Industrial Health 2018, **56**, 485–491

**Original Article**

# Charge elimination method for a charged roll using a passive type ionizer with an air assist

**Yuki WAKATSUKI[1] and Toshiyuki SUGIMOTO[1]***

[1]Graduate School of Science and Engineering, Yamagata University, Japan

*Received February 26, 2018 and accepted June 19, 2018*

**Abstract: The charge elimination method for moving charged objects was investigated using a passive type ionizer with an air assist to effectively eliminate the static charge generated at high speed by the roll-to-roll process. The passive ionizer has a grounded needle placed horizontally with respect to the moving charged roll and an air hole to eject an air flow to transport the ions from the grounded needle. The passive ionizer releases ions from the grounded needle electrode when the electric field at the tip of the grounded needle exceeds the corona inception condition. The experimental set up is composed of a moving charged roll, the passive ionizer and surface voltmeters for evaluating performance. The charge elimination current $I_e$, which corresponds to the amount of ions produced per second was measured for various movement speeds and charge potentials of the charged roll. Supply of the air flow beneath the needle electrode increased $I_e$ because the ions were effectively transported to a place where the charge elimination of the roll did not affect the corona onset condition. The difference in charge elimination performance between the proposed ionizer and a commercial active ionizer was clarified in terms of $I_e$ and the charge elimination rate.**

**Key words:** Static electricity, Passive ionizer, Corona discharge, Air assist, Charge elimination current

## Introduction

Static electricity generated in mass production processes can sometimes cause serious problems such as a decrease in productivity, damage by electrical discharge to machine operators, and the triggering of destructive explosions. Charge elimination in these processes is thus very important. Corona discharge type ionizers are widely used and are classified into two types as shown in Fig. 1. One is an active type that uses energized needles connected to positive and negative high voltage power supplies. The other is a passive type that uses grounded needles and requires no power supply. Each type has advantages and disadvantages. The active type ionizer supplies positive and negative ions transported by an air flow, as shown in Fig. 1 (a). Ions with opposite polarity to the charged target are attached to the target and eliminate a part of the charge on the target. Hence, the amount of positive and negative ions should be balanced to realize perfect charge elimination with zero potential. The amount of positive and negative ions supplied to the charged target per second is dependent only on the voltage applied to the needle and the air flow rate, and is independent of the potential or movement speed of the charged target. If the target is highly charged or moves fast, the supply of ions should be increased to eliminate the charges completely. However, the supply of ions is limited by maximum applied voltage to the needle where the corona discharge leads to spark discharge. On the other hand, the passive type ionizer produces ions from a grounded needle due to the electric field formed by the charged object at the tip of the grounded needle, as shown

---

*To whom correspondence should be addressed.
E-mail: toshi@yz.yamagata-u.ac.jp

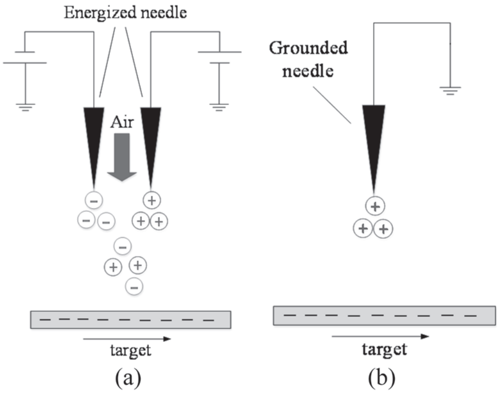

**Fig. 1. Corona discharge ionizers.**
(a) Active type,
(b) Passive type.

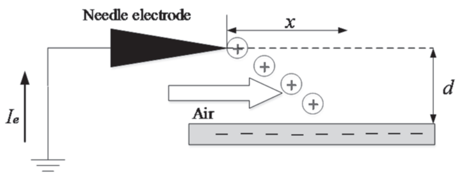

**Fig. 2. Passive type ionizer.**

in Fig. 1 (b). The passive type ionizer can produce ions depending on the potential and movement speed of the charged target when the electric field is above the corona inception voltage.

In roll-to-roll processes, static charges can be produced by contact charging at high speed, depending on the rotation rate of the roll. In this case, charge elimination using only an active type ionizer may be difficult due to a shortage of ions supplied to the charged roll. An introduction of passive type ionizers improved with highly charge elimination efficiency is significantly important. However, there is little research on improving the efficiency of passive type ionizers[1–4]. Here, we have focused on an air-assisted passive type ionizer to transport ions for effective charge elimination.

