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着火性放電を抑制したノズル型除電器の除電特性*

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Static Eliminating Properties of Incendiary Discharge-Free, Nozzle-Type Electrostatic Neutralizer*

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Abstract; Most industrial operations with powders, such as transport, filling, and emptying, involve collision and separation between the particles themselves and between particles and the walls of the installations. Thus, electrostatic charges are often generated on powdery substances. Such a charging phenomenon may cause electrostatic discharges (ESD) inside the silo and result in the ignition of flammable dusts. As one method to protect a dust explosion due to ESD, we have developed a new nozzle-type electrostatic neutralizer with a corona discharge. In this study, it was investigated experimentally whether the developed neutralizer can be used in an explosive atmosphere. The ignition testing apparatus, which consists of a testing needle electrode and an ignition vessel (2500 cm^3) filled with an ethylene-air mixture (6.5 Vol. %), was used for evaluating the ignitability of the high-voltage electrode system. The performance of the neutralizer (flange-type) was also evaluated with a full-size pneumatic powder transport system. The results obtained from the experiments are as follows:

(1) The needle electrode system with a 100 MΩ-coupling for the developed neutralizer can be used in the explosive atmosphere with a MIE (minimum ignition energy) of more than 0.1 mJ up to the applied voltage of AC or DC 7 kV.

(2) The nozzle-type neutralizer can be used for producing air ions to reduce effectively the static charges on polymer materials in a pneumatic powder conveying system by controlling the applied high-voltage.

Keywords; electrostatic neutralizer, incendiary discharge, ignitability, powder

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1. INTRODUCTION

As powder technologies have been rapidly progressing, a variety of new flammable powders have been produced and used in various industrial processes. Most industrial operations with powders, such as transport, filling, emptying, blending, and milling, involve friction between the particles themselves and between particles and the walls of the installations. Thus, static charges often occur on solid and powdery substances in powder-handling production plants.

Especially, when fine powders and dusts are transferred, loaded, or stored within a specific section and in cases of powder coating using compressed air flow, fine powders are strongly tribo-charged by the friction and collision of pipe-particles and inter-particles [1]. Such a charging phenomenon may block the flow of fine powder and generate electrostatic discharges (ESD), causing the ignition of flammable dusts.

As recently reported, some fine powders are so sensitive that even a spark with very low energy can ignite them. Technologies for the prevention of such accidents are essential to avoid discharge sparks.

For this reason, a nozzle-type of high-voltage electrostatic neutralizer has been previously proposed by Kodama [2]. However, whether a nozzle-type neutralizer can be used in an explosive atmosphere remains to be seen. Therefore, in the present study, we evaluated the practical version of the neutralizer through several tests.

2. EXPERIMENTAL

2.1 General structure of the nozzle-type neutralizer

The high-voltage nozzle-type neutralizer is briefly reviewed as follows [2]. 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, 2.1 mm; opening diameter of the nozzle 3 mm) for a corona discharge, a high-voltage power source (AC or DC), 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.

It should be noted here that the DC-type neutralizer in the present paper was used with a positive polarity, as the charged powder pellets in our pneumatic powder-transport facility were negatively charged.

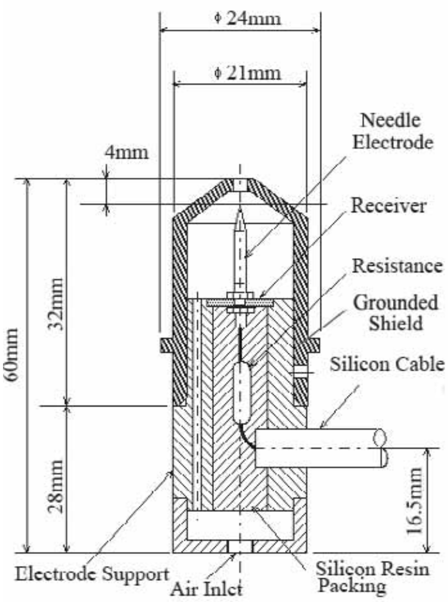


Fig. 1. Structure of a nozzle-type electrostatic neutralizer.

