Research on the static electricity of petrochemical powder pneumatic conveying and prevention of dust electrostatic explosion

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Abstract. In this paper we present the problem of electrostatic phenomena in powder pneumatic conveying, which includes the dilute phase transport and dense phase conveying. It is certified that the dust explosion of polyolefin silo in the past is related to the electrostatic discharge in the silo. By analyzing the data from the field, it is revealed that the statics of dense phase conveying and dilute phase conveying are in the same order of magnitude. However, it is more difficult for dense phase to be controlled due to the absolute value of the amplitude fluctuation. The data of field survey and basic experiments show that polyolefin silo dust explosion is closely related to the failure of controlling gas and dust during the preparation. Finally, the result of experiments by the non-equilibrium bipolar ion wind electrostatic eliminator is introduced, including the effect when its application is expanded.

1. Introduction

In the 1970s to 1980s, as the rapid development of petrochemical powder production scales and the increasing number of silo explosion accidents, the research of powder electrostatic hazard was promoted. The warring of "a discharge of high insulation and large particles of dust in accumulation state is the igniting source of powder cloud" (M.G lor. 1998) [1] has been confirmed. It is warned that "when dealing with a product which produced high potential and was rounded in the midst of explosive atmosphere, the chance of explosion would be maximized". However, because of insufficient investigations on the electrostatic produced by pneumatic conveying powder and the controlling technology, domestic powder silo electrostatic explosion accident sporadically occurs. For instance, the powder silo of the LDPE device of a factory had exploded 13 times between 1987 and 1998. The powder silo of the PP device of a factory had exploded 14 times between 1989 and 1994. The powder silo of HDPE device of a factory had exploded 12 times between 1989 and 2002 [2]. The reason why there are so many accidents during that period can be gained from following factors: firstly, defective designed devices, inadequate ability of processing gas, and hidden danger of the silo (72% of 70 accidents are related to design defect); secondly, insufficient emergency treatment for

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abnormal reaction, gas recovery and bunker ventilation equipment failure; finally, insufficient improvement of the gas recovery facilities and ventilations when promoting production capacity.

Although quantity of accidents caused by the petrochemical dust explosion has declined over the past decades, it still can be concluded from 11 cases [3] that the accidents are related to mistakes in complex process control. To avoid electrostatic explosion of the silo, it is necessary to investigate the risk of the electrostatic phenomenon caused by pneumatic conveying powder besides of strengthening regulatory of process control.

2. The electrostatic phenomenon of powder pneumatic conveying and the risk of blasting

2.1. The electrostatic phenomenon of the powder pneumatic conveying

The powder pneumatic conveying is influenced by many factors. Previous studies have indicated that the particle size is influenced by physical properties, such as the wind speed and sending capacity, air humidity, wall thickness, and roughness attachments. It is difficult to use quantitative characteristic parameters to forecast the lightning phenomenon, but the field statistic data may be significant. By simulation experiments, we collected electrostatic data of more than 200 silos conveying, including dilute phase conveying and dense phase conveying (bolt type). The major phenomena are as follows:

(1) The electrostatic phenomenon of powder silo conveying depends heavily on region and equipment. Typical data of six powder pneumatic conveying devices is listed in Table 1. These devices come from various regions of China. There are both positive and negative polarities in these data, most of which range from 0.8 to 5.8 μC kg⁻¹.

(2) Properties of the silo also have impact on the electrostatic phenomenon of powder silo conveying. As it is shown above, there are 16 silos for the LLDPE of a factory, 11 of which have their amplitude below 1.0 μC kg⁻¹, 2 in 1 ~ 2 μC kg⁻¹ and 2 in 2 ~ 4 μC kg⁻¹.

(3) The amplitude of electrostatic phenomenon keeps stable. Table 2 lists a random testing data of a LDPE suction silo in 10 months. Static electricity of A silo is -0.51 ~ -2.16 μC kg⁻¹. Static electricity of B silo is -0.5 ~ -1.2 μC kg⁻¹.

