Charging Characteristics of Sulfur powder in Elbow of Pneumatic Conveying System

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Abstract: Eliminating static electricity is a difficult thing for pneumatic conveying. In this paper, the most representative powder sulfur is selected as the research object. Therefore, in order to study the influence of pipe elbows on the charging characteristics, pneumatic conveying experimental platform was applied to conduct experiments to investigate the synergistic effects of airflow velocity, particle mass flow rate, particle water content and particle size on the charge characteristics, and the optimal ratio of elbow was designed. The results show that, when the particle size was constant, the charge-mass ratio increases with the increase of the airflow velocity, showing a linear positive relationship and increases firstly and then decreases with the increase of mass flow. When the airflow velocity was constant, particles were -40 μm, the effect of particle size on the charge-mass ratio becomes more significant. When the particle size was +40 μm, the charge-mass ratio of sulfur powder increases with the decrease of particle size, the influence is not notable. When the mass flow kept constant, the charge-mass ratio of sulfur powder increases as the particle size decreases. When the water content increases from 0 to 0.4%, the charge-mass ratio decreases by 14.3%-16.9%. However, if the water content continues to increase, the charge-mass ratio is stable. The charge-mass ratio of sulfur powder decreases with the increase of the bend ratio of right-angle elbow. As the technological layout is satisfied, the bend ratio can be increased to the range from 2.5D to 3D appropriately. This research can give reference to the design of sulfur powder pneumatic conveying system, so that the reasonable system ratio can be ensured.

1. Introduction
To improve conveying efficiency, pipeline pneumatic is usually applied to conveying superfine powder products in the dry grinding Sulphur industry. During the conveying process, the sulfur powder particles collide with the inner wall of the curve continuously, which results in generating static electricity easily, especially in the pipe elbows [1-3]. Sulfur powder belongs to high-resistivity material. Once static electricity is generated in the process of transportation, it is difficult to guide it away [4-5]. As the production continues, the static electricity of the particles will accumulate, forming a strong electrostatic field, which may lead to electrostatic sparks, burning sulfur powder and occurring dust explosion accident. In addition, the agglomeration of sulfur powder caused by static electricity will also cause blockage of the conveying system, and normal production would be finally affected [6].

In view of the charge characteristics of fluidized powders, Bafnec et al. [7] proved that the
increase of fluidized gas velocity makes the electrostatic pressure of fluidized bed rise. But most of the researches investigate the electrostatics characteristics in gas-solid fluidized bed qualitatively, lacking reliable experimental data. Masuda et al. [8] studied the static electricity generated by the collision of elastic spherical particles with metal plates. It was found that the impact velocity, contact area, initial electric and the number of impacts of the particles all have regular effects on the static electricity generation. Juray et al. [9] applied LDA to investigate gas solid mixing in the inlet zone of a dilute circulating fluidized bed. However, these investigations focused on the interaction between particles and turbulence in full-developed regime of dilute phase suspension pipe flow. Researches [10-12] also pointed out that the increase of environmental humidity can reduce the charged capacity of particles effectively. However, the mechanism of static electricity during particle pneumatic conveying is very complicated. At present, the research on the charging characteristics of powder in the process of pneumatic conveying elbow system has not been found. Recently Yan and Rinoshika [13] used PIV to measure the time averaged velocity and concentration of particles in a two-phase pipe flow. However, little attention has been paid to the dynamics of solid particles from fully-developed to acceleration-regime in the relatively dense-phase, which will provide fundamental information on the pneumatic conveying, thus motivating the present work.

In this study, self-developed pneumatic conveying experimental platform was applied to conduct experiments to investigate the synergistic effects of airflow velocity, particle mass flow rate, particle water content and particle size on the charge characteristics of sulfur powder. Meanwhile, the effect in the bend ratio of right elbow on the charge of sulfur powder was also studied, which may provide theoretical reference to industrial application.