2.2 Experimental method

2.2.1 Test for an incendiary discharge from the neutralizer

The testing method for the ignition voltage and current of the neutralizer is described as follows. **Figure 2** shows the overall structure of the ignition testing apparatus, which consists of a testing needle electrode and an ignition vessel (2500 cm^3) [3]. The needle electrode is connected to a power source via a resistor to reduce damage to the minimum even if the needle is accidentally grounded. A needle with a coupling resistor was selected for use as one of the needles of the test neutralizer.

Inside the ignition vessel, an artificial spark was generated between the needle electrode and a grounded rotating plate electrode (20 mm × 33 mm) when the rotating plate electrode approached the needle electrode. The space between the center of the needle tip and the metal plate was 0.5 mm.

The typical ignition testing procedures are described as follows:

(a) The ignition chamber was filled with an inflammable gas-air mixture.
(b) The level of voltage of the power source was set at the initial level.
(c) Generating spark by rotating the grounded plate electrode with the use of a motor (60rpm).
(d) If no ignition occurred, the spark was repeated every second up to 100 times.
(e) The level of voltage was increased, if necessary (no ignition within 100 times), and testing continued until the least sparking voltage level was obtained.

It is noteworthy that, rather than fine powders, the inflammable gas used in the experiment was ethylene (6.5 Vol. %), which is so sensitive that even a spark with very low energy, such as 0.1 mJ, can ignite it [4]. The test conditions were 20 ± 3 °C and 35 ± 5 % RH.

In general, an incendiary discharge from a neutralizer depends upon the resistance, capacitance, and inductance of the power circuit of the neutralizer. However, the effect of the inductance can be ignored since the circuit line is very short. Accordingly, in this paper, the effect of the power circuit on the incendiary discharge from the neutralizer was investigated using the resistance as parameters.

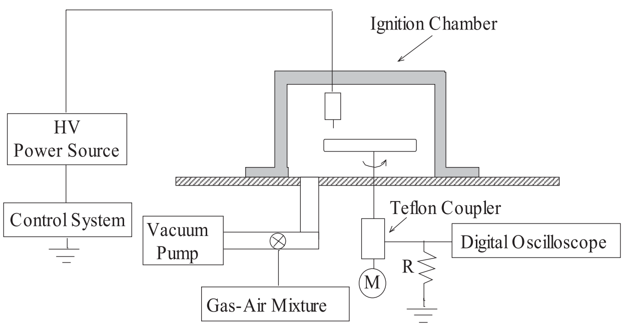


Fig. 2 Schematic diagram of the ignition testing apparatus used to evaluate the incendiary discharge occurring from the neutralizer.

2.2.2 Evaluation of the performance of the neutralizer

A full-size pneumatic powder transporting facility, as shown in **Fig. 3**, was used to evaluate the performance of the nozzle-type neutralizer. The full-size pneumatic powder transport facility consisted of a cylindrical silo (stainless steel; diameter, 1.5 m; straight body length, 2 m, and capacity 4.8 m^3), a pipeline (stainless steel; diameter, 0.1 m; total length, 20 m), an air blower (10 m^3/min) driven by an inverter motor, and an air conditioning unit controlling the temperature (30 °C) and humidity (30 % RH) of the blowing air.

The silo provided a rotary valve driven by an inverter motor to release powder (pellet flow rate, about 32 kg/min) from its bottom. For observing the electrostatic discharge inside the silo, a camera or a video camera with an image intensifier (Hamamatsu Photonics Ltd., Night Viewer C3100, Gain 60,000) was set on the window glass on the silo roof.

As powder, polypropylene (PP) pellets with mean particle sizes of 3 mm were used in this experiment. The test conditions were 26 ± 2 °C and 35 ± 5 % RH.

