On-line Monitoring of Electrostatic Charge in Powder Pneumatic Transportation Process

Satoru Watano, Teruo Suzuki and Kei Miyanami
Department of Chemical Engineering, Osaka Prefecture University*

Summary

This paper describes a novel system for continuous monitoring of powder electrostatic charge in pneumatic transportation process. An electrostatic detecting system based on the electrostatic field strength measurement, together with a purge air system for preventing powder adhesion, has been newly developed. Performance of the system has been confirmed in a powder pneumatic transportation process under various kinds of powder materials and operating conditions. Specific charge of powder and the induced current at the transportation pipe were simultaneously measured. The relationship between the electrostatic field strength and the space charge density and the measured induced current were investigated. It is found that the electrostatic filed strength has linear relationship between the space charge density and the induced current. This proves that our newly developed system is a very effective and simple device for continuously measure the electrical charge of powder. A model for the powder charge in the pneumatic transportation process has also been proposed here to understand the powder charge mechanism.

1. Introduction

Recently, powder technology tackles the electrostatic disasters and troubles, which have now developed into a social problem because they cause explosion and fire in the worst case [1-3]. For example, in the process of powder pneumatic transportation, powders are tremendously charged due to the collision between powders and inside wall of the transportation pipe. In the case such charged powders are fed into a silo, a lightning discharge (atmospheric discharge) in the upper space of the silo or cone discharge along with the accumulated powder surface are frequently observed, which sometimes induce explosion and fire [4-6]. In order to prevent these hazards beforehand, continuous motoring of powder electrical charge is required.

So far, a Faraday cage [4-6] has been well used to statically measure the electrical charge of powders. However it is not available for the continuous measure-

* 1-1, Gakuen-cho, Sakai, Osaka 599-8531, Japan
Tel: +81-722-58-3323 Fax: +81-722-54-9911
Email: watano@chemeng.osakafu-u.ac.jp

† This report was originally printed in J. Soc. Powder Technology, Japan. 34, 778-784 (1997), 35 846-855 (1998) in Japanese, before being translated into English by KONA Editorial Committee with the permission of the editorial committee of the Soc. Powder Technology, Japan.
assumed to be $q$) can be described as Eq. (1).

$$\int_0^r E_0 \cdot ds = q/\varepsilon_0$$  \hspace{1cm} (1)

where $\varepsilon_0$ and $ds$ represent an air dielectric constant and an infinitely small area on the surface of a virtual sphere where electrostatic filed is functioning at a distance of $r$ from the center, respectively.

Integrating the both sides obtains Eq. (2)

$$E_0 = q/(4\pi\varepsilon_0 r^2)$$  \hspace{1cm} (2)

Therefore, as far as distance $r$ is known, measurement of $E_0$ obtains electrical charge $q$.

**Figure 2** illustrates measurement principle of electrostatic field strength. A developed sensor measures electrostatic field strength as an alternating voltage which is induced at an electrode by periodically chopping the electrostatic field.

Assuming that the chopping cycle is $\omega$ (=500 Hz), area of the electrode where electrostatic field flows in is $S_0$, and the one which changes periodically due to the electrode vibrating is $S_1$, then the effective area of the electrode $S$ can easily be written as:

$$S = S_0 + S_1 \sin \omega t$$  \hspace{1cm} (3)

The Gauss's law calculates an electrical charge $q$, which is induced by the electrostatic field periodical change,

$$q = E S \varepsilon_0$$  \hspace{1cm} (4)

where $E$ shows an electrostatic field.

A current $I_e$ running through an electric resistance $R_e$ which connects the electrode and ground is calculated as,

$$I_e = dq/dt = E \varepsilon_0 S_1 \cos \omega t$$  \hspace{1cm} (5)

The voltage between the electric resistance is thus:

$$V_s = R_e I_e = R_e E \varepsilon_0 S_1 \cos \omega t$$  \hspace{1cm} (6)

Finally, the electrostatic field strength $E$ can be detected by measuring the voltage $V_s$ of the electric resistance $R_e$.

