Electrostatic discharges inside storage silo during loading of polypropylene powders

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***Abstract*— This study is focused on the electrostatic discharges inside a full-sized storage silo during the loading of polypropylene (PP) powders. An image-intensifier system was used in this study to observe electrostatic discharges. The silo was continuously loaded with 0.68 kg/s of PP to a total mass of approximately 800 kg. The experiment's results show that ring-shaped light, which are the electrostatic discharges, appeared at the center of the silo approximately 7 s after initial loading. The diameter of the ring-shaped light grew larger as time continued to pass after loading. This was because the diameter of the accumulated PP powders increased in the silo during the running time, meaning that electrostatic discharge occurred between settled PP powders and the grounded metal silo wall. Additionally, the electrostatic discharges during the loading of powder in this study were clearly observed and classified into three kinds of discharges: brush, linear, or broad bulk surface discharges.**

INTRODUCTION

A pneumatic conveying system for transferring powders and other dry bulk materials has several advantages, such as being more flexible, simple, and efficient than a mechanical conveyor. A pneumatic conveying system has been widely applied in the food processing and pharmaceutical industries. An electrostatic charge is inevitably generated in a pneumatic conveying system due to friction as well as pipe-particle and particle-particle collisions. As the charged powders are loaded into the large storage silo, the charge inside the silo accumulates. This charging phenomenon can lead to electrostatic discharges within the silo. In fact, dust explosions and fires related to electrostatic charges and discharges have occurred in industrial processes with pneumatic conveying systems [1].

Although many studies have investigated electrostatic discharges from powder in a silo, the phenomenon is not yet well understood. This study focuses on the electrostatic discharges inside a storage silo during the continuous loading of polypropylene powder.

EXPERIMENTAL APPARATUS AND METHODS

The following apparatuses and sample powders were also used in our previous studies [2, 3, 4].

A. *Pneumatic Powder Transport Facility*

A full-sized pneumatic powder transport facility (Fig. 1) had a conical-cylindrical silo (stainless steel; body length, 3.75 m; diameter, 1.5 m; capacity, 4.8 m^3), a pipeline (stainless steel; diameter, 0.1 m; total length, 23 m), an air blower (10 m^3/min) driven by an inverter motor, and an air-conditioning unit controlling the temperature (30 ºC) and humidity (30 % RH) of the blowing air. The silo was electrically grounded.

The hopper was provided with a rotary valve (29 rpm) driven by an inverter motor to discharge powders from its bottom. The sample powder was loaded continuously into the silo until its total mass reached approximately 800 kg.

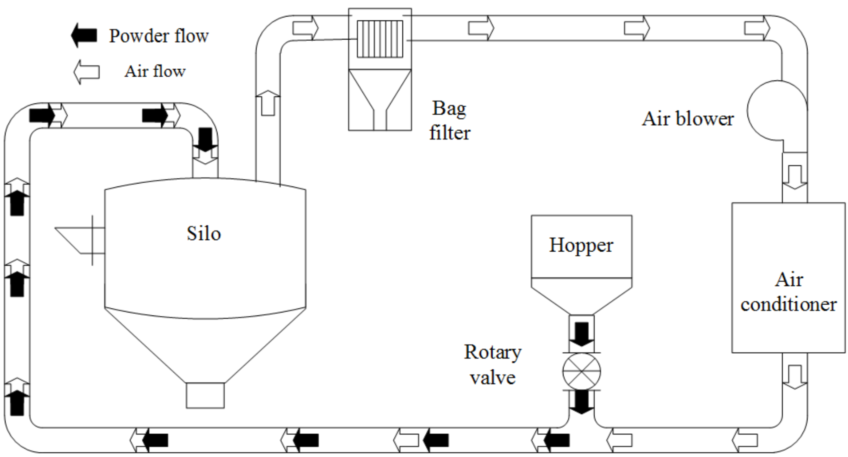


Fig. 1 Full-sized pneumatic powder transportation facility used in this study.

B. *Observation of Electrostatic Discharges*

To observe electrostatic discharges inside the silo, an image-intensifier unit (Night Viewer, Hamamatsu Photonics, Ltd.; C9016-02; max. gain, 1,000,000) was set on the windowpane of the silo roof, as shown in Fig. 2. Blackout curtains were placed around the metal silo to prevent external light, such as sunlight and fluorescent lights, from entering. The image-intensifier unit consists of an image-intensifier head, a remote controller, a wide-angle lens (18-35 mm, or a CCD camera), a power supply, an AC adapter, a displayer, and a digital image recorder. The image intensifier was operated and controlled with a remote controller or a PC via the USB interface connector provided on the rear panel of the image-intensifier head.