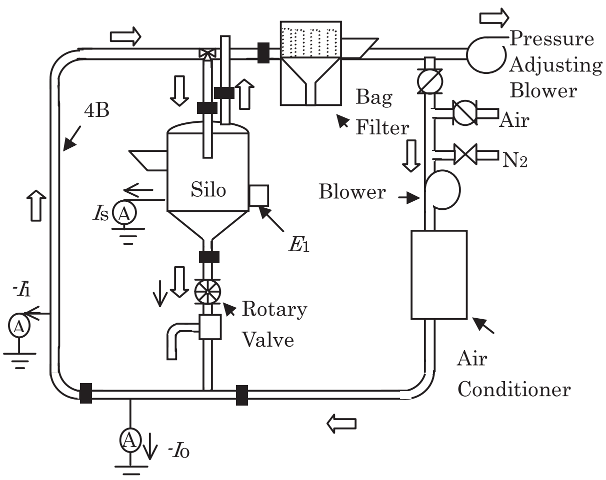


Fig. 3. Pneumatic powder transportation facility used to evaluate the performance of the neutralizer.

3. RESULTS AND DISCUSSION

3.1 Incendiary discharge occurring from neutralizer

The minimum ignition voltage (MIV) of the test gas (ethylene) was determined by repeated ignition tests with high-voltage AC (50Hz) and DC (in a positive polarity). It should be noted here that the lower the MIV, the more easily the gas can be ignited. The possibility of the suppression of ignition by the circuit impedance with a resistor was examined. Resistors from 10 MΩ to 100 MΩ were used in this study.
As a result, when the AC power source was used, the MIV showed a slight decrease with increasing the coupling resistor; 10.8 kV at 50 MΩ, 10.6 kV at 60 MΩ, and 10.5 kV at 100 MΩ.

On the other hand, the MIV increased with an increase in the coupling resistor with the DC power source: 7.5 kV at 20 MΩ, 17 kV at 50 MΩ, 30 kV at 75 MΩ, and 37 kV at 100 MΩ.

In additions, concerning the characteristics of the ion current, it is well known that a neutralizer with a coupling resistor is superior to a neutralizer with a coupling capacitor [5].

These facts suggest that a resistive-coupled electrode safely produces ion pairs for reducing static charges and that incendiary discharges are suppressed by the resistor and voltage supplied to an AC-type (50HZ) and DC-type (positive polarity) electrode of a maximum of 7 kV.

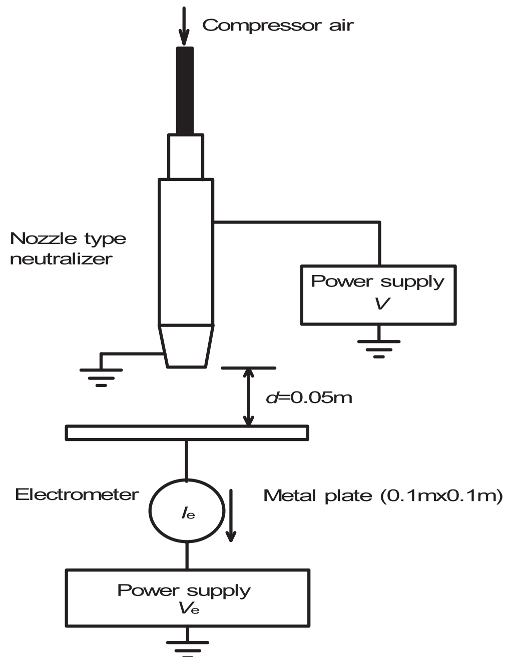


Fig. 4　Schematic drawing of ion current measurements for the nozzle type neutralizer.

3.2　Performance of the nozzle-type neutralizer

Taking the experimental results reported above into account, a 100 MΩ resistor was connected to an ionizing electrode, and high voltage was applied to the resistor to generate a corona discharge and evaluate the performance of the nozzle-type neutralizer.

For that purpose, first, the ion current, I_c, coming from the neutralizer was measured using a metal plate impressed with a high voltage, V_p (see **Fig. 4**). The high voltage applied, V_a, to the needle electrode and the corona current, I_c, were controlled and recorded automatically by a computer through a GP-IB interface. The space d between the nozzle opening of the neutralizer and the metal plate (0.1 m × 0.1m) was 0.05 m.