| Set                   | Bin number |
|-----------------------|------------|
| Yzbeta PP             | TK2505     |
| Fuxun PP              | D902       |
| KingSun 1PE           | OT-401     |
| YanHua LDPE           | OH-251     |
| Metallocene ethylene LDPE | V4264 |
| Wide ethylene LLDPE   | D6001      |

| Standard (m) | Specific charge (μC kg⁻¹) | Tapered discharge critical value (μC kg⁻¹) | D2 Trace value (μC kg⁻¹) |
|--------------|--------------------------|------------------------------------------|--------------------------|
| Yzbeta PP TK2505 | 6×21                     | 3.7                                      | 0.09                      | 0.24                     |
| Fuxun PP D902  | 2×15                     | 5.8                                      | 0.28                      | 0.72                     |
| KingSun 1PE OT-401 | 4.4×18                  | 2.0                                      | 0.14                      | 0.36                     |
| YanHua LDPE OH-251 | 4×18.5                  | 0.81                                     | 0.14                      | 0.36                     |
| Metallocene ethylene LDPE V4264 | 3.6×17           | 2.56                                     | 0.15                      | 0.40                     |
| Wide ethylene LLDPE D6001 | 5×21                | 3.6                                      | 0.11                      | 0.29                     |
Table 2. Electrostatic data on a factory's LDPE feeding tube of suction silo.

| Time       | Environment temperature (°C) | Environment temperature (%RH) | Electrostatic value (μC kg⁻¹) |
|------------|-----------------------------|--------------------------------|-----------------------------|
|            |                             |                                | A silo | B silo | C silo | D silo |
| 1995.8.16  | 28.5                        | 75                             | -1.22  | -0.83  | -1.05  | 0.27   |
| 9.1        | 76                          |                                | -0.61  | -0.95  | -1.10  |        |
| 9.16       | 72                          |                                | -0.91  | -0.5   |        |        |
| 9.26       | 63                          |                                | -2.16  | -0.99  |        |        |
| 9.27       | 65                          |                                | -2.05  | -1.07  |        |        |
| 9.28       | 72                          |                                | -1.77  | -1.12  |        |        |
| 9.29       | 76                          |                                | -1.27  | -1.20  |        |        |
| 11.24      | 42                          |                                | -0.51  |        |        |        |
| 12.12      | 16                          |                                | -1.09  |        |        |        |
| 1996.2.7   | 10                          | 54                             | -0.39  | 0.27   |        |        |

Figure 1. The data of conveying static electricity of a factory’s HDPE set.

(4) Compared to dilute phase conveying electrostatic, density phase has higher amplitude. As dense phase transportation is a new technology which was introduced several years ago, experimental data are rare. In the past, it was speculated that their static electricity may be smaller. However, the field data shows that it is incorrect to forecast the electrification according to the dilute phase electrification phenomenon. If dilute phase pressure is small, and the wind speed is high (more than 40 m s⁻¹), the pellets are "jump waft"; if dense phase pressure is big, and the wind speed is not very high (more than 10~15 m s⁻¹), it is a sand dune type waft. Figure 1 shows the measured data of conveying static electricity of 5 HDPE powder silos (bolt type) of a factory. The amplitudes fluctuate between -1 and -4 μC kg⁻¹. Table 3 lists the statistical data of powder silo conveying static electricity of 4 LDPE (bolt type). The conveying static electricity fluctuates more in blending operations, and it is more dangerous.
For comparison, Figure 2 plots the data of dilute phase conveying static electricity of 2 LLDPE devices. The data fluctuates relatively less.

Table 3. The data of static electricity of HDPE set powder silo conveying (bolt type).

| Powder silo       | Number of measurements | Charged range (μC kg⁻¹) | Average (μC kg⁻¹) |
|-------------------|------------------------|-------------------------|-------------------|
| D5301A (Feed)     | 10                     | -0.31～1.04             | -0.69             |
| D5301B (Feed)     | 10                     | -0.33～-1.28            | -0.627            |
| D5301C (Feed)     | 10                     | -0.48～-2.43            | -1.038            |
| D5301D (Feed)     | 10                     | -0.47～-1.30            | -0.635            |
| D5301A (Small-doped) | 10                 | -0.38～-1.17            | -0.758            |
| D5301B (Small-doped) | 10                  | -0.25～-1.55            | -0.572            |
| D5301C (Small-doped) | 10                  | -0.3～-1.90             | -0.802            |
| D5301D (Small-doped) | 10                  | -0.49～-1.76            | -0.953            |
| D5301A (Large-doped) | 3                   | -3.65～-4.5             | -4.2              |
| D5301B (Large-doped) | 5                   | -0.45～-0.91            | -0.754            |
| D5301C (Large-doped) | 10                  | -0.48～-2.52            | -1.38             |
| D5301D (Large-doped) | 6                   | -0.67～-1.08            | -0.855            |

Figure 2. The data of static electricity of dilute phase conveying of 2 LLDPE sets.