## Charge Elimination Principle

As shown in Fig. 2, the proposed passive type ionizer has a simple structure with a grounding needle electrode. The needle electrode is placed parallel and closer to the charged roll. When the electric field formed by the charged roll at the tip of the needle reaches the corona inception, corona discharge with the opposite polarity of the target occurs from the needle electrode. The current flowing through the needle electrode is called the charge elimination current $I_e$. The magnitude of $I_e$ is important as a measure of charge elimination performance because it can be a function of the charged potential and movement speed of the charged roll. To improve charge elimination efficiency, an air flow is added to the bottom side of the needle electrode to expand the charge elimination area. A compressed air is ejected from a small hole (2 mm in diameter) of the bottom side of the needle electrode. The distance between the needle and the charged roll is defined as $d$. $d$ is also an important parameter because the electric field at the tip of the grounded needle is strongly dependent on the distance from the charged roll. The ions are attracted to the charged roll depending on their distance from the needle, which is defined as $x$.

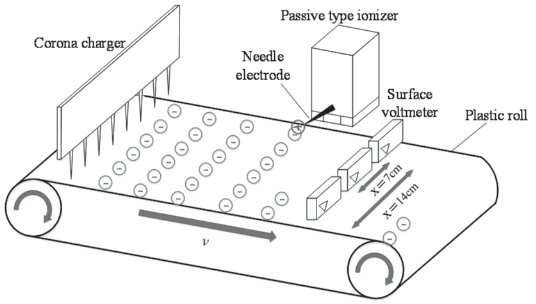

**Fig. 3. Schematic diagram of the experimental setup.**

## Experimental

Figure 3 shows a schematic diagram of the experimental setup used in this work. A needle electrode with a curvature radius of 7 $\mu$m and a length of 20 mm was used as the ion source of the passive type ionizer. A plastic roll with a width of ca. 23 cm was rotated by an induction motor with a speed of 30–150 m/min. The roll was charged by a corona charger with multiple needles.

The grounded needle of the passive ionizer was installed parallel to the charge roll and perpendicular to the direction of movement. The surface potential of the roll was measured at three different positions of $x$=0 cm, 7 cm, and 14 cm using surface voltmeters (Koganei Co. Ltd., DTY-EPS).

When the ionizer was removed from the vicinity of the charged roll, the surface potential before charge elimination $V_0$, can be measured with the surface voltmeter. The ionizer was placed above the roll, so that the surface potential after charge elimination $V_{end}$, could be measured at the same position measuring $V_0$. $V_0$ and $V_{end}$ are time average potential formed by the moving charged roll with a constant speed. The charge elimination rate $P$, was calculated according to the following equation:

$$P = \frac{V_0 - V_{end}}{V_0} \times 100 \quad (1)$$

The larger P should be expected for effective charge neutralization. However, P may exceed 100% when the polarity of $V_{\text{end}}$ become positive due to the arrival of excessive positive ion, called over neutralization. From the preliminary studies, the horizontal arrangement in Fig. 2 is found to be able to reduce the over neutralization compared to the vertical arrangement in Fig. 1. Although some experimental results suggest there is the over neutralization at the limited position where P exceeds 100%, normal charge elimination is dominant (P is less than 100%). The needle was grounded via an oscilloscope with an input impedance of 10 MΩ. $I_e$ was obtained from the measured potential divided by the input impedance. Dc corona current was observed by the corona discharge. Experiments were mainly conducted under the same initial charging potential of $V_0$=−15 kV with a movement speed of ca. 90 m/min. The charging potential includes the effect of tribo-charging between the roll and the roll holder. Because the positively charged potential of the roll never exceed +10 kV due to the effect of tribo-charging, the experiments of only negatively charged case were conducted. The charge elimination performance was evaluated with respect to $I_e$ and $P$. The temperature and relative humidity were in the range of 12–18°C and 25–45%, respectively.