2. Experiment

2.1 Saturated static electricity

During the process of multiple frictional collisions, the amount of static electricity will gradually increase at first, and then tend to be stable. This certain value is called saturated static electricity. The amount of electricity obtained per unit mass of particles during static electricity generation [14-17] can be calculated as follows.

\[
\frac{dQ}{dt} = \frac{1}{\tau} (kV_{\text{particle/wall}} - \frac{Q}{\tau}) \quad (1)
\]

Where, \( t \) is contact time between particles and metal wall, \( \tau \) is Static electricity time, \( k \) is constant of proportionality, \( \tau_r \) is ESD release time, \( V_{\text{particle/wall}} \) is Potential difference between particles and metal wall. \( \frac{dQ}{dt} \) is the amount of static electricity generated by particles during a frictional collision, the behind equation is the amount of escape that occurs simultaneously during the generation of static electricity. When \( \frac{dQ}{dt}=0 \) means the amount of static electricity is in a steady state, at this time, it is not changing and considered to be saturated:

\[
Q_{sat} = kV_{\text{particle/wall}} \frac{1}{1 + \frac{\tau}{\tau_r}} \quad (2)
\]

2.2 Experimental materials and equipment

The raw material is Powder sulfur (Moisture content of wet base ≤0.051%, Initial charge-to-mass ratio ≤0.019 nc/g)

The experimental condition is temperature is 19-20°C, air relative humidity is 51- 53%. The experimental equipment is LNIST-180A model self-developed Experimental apparatus for pipeline pneumatic conveying of sulfur powder in Figure 1.
The experimental apparatus for pipeline pneumatic conveying of sulfur powder

Fig. 1 Experimental apparatus for pipeline pneumatic conveying of sulfur powder

The experimental is consisted of a miniature vibratory feeder, pipe, dust collector and a draught fan. Miniature vibratory feeder has inverter, removable stainless-steel right-angle elbow (shown in Figure 2).

Testing instruments is consisted of Laser particle size analyzer LS-13320, Anemometer SwemaAir 50, Digital charge meter JCI-178(range: 0 ~ 200 nC, have JCI-150 faraday tube), Electrometer blower dryer GZX-9070MBE, Temperature and Humidity measuring instrument.

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2.3 Experimental process

In this study, self-developed pneumatic conveying experimental platform was applied to conduct tests. Operation parameters (Our team had ensured the parameters [18]) are listed Table 1 (Mianyang, Liuneng, Powder Equipment Co., Ltd.). In experiments, a variable frequency micro vibration feeder was used to control the feeding speed, and sulfur powder was evenly sent to the pipeline through the feeder. By using pneumatic conveying, static electricity was generated by friction and collision between right-angle elbow and inner wall of elbow. Finally, sulfur powder was collected by the bag filter, and the entire system is in a negative pressure state. A sampling point was set at the inlet of the bag filter. A silencer was set at the outlet of the induced draft fan so that the running noise of the system is no more than 90 dB. Record the feeding time per kilogram of sulfur powder with a stopwatch, adjust the system flow with the inverter of the induced draft fan. Anemometer Swema Air 50 is used to test pipe inlet wind speed. Digital charge meter JCI-178 and high precision electronic balance is tested charge mass ratio.

In order to ensure the accuracy of the experiment, all the experimenters wore insulated gloves. For each set of experiment, six values were tested and the average was calculated as charge-to-mass ratio of sulfur powder. 11.36 m/s, 15.51 m/s, 21.20 m/s, 26.63 m/s, 31.73 m/s, 34.12 m/s
Table 1. Design parameters of tests

| Parameters                      | Values                                      |
|---------------------------------|---------------------------------------------|
| Airflow velocity                | 11.36, 15.51, 21.20, 26.63, 31.73, 34.12 m.s⁻¹ |
| Bend ratio                      | R=1.5D, R=2D, R=3D, R=4D                    |
| Mass flow                       | 0.10, 0.15, 0.20, 0.25, 0.30 kg.min⁻¹       |
| Particles size                  | d₉⁷=20.95 µm, d₉⁷=31.18 µm, d₉⁷=43.56 µm, d₉⁷=52.08 µm, d₉⁷=62.88 µm |
| Water content                   | 0, 0.2%, 0.4%, 0.6%, 0.8%, 1.0%, 1.2%      |