### 3. Electrostatic Field Strength Detecting System

**Figure 3** is a schematic diagram of the detecting sensor. The sensor consists of a chopper, an electromagnet and a driving gear composed of a tuning fork and an electric magnet. The driving gear activates the chopper at a constant chopping cycle. The sensor is originally designed to miniaturize as small as possible (i.d.7×H50 mm) without any decrease in sensor sensibility by means of amplifying and transmitting signal with a high S/N ratio.

**Figure 4** illustrates the sensor extremity. The sensor is setup in a double-walled cylinder, and purge air is blowing inside of each cylinder. Due to this air purge system, powder cannot reach to the detecting sensor. The double-walled cylinder is connected with the main
4. Monitoring of Electrostatic Charge in Pneumatic Transportation Process

Figure 5 describes a schematic diagram of a pneumatic transportation system. The system consists of a transportation pipe, a measuring pipe made of stainless steel, an electrostatic filed sensor, a Faraday cage, electrometers and a personal computer. Powders are fed into the transportation pipe (inner diameter is 28 mm, 2 m in length) through a stainless funnel and then charged by collisions between powders and the pipe wall while a suction blower conveys them through the pipe. The tail end of the pipe attaches so called "a measuring pipe" that has a flange connecting the electrostatic sensor. Since the measuring pipe and the transportation pipe are both grounded, the sensor can only measure electrostatic field strength arisen by the charged powders. After passing through the measuring pipe, the Faraday cage collects powders; at the bottom of the cage, wire mesh is placed, so that the powders remain inside the cage and only air passes through the mesh. Through the electrometer, amount of charge (specific charge) is measured.

During the transportation, the generation of powder charge also induces electrical charge on the outside wall of the transportation pipe. Since the transportation pipe is grounded through the electrometer, the induced charge can also be measured as an induced current by the electrometer (the transportation pipe is not only for the powder transportation but also for the induced electrode). The transportation pipe having a function of the induced electrode is covered by a wire shield; it is the same structure as the Faraday cage.

Here, we assume that, 1) flow of uniformly charged powders is laminar and uniform, 2) there is no electrostatic generation neither relax inside the measuring pipe, 3) direction of electrostatic field strength generated by the charged powders inside the measuring pipe is radial direction and 4) direction of a current flows into the transportation pipe is defined as positive.

Figure 6 illustrates a model for the powder charge in the pneumatic transportation system. When the charged powders \( I_1 \) flow into the transportation pipe, the charge is induced at the pipe, as well. Since the transportation pipe (work as the induced electrode) is grounded through the electrometer, transient charge...
is generated to eliminate the induced charge. At the same time, powders flow with colliding each other or with transportation pipe wall, the powder and the wall are charged with different sign, respectively. When the powders flow out of the pipe, induced current \( I_2 \) and charge of powders \( I_3 \) are observed.

Therefore, the balance of the current should be

\[
I_1 = -I_2 + I_3
\]

(7)

Here, the current of charged powders \( I \) can be described by the powder feed rate \( v \) and the powder specific charge \( q \) as follows,

\[
I = q \cdot v
\]

(8)

The powder feed rate can be replaced by the product of air flow rate \( u \) and powder space density \( m \), Also, the product of the specific charge \( q \) and the powder space density \( m \) should be the space charge density \( \rho \),

\[
I = q \cdot m u = \rho u
\]

(9)

If Eq.(8) is applied to the current of powder \( I_3 \), \( I_3 \) can be expressed by the product of the space charge density and the air flow rate.

\[
I_3 = q_3 \cdot m u = \rho_3 u
\]

(10)

According to the Gauss’s theory, total charge \( Q \) is expressed by using electrostatic field strength \( E \), dielectric constant of air \( \varepsilon_0 \) and cross sectional area of the pipe \( S \)

\[
Q = E S \varepsilon_0
\]