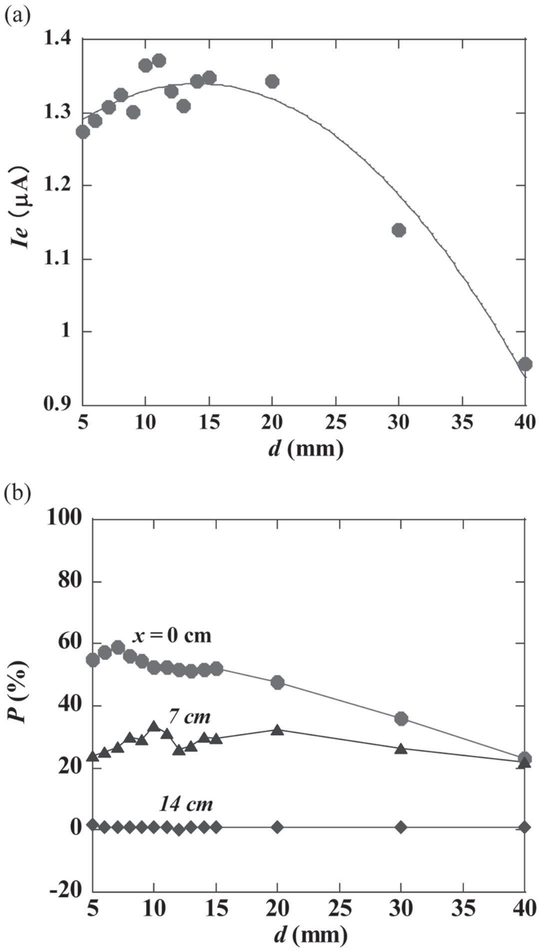

**Fig. 4. Effect of needle position on $I_e$ and $P$.**
(a) $I_e$.
(b) $P$.

## Results

### *Effect of needle position*

Figure 4 (a) and (b) show the effect of the needle position on $I_e$ and $P$, respectively. The distance $d$, between the needle and the charged roll can have a strong effect on the electric field at the tip of the needle. When the electric field becomes larger, the corona discharge current $I_e$ increases. Figure 4 (a) shows that $I_e$ is greater than 1.2 $\mu$A for $d$ shorter than 20 mm. $I_e$ has a peak value in the range of $d$=10 to 20 mm. If $d$ becomes smaller than 10 mm, then $I_e$ is decreased because the electric field at the tip of the needle is decreased due to the drop of the surface potential of the charged roll according to the potential of the grounded needle[5]. Figure 4 (b) shows the charge elimination rate $P$, as a function of $d$. $P$ is decreased with $x$, which indicates that more ions have arrived at positions closer to the needle. There are no ions arrived at $x$=14 cm. At $x$=0 cm, $P$ is decreased with $d$, while $P$ is slightly increased at $x$=7 cm. These results suggest that ions can arrive at longer $x$ when $d$ becomes longer. However, an increase in $d$ decreases $I_e$. The optimum $d$ was determined to be within 10 and 20 mm.

### *Effect of installation angle of needle*

$I_e$ was measured for different installation angles of the needle electrode $\theta$, from the horizontal level. The tip of the needle was installed at $d$=15 mm. As shown in Fig. 5 (a), $I_e$ becomes larger when the needle is positioned in an upward direction because the ions emitted from the tip of the needle electrode can be released upward and travel far from the needle. $P$ at $x$=7 cm was increased with $\theta$ by the change of the ion arrival position, as shown in Fig. 5 (b). The ion arrival position is important for charge elimina-