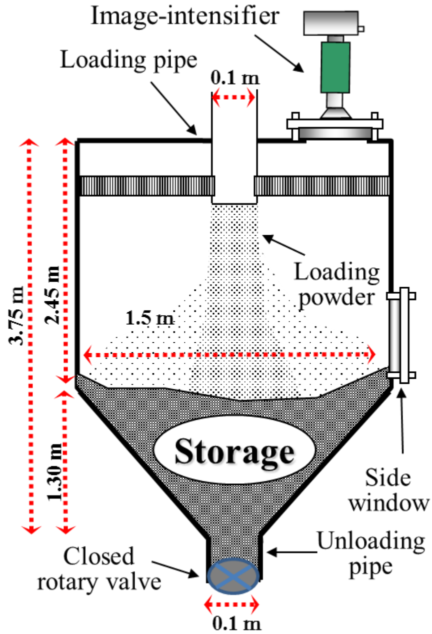


Fig. 2 Image of the conical-cylindrical silo and image intensifier used in this study.

C. Polymer Powder Sample

Since polypropylene (PP) has been widely used in chemical industries, approximately 800 kg of PP powder (Fig. 3) was employed as a sample in this experiment. The PP had a typical particle size of 2-3 mm. The apparent volume resistivity, R [Ω·m], of the PP powder was on the order of 10^{15} Ω·m.

Fig. 3 Polypropylene (PP) powder used in the test.

EXPERIMENTAL RESULTS AND DISCUSSION

Observing electrostatic discharges within silos is especially important for better understanding potential electrostatic hazards. Figure 4 shows the image of an area inside the silo in low light before the test. Approximately 400 g of powder was deposited so as to insert the direction papers and then taken out before the test. Therefore, the silo was completely empty before the test. The feeding mass of the PP powder, *u* [kg/s], was a constant 0.68 kg/s in this study. It should also be noted here that the charge-to-mass ratio, *q* [μC /kg], of the loading powders remained at a constant value of approximately -12 μC/kg while the powder was loading.

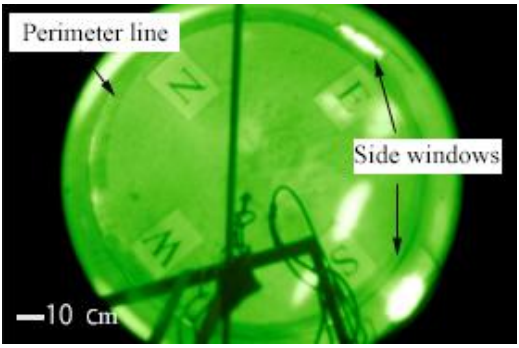
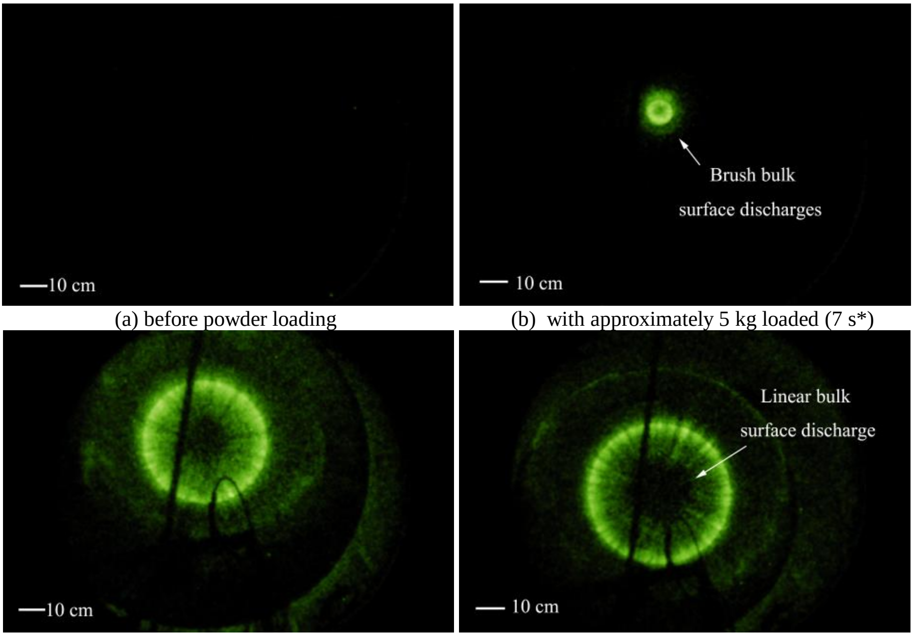


Fig. 4 Image of the area inside the silo before the test.

