applied voltage was in negative polarity. The V_{onset} without airflow was initiated at -2.3 kV. However, with airflow in the range of 0.1 to 0.3 Mpa, the V_{onset} increased up to -2.5 kV, even though the increase was small. A similar result was obtained for the voltage in positive polarity applied to the needle electrode. The results were unexpected. As in a previous study using electro-photography on the effect of an airflow on the charging performance of a corona charger with a single-wire corona electrode of 100 μm diameter (Nichrome), the airflow clearly decreased the V_{onset} [7].

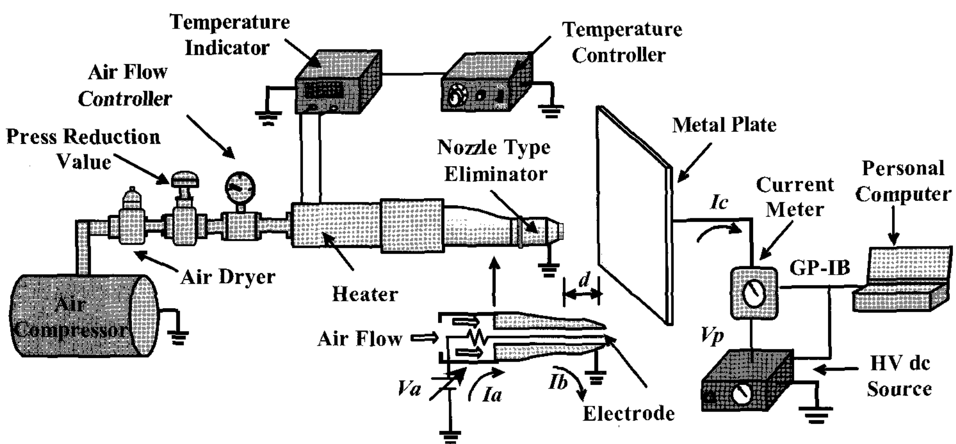


Fig. 3 Overview of the structure of the experimental apparatus

Finally, the cylindrical shape of the nozzle in the eliminator, as shown in Fig. 2, was found to be responsible for the V_{onset}; that is, the turbulence of the airflow generated in the nozzle disturbs the initial corona discharge phenomena. However, when the voltage applied to a needle electrode exceeded the V_{onset}, the airflow increased the I_c at the same applied voltage V_a. This is reported in detail in the last half of the paper.

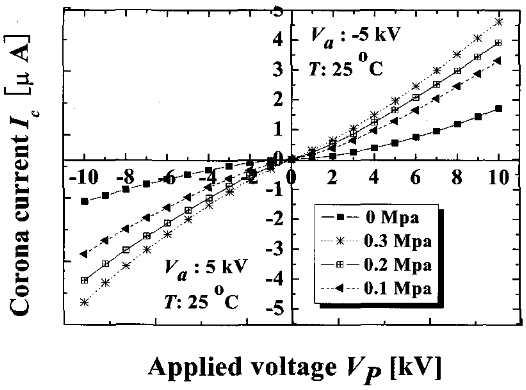


Fig. 4 I_c as a function of the V_p with various A_P

Fig. 5 shows the I_c measured as a function of the A_T of the airflow under constant conditions in tests (A_P: 0.3 Mpa, V_a: 5 kV (in bipolar), V_p: 10 kV). It should be noted here that the A_T in this study represented values measured at the centre of the opening of the nozzle-type electrostatic eliminator. Five steps of A_T, namely, 25± 2°C, 42± 2°C, 57± 2°C, 70 ± 2°C, and 82 ± 2°C, were used in this study. As a result of applying a high dc voltage of 5 kV in negative polarity to the needle electrode, the I_c increased with a swell in the A_T in the tests, that is, the I_c at 82°C had the largest value, 5.25 μA (in negative polarity), among the five temperature conditions, while the value decreased to 5.14 μA (in negative polarity) at 70°C, 5.07 μA (in negative polarity) at 57°C, 4.90 μA (in negative polarity) at 42°C, and 4.78 μA (in negative polarity) at 25°C. A similar result was obtained for the voltage in positive polarity applied to the needle electrode, as also indicated in Fig. 5.