(11)

Thus,

\[
E = \frac{Q}{2 \pi r \varepsilon_0 L}
\]

(12)

where \( r \) and \( L \) show radius and length of the pipe, respectively. Since total charge \( Q \) can also be written by the space charge density \( \rho_3 \),

\[
Q = \pi r^2 L \rho_3
\]

(13)

Following Eq. (14) can be obtained from Eqs.(12) and (13)

\[
E = \left( \frac{r}{2 \varepsilon_0} \right) \rho_3
\]

(14)

Assume that the initial powders have no electrical charge \( I_1 = 0 \),

\[
I_2 = I_3 = \left( \frac{2 \varepsilon_0 u}{r} \right) E
\]

(15)

Total electrical charge of powders \( Q \) can also be obtained by integrating the induced current \( I \) over the moving time \( t \),

\[
\int_0^t I \, dt = Q
\]

(16)

The specific charge can be obtained by dividing the electrical charge \( Q \) by the total mass of powder \( M \),

\[
q = \frac{Q}{M}
\]

(17)

**Figure 7** investigates the effect of measuring pipe materials on the electrostatic filed strength measurements. In case of using acrylic for the measuring pipe, glass beads charge to negative while the pipe to positive. However, the electrostatic field strength sensor shows that the charge is positive and it remains after the glass beads pass away from the pipe. This phenomenon is originated from the fact that the insulted acrylic pipe is tremendously charged to positive and the sensor measures its electrostatic filed strength not by the glass beads. Therefore in case of using insulated materials for the measuring pipe, the electrostatic field strength measurement is impossible.

Contrary to the acrylic pipe, a measuring pipe made of stainless steel can measure the electrostatic field strength properly. This is because the pipe is grounded so that the charge of the pipe is eliminated, and the electrostatic field strength arisen from only the charged glass beads can be measured. The metal such as stainless steel is thus required for the measuring pipe.
Figure 8 shows the temporal change in electrostatic field strength and induced current at various transport distances, X. With an increase in transport distance (X), both the electrostatic field strength and the induced current become larger. It is because the number of collisions between glass beads and wall and glass beads themselves increase awfully as the transport distance increases, leading to the simultaneous increase in electrical charge.

Figure 9 illustrates the relationship between the electrostatic field strength $E$ and space charge density $\rho_3$. Here, PMMA (polymethylmethacrylate) particles, grass beads and cellulose spherical granules having different sizes were used. During the experiments, the space charge density is obtained by the induced current measurement.

All experimental data points in Fig. 9 are well expressed by the theoretical value (Eq. (14)), showing that space charge density theoretically determines the electrostatic filed strength, regardless of the particle property and size.

Figure 10 investigates the relationship between electrostatic field strength and induced current. Fairly good linearity can be obtained between the two measurements. The induced current measurement method being used for a long time can be replaced by the electrostatic measurement. In addition, since the induced current method is not available when powders have their initial charge, the electrostatic field detecting method has more merit because it is not affected by the initial charge.

Figure 11 also describes relationship between induced current ($I_2$) and current ($I_3$) calculated from the Faraday cage measurement. Both results suggest good linearity. This confirms a theoretical formula of $I_2 = I_3$ (Eq. (15)). Also, this implies that the Faraday cage method can be replaced by the electrostatic method.
As a result, the validity of our newly developed electrostatic detecting system can be experimentally and theoretically confirmed. Since the electrostatic method is not affected by the powder initial charge nor requires no sampling devices, it can continuously monitor powder charge in any powder handling processes with high accuracy.

5. Conclusions

In this contribution, a novel system for detecting electrostatic field strength of charged powders has been developed. The performance of the system has been investigated in the powder pneumatic transportation process where powders are enormously charged due to the collision between powders and the pipe wall. It is found that the developed system could continuously monitor the electrostatic charge with high accuracy. It is theoretically and experimentally proved that the electrostatic field strength can be used to evaluate the power charge in powder pneumatic transportation process.