The I_c was measured with an electrometer connected between a metal plate impressed with V_p and the ground. The I_c as a function of the supply voltage of the neutralizer and the supply air pressure, P_a, are shown in **Figs. 5 and 6**, respectively. 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 figure.

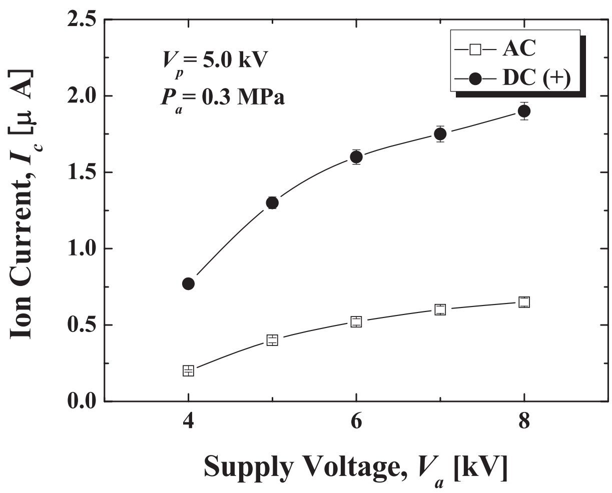


Fig. 5　Relationship between *Ic* and *Va*.

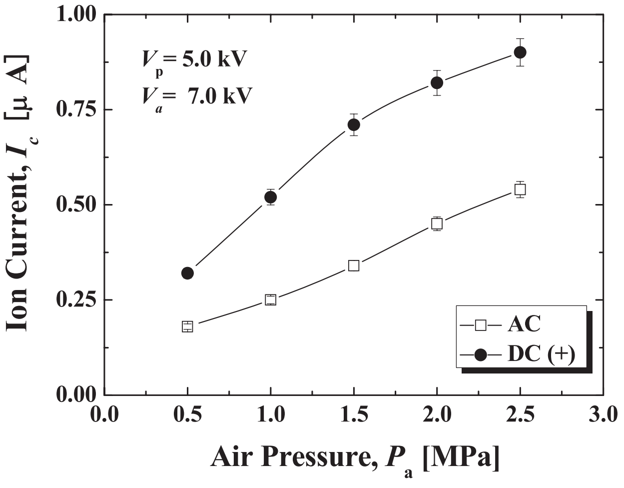


Fig. 6 Relationship between I_c and supply air pressure P_a.

When a high-voltage DC (in a positive polarity) is applied to the needle electrodes for corona discharges, the neutralizer produces a larger I_c than the neutralizer to which a high-voltage AC (50Hz) has been applied.

The I_c increased clearly with an increase in both the V_a and the P_a for both types of neutralizers, DC (in a positive polarity) and AC. The P_a (or airflow) has been reported to have an effect on the suppression gas, such as O_3 and NO_X, generated from the discharge area [6]. To maintain the corona discharge, seed electrons for discharge must be continuously produced. Any suppression gas that remains in the discharge area disturbs the maintenance of the corona discharge, resulting in a decrease of 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 was applied to the needle electrode was discussed. As a result, the I_c exhibited a rapid drop in 60 s of elapsed time in the case without a P_a. However, when a P_a of 0.3 MPa was provided to the corona electrode, the I_c changed very little over time.

These facts agree with those reported in the hypothesis, namely, that the effect of the P_a is to drive out any discharge suppression gas from the discharge area near the electrode.

Secondly, the performance of the nozzle-type neutralizer was evaluated with the full-size pneumatic powder transport system. The neutralizer, provided with sixteen ionizing needle electrodes (flange-type), was attached to the end of the inlet pipe of the silo. The pellets were negatively charged because the pipeline was made of stainless steel, which has a tendency to be positively charged. The electric field strength in the silo was measured with an electrostatic air-blow field sensor (KSF-0201, Kasuga Denki INC), which was installed on the side wall of the silo at a distance of 40 mm from the heap surface. The distance for testing was always constant. The field sensor, which is equipped with 100kPa air blower to prevent dusts from coming into the detector, was originally developed to measure the field due to a charged dust cloud in a silo [7].