The increased efficiency in the I_c of the electrostatic eliminator, η [%] (see Fig. 6), was calculated by the following formula (1):

$$\eta = (I_1 - I_0) \times 100 \; / \; I_0 \qquad (1)$$

where I_0 [μA] and I_1 [μA] are the I_c without and with a hot airflow, respectively.

A high dc voltage of 5 kV (in bipolar) was applied to the needle electrode in the electrostatic eliminator. The A_P and A_T in the case with a hot airflow were 0.3 Mpa and 82 ± 2°C, respectively. The results confirmed that the ion-generation ability of the electrostatic eliminator by a hot airflow was improved from 300% to 900%.

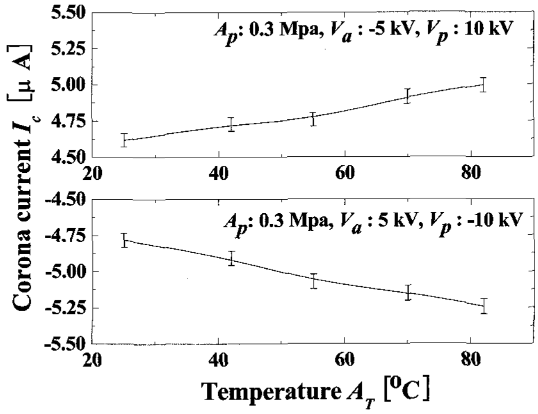


Fig. 5 I_c as a function of the A_T to the needle electrode

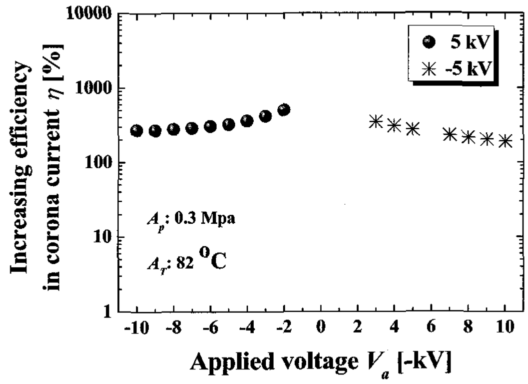


Fig. 6 η with a hot airflow as a function of V_a

Furthermore, to evaluate the performance of the nozzle-type electrostatic eliminator using a hot airflow, the decay of the surface potential on the charged object was observed The space between the electrostatic eliminator and the charged object was 30 cm. The charged object was a metal plate, which had a grounded metal plate of the same diameter set parallel to it. The object was separated using Teflon film (cross-sectional area; 20 cm × 20 cm, thickness; 2 mm). The capacitance of the object measured with a LCR Hi-tester (Hioki: 3522), C [F], was 100 pF. The surface potential on the upper plate electrode was measured with a high-level surface-potential meter installed at a distance of 30 mm from the surface of the plate electrode. A DC voltage of 8 kV (in positive polarity) was supplied to the object. The surface potential of the object before elimination, V_I [V], was 8 kV (in positive polarity). The result is shown in Fig. 7. When using a hot airflow for elimination, the surface potential decay was relatively faster than that when airflow alone was used. In particular, it was confirmed that the nozzle-type neutralizer without an airflow was ineffective for reducing electrostatic charges from a charged object. Almost the same result was obtained for the voltage in positive polarity applied to the needle electrode. It was confirmed that the hot airflow had a marked effect on the eliminating performance of the nozzle-type electrostatic eliminator.

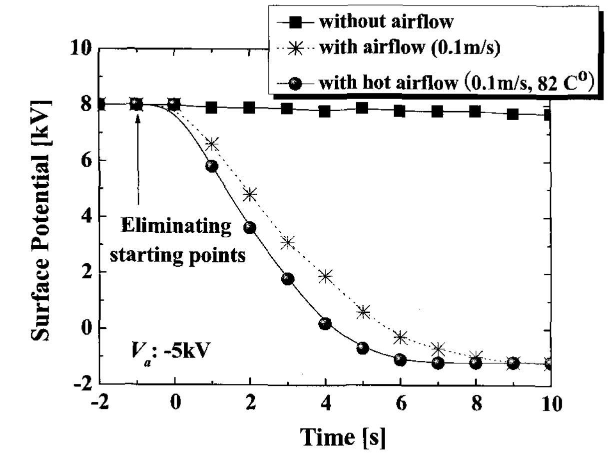


Fig. 7 Decay of the surface potential on the changed object (initial surface potential; DC +8kV) as a function of time