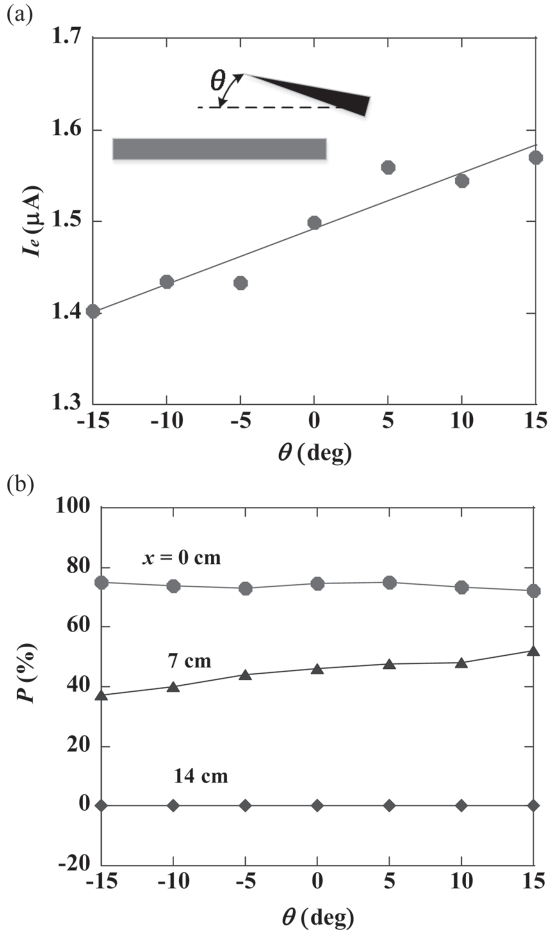

**Fig. 5. Effect of installation angle on $I_e$ and $P$.**
(a) $I_e$.
(b) $P$.

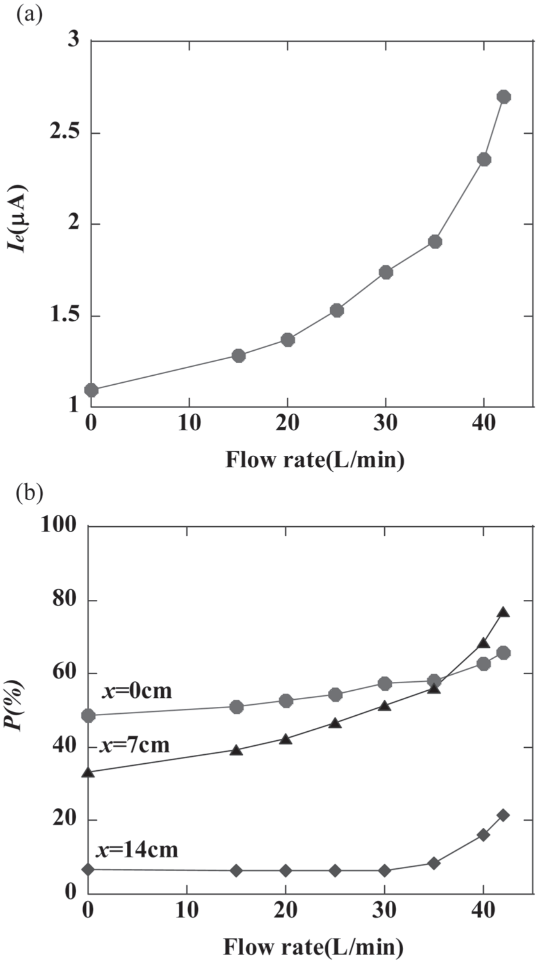

**Fig. 6. Effect of air flow on $I_e$ and $P$.**
(a) $I_e$.
(b) $P$.

tion with a passive ionizer. The electric field at the tip of the needle can be reduced with a reduction of the charge amount due to charge elimination if the position of the charge eliminated is close to the needle. The ions should be forced as far as possible from the needle to maintain a sufficiently high electric field at the tip of the needle.

### *Effect of air flow*

An air flow was supplied between the needle and charged roll to transport ions far from the needle. $I_e$ and $P$ for $d$=10 mm at $v$=90 m/min with an air flow are shown in Fig. 6 (a) and (b), respectively. Both $I_e$ and $P$ are increased with the flow rate. In particular, $P$ at $x$=7 cm is increased significantly with the flow rate, which indicates that the ion arrival distance from the needle can be expanded by the air flow. The charge elimination performance is thus significantly improved by the addition of an air flow. This is because ions emitted from the tip of the needle electrode are transported farther from the needle electrode where the charge neutralization does not affect the reduction of electric field at the grounded needle tip.

### *Effect of initial potential*

Figure 7 shows the relationship between the initial potential of the charged roll $V_0$ and the surface potential after the charge elimination $V_{end}$ for $d$=10 mm at $v$=90 m/min. Corona discharge occurs at $V_0$=5 kV. The corona discharge makes the surface potential kept less than 6 kV regardless of increasing the initial potential. Figure 8 shows the charge elimination current $I_e$ as a function of the potential difference $V_0$-$V_{end}$ at the same condition of Fig. 7. $I_e$ is linearly increased with the potential difference. That is why the surface potential after the charge elimination is suppressed in spite of increasing initial potential.

