Research and Optimization Design of Mixing Characteristics of High-speed Centrifugal Mixer Based on DEM

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Abstract. Aiming at the special production process of an environmental protection building material, a new mixing equipment, high-speed centrifugal mixer, was designed. In this paper, the mixing characteristics of high-speed centrifugal mixer were studied by using discrete element method (DEM). By constructing the contact model and establishing the evaluation system, the mixing process was simulated and analyzed by EDEM software, and the mixing situation of the two raw materials in the centrifugal mixer was obtained. At the same time, according to the two important factors affecting the mixing results, the comparative experimental analysis was carried out under different conditions, and finally the optimization suggestions for the equipment were put forward.

Keywords: DEM; high-speed centrifugal mixer; mixing characteristics; EDEM.

1. Introduction
Mixing is an important process link in industrial production. In the design process of mixing equipment, we need to constantly use theory and practice to produce the mixing equipment with the highest mixing efficiency and most in line with the actual production conditions. Similarly, cost, energy saving and efficiency also need to be considered (Wang et al., 2000). There is a new type of lightweight environmental protection wallboard, which mainly uses industrial waste (desulfurized gypsum, fly ash, etc.) as the main production raw materials. The raw materials are granular materials, and the mixing uniformity of raw materials is closely related to the product performance of wallboard. For this product, a high-speed centrifugal mixer has been designed. In this paper, the mixing characteristics in the production process of environmental protection wallboard were studied by using the discrete element method, and the mixing equipment was optimized to help improve the production stability and product performance of the product, so as to promote the development of building environmental protection industry.

2. Research Method of Mixing Uniformity

2.1. Numerical Analysis Method
Numerical simulation method is an important means to study the mixing process. It can accurately and efficiently predict the material trajectory and greatly reduce the development cost of equipment. At
present, there are two main research methods for simulating particle behavior: one is computational fluid dynamics (CFD) method (Ning et al., 2016) and the other is discrete element method (DEM) (Moakher et al., 2000).

The discrete element method (DEM) is suitable for solving discontinuous media problems or material failure problems, which was proposed by Cundall (1971). This method divides the discontinuous body into several rigid elements, and reveals the influence of the interaction between particles on each other and the whole. In China, DEM was first introduced in the engineering field (Wang et al., 1995). At the beginning, it was used by scholars to solve the problems of slope edge and rock dynamics in the rock field. For example, the opening process of joint surface caused by slope excavation was numerically simulated by discrete element method (Li et al., 2002). Later, it has been applied to powder technology in engineering, and has been applied to a variety of equipment, such as vertical mixer, horizontal mixer, powder mill, etc.

In the simulation study, the mixing efficiency of ribbon mixer was studied by discrete element method, and numerical simulation was carried out (Basinskas et al., 2016). A complex mixing equipment was simulated by discrete element method, and it was obtained that the mixing uniformity first decreased and then increased with the increase of mixing speed (Lemieux et al., 2008). The flow of dry and wet particles in the mixer was simulated by DEM, and it was found that the mixing characteristics of dry and wet particles were very different (Radl et al., 2010).

2.2. Build Particle Contact Model

Contact model is the core of discrete element method. The raw materials of desulfurized gypsum particles and fly ash particles in the mixing process are analyzed, and the spring-damping-vibration model in the contact process of the two particles is constructed.

\[ m \ddot{x} + c \dot{x} + kx = 0 \]  
(1)

Where \( x \) is the displacement of deviation; \( m \) is the mass of the vibrator; \( c \) and \( k \) are spring damping coefficient and elastic coefficient respectively.