Acknowledgement

The authors wish to thank Mrs. T. Taira, T. Numa and T. Kurooka for their assistance in part of the experimental work.

References

1) Jones, T. B. and J. L. King, “Powder Handling and Electrostatics”, Lewuis Publisher (1991).
2) Van Larr, G. F. M., “How to Protect a Brewery against Dust Explosions”, Powder Handling & Processing, 10, 55-59 (1988).
3) Bours, R., "Dust Explosion Protection: A Difficult Choice?" Powder Handling & Processing, 10, 191-192 (1998).
4) Glor, M. and K. Schenzfeuer, “Occurrence of Cone Discharge in Production Silos”, J. Electrostatics, 40 & 41, 511-516 (1997).
5) Schenzfeuer, K. and M. Glor, “Tests to determine the ignition of dust by brush discharges”, J. Electrostatics, 30, 115-122 (1993).
6) Glor, M., "Ignition Tests with Discharges from Bulked Polymeric Granules in Silos (Cone Discharges)", J. Electrostatics, 30, 123-134 (1993).
7) Yamada, H. and T. Kobayashi, “Vibration Type Surface Potential Sensor”, J. Inst. Electrostatics Japan, 10, 213-216 (1986).
8) Watano, S., Y. Ito, T. Suzuki and K. Miyanami, “The Online Monitoring of the Electrostatic Field Strength in Fluidized Bed Granulation and Drying Using a Newly Developed Electrostatic Field Detecting System”, J. Soc. Powder Technol., Japan, 34, 32-38 (1997).
9) Watano, S., T. Suzuki, T. Taira and K. Miyanami, “Continuous Monitoring and Mechanism of Electrostatic Charge of Powder in Fluidized Bed Process”, Chem. Pharm. Bull., 46, 1438-1443 (1998).
10) Suzuki, T., S. Watano, T. Numa, T. Taira and K. Miyanami, “On-line Monitoring of Electrostatic Field Strength in Powder Pneumatic Transportation Process Using Newly Developed Electrostatic Field Detecting System”, J. Soc. Powder Technol., Japan, 35, 846-855 (1998).
11) Watano, S., T. Suzuki, T. Taira and K. Miyanami, "Monitoring of Electroscopic Charge in Powder Pneumatic Conveying Processes", Powder Handling & Processing, 11, 431-434 (1999).
Author’s short biography

Satoru Watano
Satoru Watano received his B.S., M.S. and Ph.D. degrees in chemical engineering from Osaka Prefecture University. Currently, he is an associate professor at the department of chemical engineering, Osaka Prefecture University. He is also a visiting professor at Particle Technology Center, New Jersey Institute of Technology (U.S.A.) since 1997. His major research interest lies in measurement, control, optimization, computer simulation and scaling up of powder handling processes. Now, he is an editor of Journal of the Society of Powder Technology, Japan and Journal of Advanced Powder Technology.

Teruo Suzuki
Teruo Suzuki graduated from the Tokyo Denki University in 1979 and received his Ph.D. in chemical engineering from Osaka Prefecture University. He has been active in the field of electrostatics for the past 20 years. Currently, he is working at Kasuga Denki Inc. and responsible for the design and development of novel devices for detecting and eliminating electrostatics in powder handling processes. He is an editor of the Journal of Electrostatics, Japan.

Kei Miyanami
Kei Miyanami graduated in Chemical Engineering from Osaka Prefecture University (OPU). After four years research on computer control of chemical plants at Hitach, Ltd, he obtained faculty position at Chemical Engineering, OPU in 1965. He obtained Ph.D. degree in Chemical Engineering from OPU in 1971. In 1979, he became Professor of Chemical Engineering at OPU. Currently he is the Emeritus Professor. He was at the position of former editor in chief of KONA Journal of HOSOKAWA Foundation in the past seven years. Now he is working as members of many councils and committees in local governments for environmental assessment-protection-affairs and wastes management.