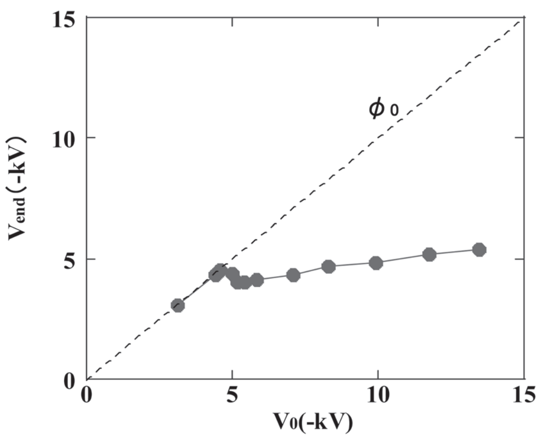

Fig.7. Relationship between $V_0$ and $V_{end}$.

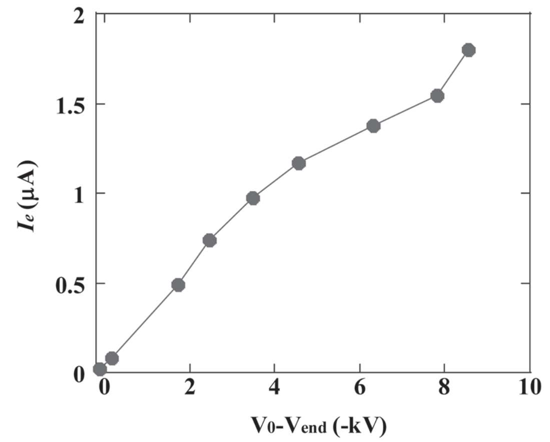

Fig.8. $I_e$ as a function of $V_0$-$V_{end}$.

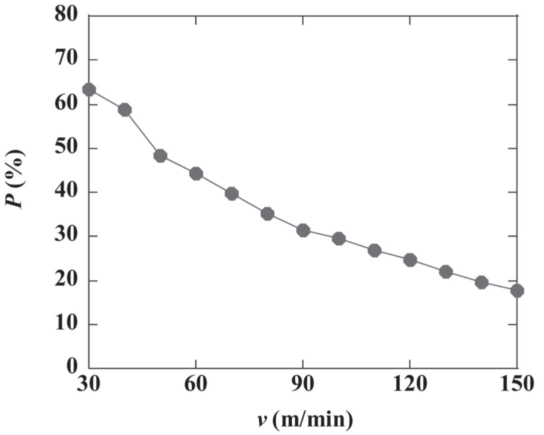

Fig. 9. Effect of movement speed on *P* for an active type ionizer.

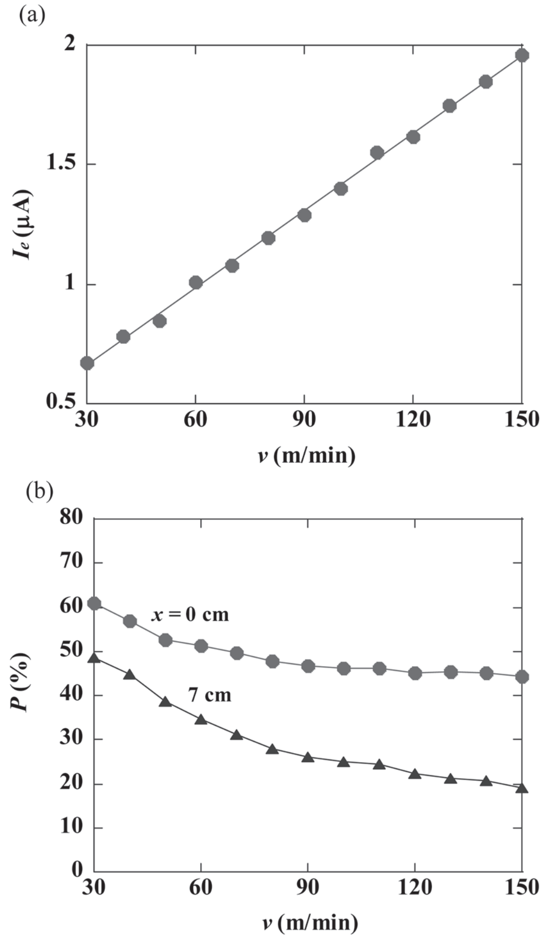

Fig. 10. Effect of movement speed on Ie and P for a passive type ionizer.
(a) $I_e$.
(b) *P*.