The normal vibration motion equation is:

\[ m_{ij} \cdot \frac{d^2 u_n}{dt^2} + c_{n} \cdot \frac{du_n}{dt} + K_n u_n = F_n \]  
(2)

Tangential sliding and rolling between particles constitute the tangential vibration motion equation:

\[ m_{ij} \cdot \frac{d^2 u_t}{dt^2} + c_{s} \cdot \frac{du_t}{dt} + K_s u_s = F_s \]  
(3)

\[ I_{ij} \cdot \frac{d^2 \theta}{dt^2} + \left( c_{s} \cdot \frac{du_t}{dt} + K_s u_s \right) s = M \]  
(4)

Where \( m_{ij} \) is the equivalent masses of particles \( i \) and \( j \); \( u_n \) and \( u_t \) are normal and tangential relative displacements; \( c_n \) and \( c_s \) are normal and tangential damping coefficients, \( F_n \) and \( F_s \) are components of external force in normal and tangential directions; \( I_{ij} \) is the equivalent moment of inertia of particles \( i \) and \( j \); \( \theta \) is the particle rotation angle; \( s \) is the radius of rotation; \( M \) is the moment on the particle.
2.3. Construction Evaluation Method

In this study, the concept of coefficient of variation is quoted to establish an evaluation method of mixing uniformity. The sampling samples are \( n \) groups, the number of desulfurization gypsum particles in sample \( i \) is \( n_i \) and the total number of particles is \( N_i \), then the proportion \( p_i \) of desulfurization gypsum particles in sample \( i \) is:

\[
p_i = \frac{n_i}{N_i}
\]  

(5)

Index value of sample \( X_i \):

\[
X_i = \frac{p_i}{p}
\]  

(6)

Average value of sample index value:

\[
\bar{X} = \frac{1}{n} \sum_{i=1}^{n} X_i
\]  

(7)

Standard deviation:

\[
S = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (X_i - \bar{X})^2}
\]  

(8)

Coefficient of variation:

\[
C = \frac{S}{\bar{X}} \times 100\%
\]  

(9)

The coefficient of variation \( C \) reflects the stability of mixing degree in the high-speed centrifugal mixer. The smaller the coefficient of variation, the better the mixing uniformity.

3. Design of High Speed Centrifugal Mixer

The production process of wallboard is special. A small amount of water and additives need to be injected in the process of raw material mixing, which makes the mixed materials have strong adhesion and easy to condense into blocks in the process of standing. Therefore, the mixing equipment is required to quickly mix and discharge materials, and has self-cleaning function.

According to the design requirements, a high-speed centrifugal mixer is designed, and the simplified model diagram is shown in Figure 2. The utility model is mainly composed of an end cover, a mixing container, a revolving disc, a dispersion device and mixing tools. The end cover is provided with feed, and the bottom of the end cover is provided with annular water injection holes for injecting water into the mixing container, and the side wall of the mixing container is provided with a discharge port.

![Figure 2. Model diagram of high speed centrifugal mixer.](image)

Its working principle is shown in Figure 3: the materials enter from the feed port on the end cover and contacts with the conical dispersion device, so as to deviate from the center of the circle and fall on the high-speed rotating disc. The water injection hole at the bottom of the end cover begins to inject water. And the component of the friction force between the particles and the revolving disc forms a centrifugal force. Under the action of the centrifugal force, the materials accelerate to disperse to the inner wall of the mixing container, and contact with water in this process. The four types of mixing knives installed
on the revolving disc can mix and stir the particles in different areas and clean the materials attached to the inner wall. After the materials are mixed, they are finally sent out from the discharge port by the mixing knife installed at the bottom.

Figure 3. Working diagram of high speed centrifugal mixer.

4. Simulation Process and Analysis

4.1. Study on Mixing Characteristics

The simplified model of high-speed centrifugal mixer is introduced into EDEM, and the material is set as steel. Considering the calculation speed of computer, the particle size is appropriately enlarged to 5mm in this study. At present, the motion analysis of particles is carried out in the form of equal magnification in most studies. Relevant studies also show that properly enlarging the size of particles has little effect on the mixing results (Remy et al., 2009).

A cylindrical particle factory is set at the top feed port to simulate the feeding of particles. Desulfurization gypsum particles are generated on the left and fly ash particles are generated on the right. Each part generates 5000 particles per second, as shown in Figure 4. Since the content of additives and water is very small, it is ignored in the formation of particles. According to the wetting characteristics of materials, Hertz-Mindlin with JKR cohesion contact model is selected for analysis in the simulation.