2.2. Powder silo electrostatic dangerous analysis
Conical discharge on the surface of the stockpile is more possible amount all forms of discharge. Energy coming from discharge is a function of the powder silo diameter \((D)\) and particle diameter \((d)\). The upper limit value of 3m diameter silo can be expressed by \(W = 5.22D^{3.36}d^{1.462}\). Such discharges can ignite miscellaneous mixed dust which contains gas, or combustible dust with the minimum
ignition energy \((MIE) \leq 10\ \text{mJ}\). We can make use of a simple calculation \(E = \frac{\rho R}{2\varepsilon_0}\) of the silo farm or computer software (FDCS) to estimate the conditions of discharge. Assuming that there is a cone-shaped discharge conditions when the electric field strength is larger than 3 MV m\(^{-1}\). The calculated data in Table 1 is from FDCS by different materials and different sizes of a silo in the tank wall and the center of the tank, with the charge to mass ratio critical value of \(E > 3\ \text{MV} \ \text{m}^{-1}\). The result shows that in 3 ~ 6 m diameter polyolefin silo, if the material charge for quality is between \(-0.1\) and \(-0.36\ \mu\text{C kg}^{-1}\), the surface of the stockpile can generate "linear" or "planar" conical discharge. The electric field distribution of the surface of the stockpile is illustrated in Figure 3. It is a factory 1PE silo.

![Figure 3](image)

**Figure 3.** The surface of the stockpile electric field and potential calculation model.

If the charged material heap plane of the metal protrusions, including clean air damper mouth, level meter, the mixing tube or cutting tube mounting bracket, concentrated discharge can occur. This kind of discharge can ignite combustible dust with \(MIE \leq 30\ \text{mJ}\). Figure 4 shows the data of potential distribution of simulated silo wall. The experiments show that when the material charge is more than \(1.65\ \mu\text{C kg}^{-1}\), and from the silo wall 170 mm at the stockpile surface potential is equal to or larger than 40 kV, metal protrusions discharge can ignite the dust with \(MIE \leq 30\ \text{mJ}\) or miscellaneous mixed dust.

![Figure 4](image)

**Figure 4.** Surface potential distribution of the different charged powders in silos.
If the silo wall with sticky wall material or coating ($\delta = 4 \sim 8$ mm), or silo mixing tube stent, or purify the air damper mouth, is buried, complex material surface effects will accumulate because more charge of the back electrode can be induced by the distributed brush discharge. The discharge energy can be from several hundred to thousands mJ and can ignite most of polyolefin dust. If the insulated conductors of silo are not grounded, or there are ungrounded fasteners, broken pipe, or shedding parts caused by design shortcomings or improper maintenance in the silo, hundreds mJ of spark discharge may be induced. That can ignite most polyolefin dust.

3. Analysis of the combustible gas in powder hopper and its ignition danger

Every polyolefin powder processing device has a combustible gas processing unit which has two main functions. One is the process before granulation, in which the unreacted gas is extracted and recycled. The other one is the process after granulation, in which the gas is purged and emptied. When the reaction is abnormal, such as the gas processing equipment fails to work, or hopper's ventilation has something wrong etc., the overflowing gas in the hopper is extraordinary, gas concentration in dust space will increase and the minimum ignition energy of a mixture will decline. Finally, dust explosion will occur. For example, in the survey of 70 accidents, 60 accidents (about 86%) are caused by gas control failures.

![Figure 5. Analysis curves of combustible gases within the silo.](image)

Figure 5 illustrates a detection data of LDPE exhaust hopper gas from a factory. Because of the bad design of back flush clean wind (24m$^3$ min$^{-1}$), the safe value is only 50% of theory. There are 14 explosions occurring in exhaust hopper, admixture hopper, and unqualified hopper in 4 years. As another example, a PP equipment in a factory was expanded and reconstructed. Dryer N2's pressure decreased from 0.6 MPa to 0.2~0.4 Mpa. Materials volatile increased to 2000~3000 ppm, which were larger than the design value of 1000 ppm. As a result, 11 explosions occurred in the admixture hopper in four years.

Figure 6 illustrates experimental data of LDPE dust and ethylene gas mixture's minimum ignition energy from a factory. The dust MIE collected in spot is 15.6 mJ. When the ethylene concentration in the mixture increases to 0.6 %Wt, the MIE of the mixture is 10 mJ. The experimental data is very close to the calculated value (curve1) recommended by CIBA. The experiment shows that with the increase of gas concentration, MIE of the mixture declines at an exponential rate. When the gas concentration is 0.5 %Wt, MIE of the mixture is 10mJ. Even if conical discharge occurs, the probability of ignition still exists. The higher the gas concentration is, the higher the chance for ignition will be. This is the main reason for the increasing hopper explosions when gas control fails in spot.
4. Research on the elimination of static electricity in powder pneumatic conveying