*Effect of target movement speed*

The movement speed of a charged roll can affect the potential after charge elimination. Figure 9 shows the charge elimination rate *P* for the active type ionizer (Koganei Co. Ltd., DTY-BX01-200) as a function of the movement speed *v* for comparison with that for a passive type ionizer. The measuring method of $V_0$ and $V_{end}$ is the same as that for the passive type except for replacing the ionizer. The distance between the ionizer and the charged roll is 40 mm (minimum limit of the recommended installation). *P* is decreased significantly with *v* because the amount of ions supplied per unit time is constant for a constant applied voltage to the needle electrode, regardless of *v*. *P* becomes less than 20% at *v*=140 m/min.

Figures 10 (a) and (b) shows the effect of target movement speed *v* on $I_e$ and *P*, respectively, for the passive type ionizer. $I_e$ is proportional to *v*. *P* is maintained over 40%

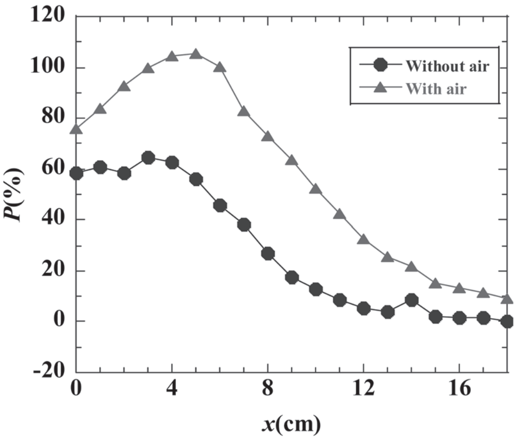

**Fig. 11. *P* as a function of *x*.**

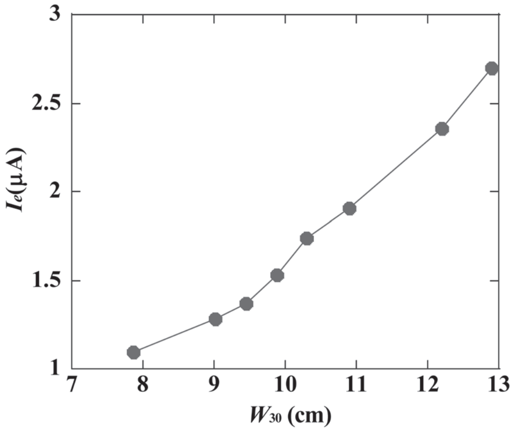

**Fig. 12. Relationship between *W* and $I_e$.**

at $x$=0 cm and $v$=150 m/min. The increase in $I_e$ can result in higher $P$, even if $v$ is increased because the passive type ionizer can supply ions while the tip of the needle electrode is above the corona inception condition. In addition, while the active type ionizer supplies bipolar ions to the charged object, the passive type ionizer supplies only ions with polarity opposite to the charged roll. The results indicate that the passive type ionizer is more suitable than active type ionizer, especially for a charged object moving at high speed.

## Discussion

### *Charge elimination model*

The passive ionizer can emit ions only while the electric field at the tip of the needle electrode is kept above the corona onset. However, when the ion arrives at the target, the electric field of the needle tip is rapidly reduced due to the neutralization of charge on the target, depending on the arrival position of ions. Figure 11 shows the charge elimination rate $P$, as a function of $x$ for $d$=10 mm at $v$=90 m/min. $P$ is ca. 60% at $x$=0 cm and decreases with $x$. At $x$=14 cm, $P$ is ca. 0%, which indicates that there is no arrival of ions. The amount of ions that arrive at the position $x$ is the same as the profile of $P$. With an airflow, the $P$ profile shifts upward because the ions can be transported far from the needle without reducing the electric field at the tip of the needle. The ion transport length is defined by $W_{30}$, where $P$ is decreased to 30%. $W_{30}$ becomes longer with the supply of an air flow.

Figure 12 shows the relationship between the charge elimination current and ion transport length $W_{30}$ by charging the amount of airflow for $d$=10 mm at $v$=90 m/min. $I_e$ is increased with $W_{30}$ because of extending charge elimination area.