Figure 5 (a to d) shows electrostatic discharges generated inside the silo with between 0 and 100 kg of powder loaded. These photos were taken randomly during loading. This study showed that the electrostatic discharges appeared as light in the shape of rings clearly 7 s after loading the powder into the silo (Fig. 5 (b)). The electrostatic discharges were generated in the unloading pipe attached to the bottom of the silo, as shown in Fig. 2. The diameter of the ring shape grew larger as more loading time passed (see Fig. 5 (b, c, and d)). This is because the diameter of the accumulated powders increased in the silo during the running time in the conical part of the silo. This kind of electrostatic discharges can be called brush bulk surface discharges or also just brush discharges. Brush discharges occurred conspicuously between settled PP powders and the grounded silo wall due to the strong electric fields occurring at the edges of the powder bed. A multiplicity of very small discharge channels occurs among them. Even if experiments with flammable gases of known ignition energy indicate that the brush discharges dissipate a maximum energy that is equivalent to approximately 3 mJ - 4 mJ, brush discharges have not been reported to ignite combustible dust [5]. However, in the chemical process, powders wetted with solvents must be carefully handled, as these kinds of powders can be ignited with brush discharges. We also observed that linear bulk surface discharges are a stretched form of brush discharges. This kind of electrostatic discharges can be also called a brush streamer or super brush discharges. It discharges across a PP powder heap when the electric fields across the surface of the heap due to charged powder compaction are sufficiently high. The energy of the linear bulk surface discharges will be discussed after mentioning broad bulk surface discharges.



(a) before powder loading (b) with approximately 5 kg loaded (7 s*)

(c) with approximately 50 kg loaded (73 s) (d) with approximately 100kg loaded (147 s)

Fig. 5 Electrostatic discharges generated inside the silo with between 0 and 100 kg of powder loaded (*time after initial loading).

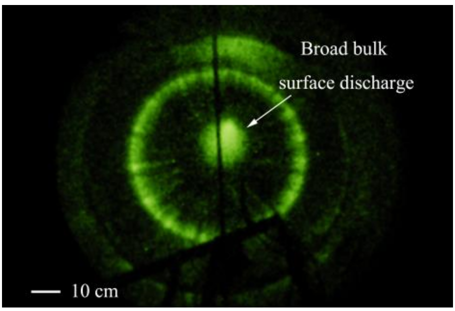
Figure 6 shows the electrostatic discharges generated inside the silo with between 100 and 400 kg of powder loaded. The diameter of the ring shaped light grew larger as more of the loading time passed because the diameter of the accumulated powders still increased in the silo during the running time in the conical part of the silo. In an important finding of this study, the broad bulk surface discharges frequently occurred in places where linear discharges did not reach. They started clearly appearing approximately 166 s after loading the powder into the silo (loaded powder: 112 kg, diameter of the accumulated powders: 0.9 m). These discharges were triggered by the ends of the linear discharges. The total charge amount of powders accumulated around the center of the silo was high even though the charge to mass ratio was low because a lot of powder falls in that area. Several additional tests were carried out to investigate the relationship between broad bulk surface discharges and the generation time (or loaded powder mass, diameter of the accumulated powders). They all agreed with the results of the test above, showing a time of around 170 s. This detail, however, must be thoroughly tested in the future.

Some publications cannot differentiate between linear and broad bulk surface discharges, calling all of them cone (or bulking) discharges generated during powder loading [6, 7]. It is well known that the energy released in cone discharges depends on the diameter of the silo and the particle size of the products forming the powder heap. For silos with diameters in the range of 0.5 m to 3.0 m and powders with a median range of 0.1 mm to 3.0 mm, the energy released in cone discharges can be estimated using the following Equation [8]:

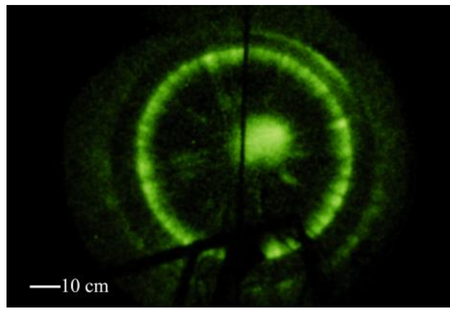
$$W = 5.22\, D^{3.36}\, d^{1.46}, \quad (1)$$

where W is the upper limit of the energy of the bulk surface discharge (mJ), D is the diameter of the silo (m), and d is the median of the particle size distribution (mm).