In order to suppress the electrostatic explosion of powder hopper, relevant norms at home and abroad recommend the use of ion wind static eliminator. Relative to the gas control and dust control in spot, the practicality and operability of this measure are much better. Unbalanced bipolar ion wind static eliminator is a new technology and now has become more and more famous. Figure 7 shows the experimental data on the 50 mm pipeline simulator. The experiments show that the efficiency of electrical elimination of the unbalanced bipolar control is superior to the AC and DC mode. By the experiments, the conclusion of [4], which says that ion wind static eliminator must be supplemented by the online monitoring. That means this method avoids not only the risk operation of "reverse charged", but also the requirement of realizing the high eliminates electrical efficiency for the large hoppers demand. Since 2003, we have used the unbalanced bipolar ion wind static eliminator with online monitoring and feedback regulation. We tested it in 19 sets of devices and 167 hoppers, and we are very satisfied with the experience and effects.
Figure 8. A corporate silo elimination electrical of two sets of PE usage.

Figure 9. A corporate silo elimination electrical of a set of HDPE usage.

Table 4. Test data of electrostatic elimination of two sets of LDPE plant silo (dense phase) in an enterprise.

| Powder silo | 1PE451A/D | 1PE2451A/D | 1PE3451A/D | 2PE8011/80 |
|------------|-----------|------------|------------|------------|
| Quantity   | 4         | 4          | 4          | 6          |
| Before electrostatic elimination | Charged range (μC kg⁻¹) | -2.62~7.49 | -1.67~5.1 | -1.04~3.0 | -0.6~1.4 |
| Average (μC kg⁻¹) | -4.585 | -3.357 | -2.14 | -0.766 |
| After electrostatic elimination | Charged range (μC kg⁻¹) | -0.01~0.14 | -0.01~0.12 | -0.02~0.18 | -0.03~0.17 |
| Average (μC kg⁻¹) | -0.07 | -0.067 | -0.097 | -0.071 |
| Electrostatic elimination efficiency (%) | 98 | 95 | 91 |

Figure 8 is an application example of two PE plants (dilute phase conveying) of a factory in South China. Figure 9 is an application example of the HDPE plant of a factory in North China. Table 4 and
Table 5 list the statistics of them. It can be concluded that the technology can be used to eliminate non-equilibrium bipolar ion wind static electricity under electric charge online monitoring and feedback control. The efficiency of the elimination of electric charge is basically more than 90%. We can achieve management objectives of no-spark discharge and operate requirement of instrument management.

| Powder silo         | Before electrostatic elimination | After electrostatic elimination |
|---------------------|----------------------------------|---------------------------------|
|                     | Charged range (μC kg\(^{-1}\))   | Average (μC kg\(^{-1}\))       | Charged range (μC kg\(^{-1}\)) | Average (μC kg\(^{-1}\)) |
|                     | -1.06〜-3.73                     | -1.83                           | -0.03〜-0.25                     | -0.128                      |
|                     | -0.93〜-2.93                     | -1.55                           | -0.06〜0.2                       | 0.126                       |
|                     | -0.76〜-2.89                     | -1.89                           | 0.03〜0.19                       | 0.09                        |
|                     | -1.04〜-2.99                     | -1.69                           | 0.02〜-0.15                      | 0.113                       |
| Electrostatic elimination efficiency (%) | 93                              | 92                              | 95                              | 93                          |

5. Conclusions
(1) Petrochemical powder hopper dust explosion occurred in the past is confirmed by on-site investigation and testing. The vast majority of the powder pneumatic is related to the conveying of electric discharge. The failures of gas control and dust control in the manufacturing process are induced by external causes of the accident. However, it is difficult to control and easy to affect. (2) The conveying electrostatic phenomenon of powder dense phase pneumatic (bolt) fluctuates more easily than the dilute phase pneumatic. (3) In the dilute phase and dense phase pneumatic conveying process pipelines, online monitoring and timely control of non-equilibrium bipolar ion wind static eliminator help to achieve the ideal goal of discharging without spark. (4) The production process lost control or with a temporary failure is most dangerous for the dust electrostatic explosion frequency. That includes dealing with substandard material or transitional material, the production of high-melting grades of resigning material containing high-boiling gas-liquid materials (which includes raw material gas, catalyst, thinner, cold-induced, etc.), degassing equipment or ventilation equipment failure, granulator cutting knife or templates badly worn, metal off pieces or mixing tube breaking in the warehouse, and the temporary stop or start early etc.

Above period is not only prone to the flammable explosive atmospheres, its static electricity from powder is most unstable. The hopper is easy to produce an electrostatic discharge and dust explosion. The application of practice proved that the non-equilibrium bipolar ion wind static elimination is the final barrier to prevent dust explosions.

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