$I_e$ is simply expressed by Eq. (2) from the change of the static charge before and after the charge elimination:

$$I_e = (\sigma_0 - \sigma_{end}) W v_{roll} \quad (2)$$

where $\sigma_0$ and $\sigma_{end}$ are the surface charge density on the charged roll before and after charge elimination, respectively, $W_{30}$ is the actual ion transport length, $v_{roll}$ is the movement speed of the roll. Because $\sigma_0$ and $\sigma_{end}$ are difficult to directly measure and dependent on surface potential. Eq. (2) can be expressed by Eq. (3).

$$I_e = k(V_0 - V_{end}) W v_{roll} \quad (3)$$

Where $k$ is a coefficient relating surface charge density to the surface potential and also relating $W_{30}$ to $W$. Equation (3) suggests that $I_e$ is linearly increased with $V_0$-$V_{end}$, $W$ and $v_{roll}$ , which is consistent with the experimental results shown in Figs. 8, 12 and 10 (a). The experimentally obtained value of $k$ is 2.1 to 2.4 × $10^{-9}$ [As/Vm$^2$].

Equation (3) also shows that a passive type ionizer can be applied as an initial charge potential detector for the production process because $I_e$ and its polarity are dependent on the surface potential and its polarity of the target. Hence, it should be significantly effective to use for preliminary charge elimination in conjunction with an active type ionizer. After detection of the target polarity and potential, the active type ionizer can adjust the amount of positive and negative ions so that ions with opposite polarity of the target are supplied more than same polarity ions to achieve faster elimination of the target charge.

The charge elimination area achieved by a single grounded needle is limited by the ion transport length $W$. Therefore, multiple needles are required for a wider

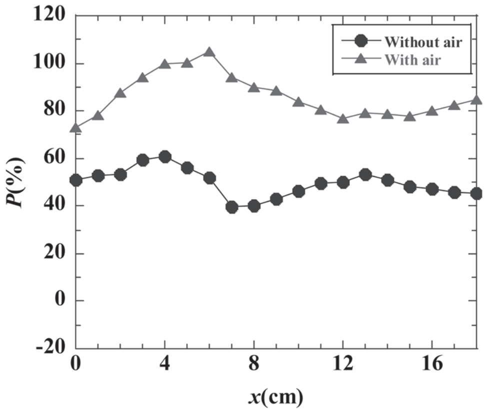

**Fig. 13. Charge elimination efficiency for multiple needles (*x* =0 and 12 mm).**

charge elimination area. Figure 13 is the charge elimination efficiency for multiple needles where the two needle electrodes are placed at *x*=0 cm and *x*=12 cm. (same as the ion transport length). By arranging the needle electrode considering the ion transport length, the charge elimination efficiency can be drastically improved to over than 80%. The optimum combination with an active type ionizer should thus be investigated as the next step of this study.

## Conclusions

The passive type ionizer with an air assist to effectively eliminate static charge were investigated. The effect of the air flow on charge elimination performance was verified and compared with the performance of an active type ionizer. The passive type ionizer was confirmed as more effective than the active type ionizer for charged material moving at high speed, and an air assist significantly improved the charge elimination performance. The charge elimination model predicting the charge elimination current was proposed. The passive ionizer is found to effective not only for eliminating static charge but also detecting surface potential of the target.

In future work, we plan to investigate the optimum combination of charge elimination where both passive type and active type ionizers are employed for faster and perfect charge elimination.

## References

1) Robinson K, Durkin W (2010) Electrostatic issues in roll-to-roll manufacturing operations. IEEE Trans Ind Appl **46**, 2172–8.
2) Robinson K (2014) Maximize static dissipator neutralization efficiency, proceeding of IEEE industrial applications society annual meeting 2014, EPC-0299.
3) Kodama T, Yamakuma M, Suzuki T, Mogami S (2005) Development of a passive type electrostatic eliminator for pneumatic powder transport. Nat Inst Saf NIIS-RR **2004**, 81–90.
4) Sugimoto T, Kitamura A, Higashiyama Y (2011) Air-assisted passive ionizer for a charged pipe. IEEE Trans Ind Appl **47**, 1929–34.
5) Sugimoto T (2014) Charge elimination model and improvement of a passive type ionizer. Proc Inst Electrostatics Jpn **38**, 139–44.