The way in which a hot airflow affects the ion-generation ability of the electrostatic eliminator is explained as follows. First, the corona discharge is activated by the hot airflow; that is, the hot airflow influences the motion of ions and electrons for their activation or reaction [5]. When the voltage resulted in a stable corona discharge, for example, 3.5 kV in negative polarity, the I_c without an airflow was 22.6 μA. However, the airflow (7m/s) increased the I_c to 22.6 μA (in negative polarity). The hot airflow markedly increased the I_c to 29.4 μA (in negative polarity). The same result was obtained for the voltage in positive polarity applied to the needle electrode: 20 μA without an airflow, 21 μA with an airflow of 7m/s, and 23.8 μA with a hot airflow (0.1 Mpa and 82 ± 2 °C). That is, the hot airflow increased the I_c at the same V_a.

Secondly, the explanation for the A_T, considering the kinetic energy, *ke*, of a molecule, is that the velocity v_2 [m/s] of molecules after increasing the A_T can be expressed as [8]:

$$v_2 = (\sqrt{T_2} / \sqrt{T_1}) v_1 \tag{2}$$

where v_1 is the velocity of molecules before the increase of T. T_1 and T_2 are the temperatures in Kelvin before and after the increase, respectively.

In other words, the T has a direct effect on the velocity of molecules.

Thirdly, as another explanation for the A_T, the decomposition of a suppression gas, such as O_3 and NO_X, generated by the corona discharge, was promoted by increasing the temperature near the needle electrode [9]. Various reports, including some on the effect of the temperature on O_3 generation, have been published on this phenomenon over a long period of time [10].

Finally, the airflow has been reported to have an effect on the suppression of gas generated from the discharge area [5] as well as the change of the distribution of the current densities on the electrode [11]. To maintain the corona discharge, a seed electron for discharge must be continuously supplied. Any suppression gas that remains in the discharge area disturbs the maintenance of the corona discharge, resulting in a decrease of the I_c at the same V_a. The change in I_c as a function of time when a high dc voltage of 5 kV (in negative polarity) was applied to the needle electrode, as shown in Fig. 8, is discussed.

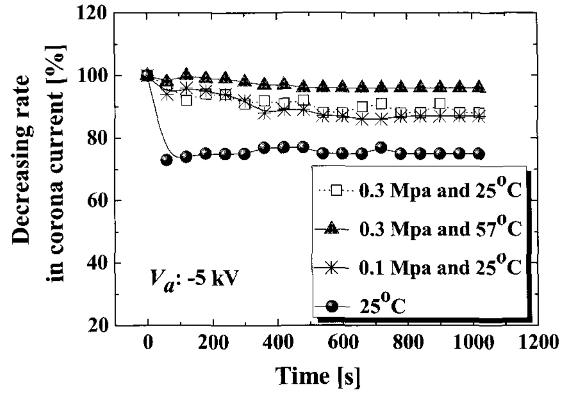


Fig. 8 Change in the corona current as a function of time

As a result, the corona current showed a rapid drop in 60 s of elapsed time in the case without an airflow. However, when the airflow (0.3 Mpa) was provided to the corona electrode, the corona current changed very little over time. These facts agree with those reported in the hypothesis, namely, that the effect of the airflow is to drive out any discharge suppression gas from the discharge area near the wire. In addition, it was found that the discharging current present with the hot airflow (0.3 Mpa, 57± 2°C) was more stable than that of the others.

4. Conclusion

The improvement of the performance of the nozzle-type electrostatic eliminator by way of hot airflow was experimentally introduced. The results are summarized as follows:

(1) The hot airflow markedly improved the eliminating performance of the nozzle-type electrostatic eliminator used in this study.
(2) The ion-generation ability depended on the magnitude of two factors, the pressure and the temperature, of the airflow provided to the needle electrode.
(3) These results were attributed mainly to the activation of the corona discharge by increasing the temperature (and/or the air pressure) and blowing off the suppression gas near the corona electrode by the airflow.

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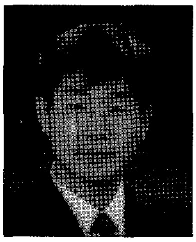

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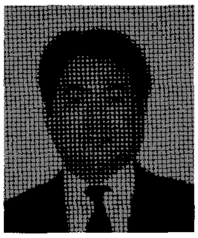

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