The detection grid is set as shown in Figure 5 to record the change of the overall particle number in the mixer and the change of the particle number at the discharge port during the mixing process.

Figure 4. Mixing process. Figure 5. Particle detection grid.

The distribution of particles in the mixing container is shown in Figure 4. The material particles are mainly concentrated in the upper area of the mixing container, the main reason is that the particles are light. After contacting the inner wall, the particles are suspended under the high-speed rotation of the mixing tool. When the number of particles in the upper layer accumulates to a certain number, under the action of gravity, some particles settle and are sent out of the mixing container from the discharge port by the bottom blade. Therefore, it is inferred that the two factors affecting the mixing uniformity of materials are rotating speed and the height of the discharge port.

4.2. Influence of Rotating Speed on Mixing Uniformity

Simulate the mixing process of high-speed centrifugal mixer, set the rotating speeds of revolving disc as 200rpm, 300rpm, 400rpm, 500rpm and 550rpm respectively for comparative analysis. The change of particle number at the discharge port is recorded by detecting the grid. According to the calculation formula of variation coefficient of sample value, the curve of variation coefficient with time is obtained, as shown in Figure 6.
Judging from Figure 6, at the same time, the higher the speed, the lower the coefficient of variation of the sample value, and the closer the mixing uniformity is to the optimal mixing ratio. With the passage of time, the coefficient of variation will gradually become stable, which means that the mixing uniformity will become more stable. When \( t=16s \), the coefficient of variation at 200prm, 300prm, 400prm, 500prm and 550prm is close to 25%, 21%, 18%, 15% and 14% respectively. From the simulation results, selecting a higher speed is undoubtedly more favorable for industrial production, but when applied to the actual production process, the faster speed has higher requirements for the driving equipment, and the high-speed rotation will accelerate the loss of mixing tools and other parts. Considering comprehensively, since the variation coefficient changes little when the speed increases from 500prm to 550prm, it is recommended to set the speed as 500prm.

4.3. Influence of Discharge Port Height on Mixing Uniformity

The height of the discharge port of the mixer will affect the discharging time of suspended particles in the mixing container, thus affecting the mixing effect. In order to improve the mixing effect of mixing equipment, the models with different discharge port height were compared and analysed. Set the height of discharge port to 165mm, 145mm and 125mm respectively for simulation experiment, as shown in Figure 7.

In the simulation results, the variation coefficient at each time is calculated according to the calculation formula of variation coefficient of sample value, and its variation curve with time is shown in Figure 8. The simulation results show that the variation coefficients of sample values with discharge port heights of 165mm, 145mm and 120mm are finally stable at about 15%, 9.7% and 11% respectively. And the discharge port height is not inversely proportional to the coefficient of variation of the sample value. This shows that other factors in the mixing process need to be considered in the setting of the height position of the discharge port. The particles with the same particle size have different quality and different physical characteristics. When the height of the discharge port is reduced and adjusted to a certain height, the particles are affected by gravity, the particles with large mass settle faster and are relatively easy to separate from the discharge port. It can be concluded from this study that the height of the discharge port of the high-speed centrifugal mixer should be set according to the actual mixed substances. For the mixing of desulfurization gypsum powder and fly ash powder, it is suggested that the height of the discharge port should be set as 145mm.
5. Conclusion

(1) In this paper, the mixing characteristics of materials in high-speed centrifugal mixer were studied by discrete element method. The simulation results were obtained by numerical simulation, which verifies the working principle of high-speed centrifugal mixer.

(2) The speed and discharge port height of high-speed centrifugal mixer are the key factors affecting the mixing efficiency. The simulation experiments at different speeds were carried out, and the variation coefficient of particle proportion was calculated. Through data comparison and comprehensive consideration, the speed of mixer is determined as 500rpm; With the same method, the simulation experiments of different outlet heights are carried out respectively, and the experimental results are analyzed. Finally, it is determined that it is the most appropriate to adjust the outlet height to 145mm.

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