The switch of the neutralizer was turned on (DC 3 kV in a positive polarity), and the change in the electric field strength in the silo was observed. The results are given in **Fig. 7**. The electric field strength above the pellet heap decreased significantly by the operation of the neutralizer. And then, the field strength increased to near the original value when the neutralizer was turned off.

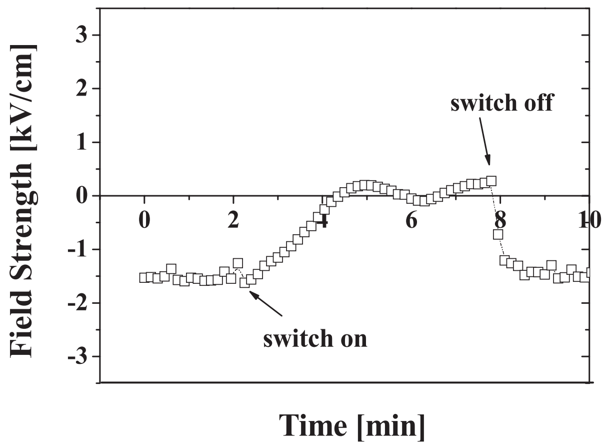


Fig. 7 Field strength in the silo as a function of time.

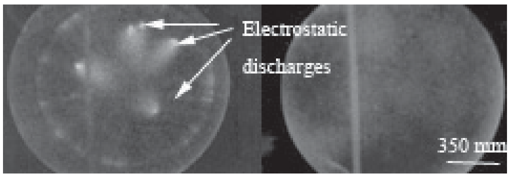
A large number of electrostatic discharges along the pellet heap in the silo were observed using a camera with an image intensifier set on the window glass of the silo roof, as shown in **Fig. 8(a)**.

However, in the case with the neutralizer (DC 3kV), the electrostatic discharges completely died out in the silo (**Fig. 8(b)**). It was confirmed that the nozzle-type neutralizer is effective for reducing electrostatic charges from polymer materials.

Figure 9 shows the performance of the AC (50Hz) and DC-type (in a positive polarity) neutralizer as a function of the voltage applied to the neutralizer. The electrostatic field strength in the silo decreased with an increase in the applied voltage to the AC-type neutralizer. The AC 7 kV used in our experiment was not sufficient for the elimination of the charges of the powder.

On the other hand, the performance of the DC-type neutralizer was superior to that of the AC-type one. However, a DC (in a positive polarity) voltage of above 5 kV brought about significant reverse charging.

The application of a grid electrode was found to be effective to improve the performance of the AC-type neutralizer [8]. A feedback control-type neutralizer may also be effective for the prevention of reverse charging in the DC-type neutralizer. This type will be described in our next report.



(a) without neutralizer (b) with neutralizer

Fig. 8 Photos of the electrostatic discharge inside the silo.

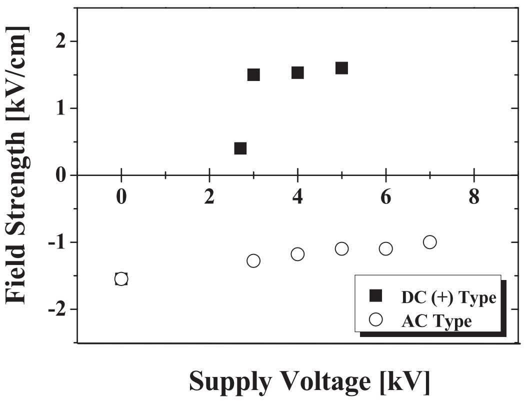


Fig. 9 Effect of AC- and DC-type neutralizers as a function of the voltage applied to the neutralizer.

4. CONCLUSIONS

The safe performance of a nozzle-type electrostatic neutralizer was examined experiment-ally in an explosive atmosphere. The electrostatic elimination performance of the nozzle-type neutralizer was also evaluated with a full-size pneumatic powder transport system. The results are summarized as follows:

(1) The resistivity of a 100 MΩ-coupled electrode produced ion pairs safely for reducing static charges, and incendiary discharges were suppressed by the resistor and voltage supplied to the electrode.