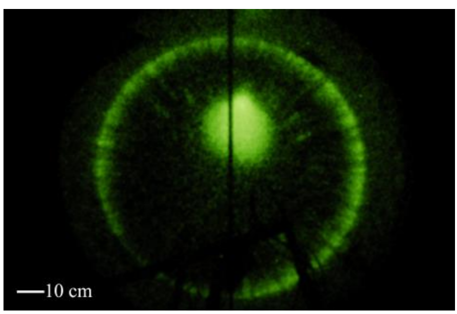
In this study, the D of the silo and the d of the PP were 1.5 m and 2 to 3 mm, respectively. Following Equation (1) above, W was 56 mJ to 101 mJ. These energy values can easily ignite combustible powders.



(a) with approximately 150 kg loaded (220 s)



(b) with approximately 250 kg loaded (367 s)

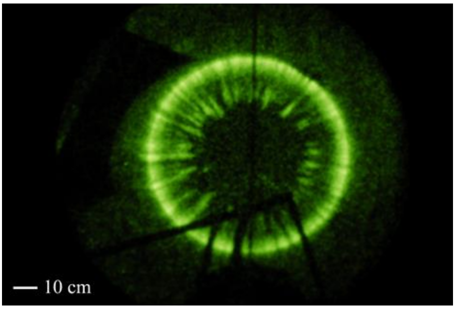


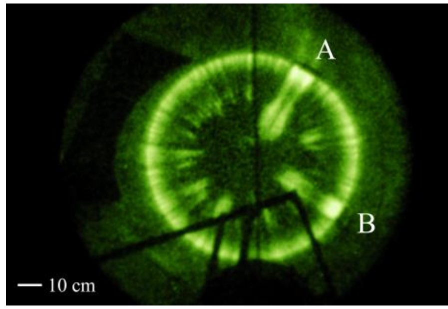
(c) with approximately 350 kg loaded (514 s)

Fig. 6 Electrostatic discharges generated inside the silo with between 100 kg and 400 kg of powder loaded.

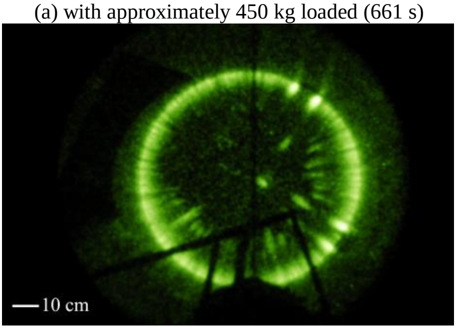
Figure 7 shows the electrostatic discharges generated inside the silo with between 400 and 800 kg of powder loaded. The diameter of the ring shaped light did not change because the diameter of the accumulated powders was consistent in the cylindrical part of the silo during the running time. This is also evidence that electrostatic discharges are generated on the heap surface of the accumulated powders. As seen in Fig. 7 (b, c, and d), there were stronger and longer streaks of linear bulk surface discharges heading toward the center, while the inner central broad bulk surface discharges disappeared, as compared to Figs. 6. In other words, this means that the linear bulk surface discharges neutralize the surface of the heaped powder. Strong brush discharges were also found at two points, A (East) and B (South), which are in front of the side windows, as shown in Fig. 4. This was because the side windows had protrusions-bolts.

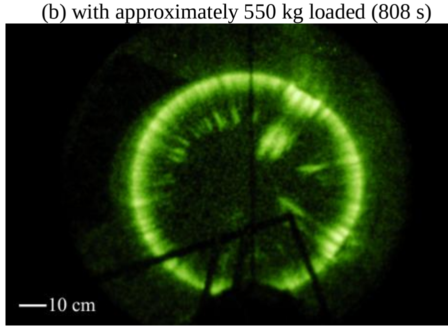
Many different testing conditions, such as the kinds, sizes, and feeding masses of granules and the size of the silo, may affect the electrostatic discharging of granules; this needs to be examined in the future.





(a) with approximately 450 kg loaded (661 s) (b) with approximately 550 kg loaded (808 s)





(c) with approximately 650 kg loaded (955 s) (d) with approximately 750 kg loaded (1102 s)

Fig. 7 Electrostatic discharges generated inside the silo with between 400 and 800 kg of powder loaded.

ACKNOWLEDGEMTNS

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