3. Results and discussion

3.1 Synergistic effect of airflow velocity and particle size on the charge characteristics of sulfur

Figure 3 showed the effect of airflow velocity and particle size on charge characteristics of sulfur powder.

Observed from Figure 3, when the particle size was 62.88+29.69 µm, airflow velocity was between 11.36 and 34.12 m/s, the range of charge-mass ratio of sulfur powder was from -1.02 to -3.96 nC/g. When particles kept constant, the charge-mass ratio of sulfur powder increases with the increase of the airflow velocity, and showing a linear positive relationship. At a certain airflow velocity, the charge-mass ratio of sulfur powder increases with the decrease of particle size. When particles are larger than 40 µm, the growth rate becomes slower. When particles finer than 40 µm, the growth rate is rapid, and the effects of particles on the charge-mass ratio become more significant. The main reason for this is that, when the airflow velocity is small, the acceleration obtained by the large particles is lesser, the momentum of larger particles is lesser than that of finer particles, the specific area of larger particles is smaller, so the charge-mass ratio is smaller relatively. For particles less than 40 µm, as the particles are finer, the contact area between the finer particles increases. When colliding with the elbow wall, particles have greater momentum and the charge-mass ratio increases rapidly. As the airflow velocity increases, the momentum when the particles collide with wall is greatly affected by the airflow velocity. Therefore, the difference between the charge-mass ratio further increases.

3.2 Synergistic effect of mass flow and particle size on the charge characteristics of sulfur powder

Figure 4 showed the effect of mass flow and particle size on charge characteristics of sulfur powder when the airflow velocity was 15.51 m/s and the bend ratio of right elbow R was 2D.

Observed from Figure 4, as the mass flow was constant, the charge-mass ratio of sulfur powder
increases with the decrease of particle size. When the particle size was constant, the charge-mass ratio increases firstly and then decreases with the increases of mass flow rate. When particles are finer than 40 μm, the charge-mass ratio of sulfur powder reaches the maximum at the mass flow of 0.15 kg/min, which was -2.48 nC/g. When particles larger than 40 μm, the charge-mass ratio of sulfur powder reaches the maximum as the mass flow of 0.20 kg/min, which was -1.72 nC/g. The reason for this is that, at a constant mass flow, the finer particle had more suspended particles per unit volume, the random collision of particles in the pipeline was more intense, the more collisions occur, lead to an increase in the charge-mass ratio of sulfur powder. The number of suspended particles per unit volume continues to increase as the size of particle further decreases, which leads to less chance of each particle collides within the pipe, then the electric charge per unit mass begins to decrease.

![Fig.4 The cross-impact of mass flow rate and particle size on the charge-to-mass ration of sulfur powder](image.png)

3.3 Synergistic effect of water content and particle size on the charge characteristics of sulfur powder

The effect of water content and particle size on charge characteristics of sulfur powder is illustrated in Figure 5.