(2) The nozzle-type electrostatic neutralizer performed well in general, but there were also several problems, i.e., the nozzle-type neutralizer with AC-applied voltage had insufficient elimination, while the DC-applied voltage brought about reverse charging unless the applied voltage was properly controlled.

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屋根工事における軒先からの墜落防止に関する研究

日野泰道

本報は，低層住宅工事における屋根からの墜落災害に焦点を絞り，災害発生状況とその防止対策について検討を行ったものである。検討の結果，①足場先行工法のガイドラインの基準を満たす足場が設置された現場でも，墜落死亡災害が発生している場合があることが分かった。また実験的検討により，②墜落防護を完全に行うためには，限られた本数の手摺・中桟を使用する方法では難しいことを明らかにした。これらの結果を踏まえ，墜落防護方法としてネットを用いた方法を取り上げ，その適切な設置方法について実験的に検討を行った。その結果，③ネットに衝突後の跳ね返りにより，被災者が頭部を屋根面に強打することで傷害の発生可能性があることが明らかとなった。そのため，④屋根からの墜落防止用として安全ネットを設置する場合には，屋根面への跳ね返りを防止するための措置が必要であることが明らかとなった。　（図14，表3，参考文献16）

RFIDを用いた広大空間における再起動防止に関する研究

深谷　潔

危険空間が広大になると，操作装置の位置から全体を見通すことができず，作業者がその空間内にいても分からず誤って機械を起動し，事故となることがある。このような事故を防止するため，RFIDを用いて危険空間内部の作業者の位置を常時モニターするシステムを開発し，評価した。

格子状に設置したタグを作業者が所持するリーダーでその位置を読み取るシステムであるが，周りの物の配置により電波の受信距離が異なり遠くのタグを受信することもあり，位置計測の誤差となることがあった。実用化のためには，装置を小型化すると共に誤差を考慮したシステム設計が必要である。

（図5，表2，写真3，文献7）

着火性放電を抑制したノズル型除電器の除電特性

崔光石，山隈瑞樹，児玉勉，鈴木輝夫，最上智史

粉体輸送プロセスにおける静電気トラブルの発生を防止する方法として，粉体の帯電量を静電気トラブル発生レベル以下に制御できるノズル型除電器（コロナ式）を開発した。しかし，コロナ式除電器は，高電圧を利用しているために何等かの原因で異常作動すると，まれに着火性放電を起こし，爆発，火災を誘発する危険性がある。そこで著者らは開発したノズル型除電器の安全性を着火試験によって評価した。その結果，放電針と高電圧源の間に100MΩの高抵抗（結合抵抗）を有する放電電極は，印加電圧が7kV以下（交流又は直流）であれば，放電針からの放電火花が最小着火エネルギー0.1mJ以上の可燃性雰囲気の着火源にならないことが判明した。また，このノズル型除電器を内蔵したフランジ型除電器を実規模大の粉体空気輸送帯電実験装置のサイロ内に設置して，実際に粉体を除電してその効果を調べた。その結果，上記の電圧範囲内で印加電圧を制御することによって粉体の帯電を効果的に除電できることが明らかになった。したがって，本除電器は，改良を加えることにより可燃性雰囲気を伴う粉体プロセスにおける静電気障災害の防止に十分寄与できると考えられる。　（図9，参考文献8）

高強度アルミニウム合金重ね継手の疲労き裂モニタリングとその疲労破壊特性

佐々木哲也，本田　尚

高強度アルミニウム合金重ね継手の疲労破壊を防止するために，ボルト内に埋め込んだひずみゲージの出力で疲労き裂をモニタリングすることを試みた。実験の結果，ひずみゲージ出力の平均値よりも変動幅の方が疲労き裂進展に伴う変化の割合が大きく，疲労き裂モニタリングに適していることが明らかになった。なお，ボルト穴に初期切欠きのない重ね継手の疲労破壊位置は，大きく3箇所に分類できたが，いずれの場合も疲労寿命に大きな差はなかった。

（図6，写真1，表2，参考文献12）