As the water content of sulphur powder increases from 0 to 0.4%, the charge-mass ratio of sulphur powder decreases at remarkable rate of reduction, by 14.3%~16.9%. The water content continues to increase, the rate of decrease of the particles finer than 40 μm is slower. For particles larger than 40 μm, the charge-mass ratio is stable and does not change. The reason for this is that, sulfur powder belongs to a high-resistance material. During the pneumatic conveying process, it collides with the inner wall of the pipeline and is easy to generate static electricity, so a large amount of static electricity cannot escape. When the water content of sulfur powder particles increases to 0.4%, the surface of sulfur particles will form a water film because of the hydrophobic property of sulfur, which contains impurities and solubility, and can reduce the surface resistance of electrostatic carriers rapidly, accelerate the escape and leakage of static charges. The water content continues to increase, the electrical resistivity of sulfur powder particles was not obvious. When the generated static electricity and the dissipated static electricity reach an equilibrium value, the charge-mass ratio of sulfur powder hardly changes as the water content continues to increase. For powders which are prone to static electricity, it is an effective and low-cost method to reduce the static electricity of the powder by increasing the water content without affecting the properties of the material, but the amount of water content is not as high as possible. The deterioration of the fluidity of the powder caused by the increase in the water content of the particles also needs to be considered.
3.4 Synergistic effect of airflow velocity and bend ratio on the charge characteristics of sulfur powder

The size of the bend ratio directly affects the structure of the pipe elbow. In this experiment, the right-angle elbow of bend ratio was set from 1.5D to 4.0D to analyze the influence of right-angle elbow on the charge-mass ratio of sulfur powder, the experimental results are shown in Figure 6.

From Figure 6, when bend ratio was constant, a larger airflow velocity would lead to a larger charge-mass ratio. When the airflow velocity was constant, the charge-mass ratio of sulfur powder decreased gradually as the bend ratio increased and finally tended to be stable. The smaller bend ratio is, the smaller influence of the airflow velocity on the charge-mass ratio.

In the early stage of pneumatic conveying, the right-angle elbow of bend ratio as high as 8 to 24 \[^{19-20}\]. Unlike the traditional pneumatic conveying, the collection system of sulphur powder conveying adopts integrated equipment. The connection and layout between the conveying pipeline and the collecting system have strict requirements. It is impractical to use large bend ratio just to reduce the charge-mass ratio, it will increase the cost of equipment, cause the inconsistency of the spatial arrangement of the entire equipment, and also cause inconvenience to equipment control and product collection. Therefore, when the airline velocity was less than 16.07 m/s, the right-angle elbow of bend ratio was 2D. When the airline velocity is higher than 16.07 m/s and less than 30.14 m/s, the optimum bend ratio is 3D. If the airline velocity was increased, the bend ratio should be increased accordingly to ensure that the charge-mass ratio of sulfur powder is not increased rapidly.
4. Conclusions
In this study, we numerically investigated charging characteristics of sulfur powder in elbow of pneumatic conveying system. The conclusions drawn from this experimental study are summarized as follows:

1) In right elbow, when the particle size is constant, the charge-mass ratio of sulfur powder increases with the increase of the airflow velocity, showing a linear positive relationship. The charge-mass ratio increases firstly and then decreases with the increase of mass flow. When the airflow velocity is constant, the charge-mass ratio of sulfur powder increases with the decrease of particle size. For particles finer than 40 μm, the effect of particle size on the charge-mass ratio becomes more significant. when the particle size is larger than 40 μm, the influence is not obvious. The charge-mass ratio of sulfur powder increases as the particle size decreases when the mass flow keeps constant.

2) The static electricity of sulfur powder can be effectively reduced by increasing the water content. When the water content of sulphur powder increases from 0 to 0.4%, the charge-mass ratio of sulphur powder decreases by 14.3%~16.9%. If the water content continues to increase, for particles finer than 40 μm, the charge of the rate of decrease is slower, while that of particles larger than 40 μm is stable and does not change.

3) The charge-mass ratio of sulfur powder decreases with the increase of the bend ratio of right-angle elbow. When the airline velocity is less than 16.07 m/s, the right-angle elbow of bend ratio is 2D, the charge-mass ratio of sulfur powder is reduced 22% than bend ratio is 1.5D. When the technological layout is satisfied, the bend ratio can be increased to the range from 2.5D to 3D appropriately if the airline velocity increases continuously.

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