Discrete element simulation of the grain mixing law in brown rice germination device

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Abstract: The discrete element method (DEM) was used in this study to numerically simulate the mixing process and motion law of particles in brown rice germination device. And the reliability of simulation experiments was verified through physical experiments. In the discrete element simulation experiment, there were three mixing stages in the mixing process of the particles. The particle motion conditions at different rotational speeds were rolling, cascading, cataracting and centrifuging. The lower the filling degree, the higher the particle mixing efficiency. The radial trajectory of the particles was approximated as an elliptical helix that continuously shrank towards the axis. The research results indicated that under the same speed and filling conditions, the motion of brown rice particles in both the simulated and physical test environments is rolling and the drop height is the same.

Keywords: brown rice germination device tank, brown rice particles, discrete element method, motion law, mixing characteristics

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1 Introduction

Germinated brown rice is a whole grain food, rich in a variety of physiologically active ingredients[1-3]. At present, domestic and foreign scholars mostly use soaking method to produce germinated brown rice. During this process, brown rice absorbs water sharply, resulting in an increase in the rate of burst waist. It will ultimately affect the quality of germinated brown rice[4-7]. In recent years, the research group has proposed a new process for preparing germinated brown rice by cyclic humidifying and conditioning treatment. The process continuously humidifies the surface of the brown rice, and cooperates with the stirring treatment to make the brown rice reach the target moisture content for germination. The process of humidifying and conditioning brown rice is also the process of mixing brown rice particles. Its mixing uniformity directly affects the quality of germinated brown rice. Therefore, it is necessary to study the mixing process and motion law of brown rice particles in the tank of brown rice germination device.

At present, the structure and parameter design of brown rice germination device mostly depend on previous experience. The structural parameters and process parameters are determined through continuous experimental optimization[8]. Moreover, there are few researches on the tank body of the brown rice germination device matched with the circulating humidification process. The new brown rice germination device mainly makes brown rice contact with water through the operation of circulating humidification, and realizes brown rice tumbling by stirring, which drives brown rice to flow and makes brown rice moisture distribution even. The essence of the humidification and conditioning process of brown rice particles is the particle mixing process. Its mixing performance directly affects the humidification uniformity. At present, the particle mixing process is mainly predicted and evaluated by means of spectroscopy, particle image velocity method, etc[9]. However, the mixing process of particles in the tank of the brown rice germination device is very complicated. The results of most experiments cannot directly obtain the particle motion information and accurately evaluate the mixing uniformity of the particles in the tank[10,11]. The optimization design through continuous experiments also has problems such as money-consuming and time-consuming[12].

In recent years, with the development of information technology, the discrete element method has become an important means of studying particle mixing[4]. The discrete element method can be used to obtain information such as the speed and direction of a single particle. It can also directly reflect the motion law and characteristics of the particle group during the mixing process[13]. Quantitative analysis of mixing process and particle motion law is the theoretical basis for structural design and parameter optimization of germinated brown rice tanks[14]. In using the discrete element method to study and analyze the mixing of particles in the mixer, many scholars study the hybrid conditions of rotating the particles in the rotating drum through the discrete element method[15,16], divide the mixing area in the particles system in the drum, and explore the impact of speed and filling on hybrid performance[17,18]. For example, Li et al.[19] utilized numerical simulation methods to change the rotating drum size, rotational

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speed, particle filling level and other conditions to predict the mixing flow behavior of particles in the drum. The results showed that the speed would change the flow stat e of the particles in the drum and the high rotational speed could improve the mix of particles. To verify the accuracy of the simulation results, Wu et al.[20] studied the mixing degree of the rotating drum in the experimental environment and the discrete element simulation environment. The results indicated that the mixing degree in the stable mixing state was close between the experiment and the simulation. Santos et al.[21] used the discrete element method to describe the flow state of the particles in the rotary drum, and experimentally verified the flow behavior of the particles in the rotary drum. At present, there are few studies on the application of discrete element method to the mixing process of brown rice particles in the tank of brown rice germination device. The mixing characteristics of particles in the tank still need to be further studied.

The germinated brown rice is prepared by the method of the principle of cyclic humidifying and conditioning treatment, and the uniform mixing of brown rice particles during the humidification process is difficult to obtain in practical experiments. Therefore, in this paper, the discrete element method is used for the numerical simulation of the mixing process of brown rice particles in two typical brown rice germination device tanks. The mixing discrete element simulation system for brown rice particles is established. And the accuracy of the discrete element simulation results is verified through experiments. The mixing process and motion law of particles in the tank are studied. It provides theoretical reference for the optimal design of structural parameters of brown rice germination device.

2 Materials and methods

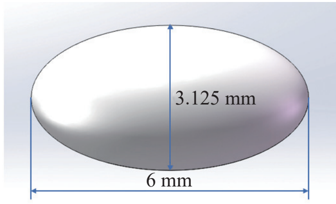
2.1 Numerical simulation system

Two typical brown rice germination devices were used for simulation experiments. The brown rice model selected in the experiment was Dongnong 429. The DL91150 digital vernier caliper with an accuracy of 0.01 was used to measure the long axis and short axis of 100 brown rice of rice. The long axis of brown rice ranges from 5.5 to 6.8 mm. The short axis of brown rice ranges from 2.6 to 3.1 mm. Each brown rice germination device tank was filled with long particle or short particle.

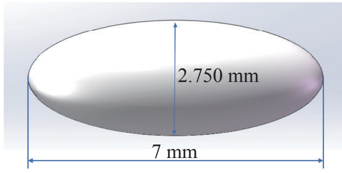
2.1.1 Numerical simulation system of blade brown rice germination device

The particles simulated in this study are brown rice with ellipsoid shape. In order to get similar brown rice particles models, it was filled with 5 different radius balls. Its short particles models and long particle models are shown in Figure 1. The particle density was 1538 kg/m^3. The particle shear modulus was 1.1×10^7 Pa. The Particle Poisson's ratio was 0.40.

The blade brown rice germination device tank consisted of three parts, namely tank shell, inner plate and central axis. The diameter of the tank was 1600 mm, and the length of the main mixing area was 1000 mm. There were straight panels and oblique boards in the cylindrical pillar and the two baffles were evenly distributed inside the cylinder. The number of straight boards was 12 and the length was 50 mm. The number of oblique boards was 4, and the length was 160 mm. The central axis size: the angle of the blades was 42°, the thickness of the blades was 2 mm, the width was 210 mm, and the vertical distance was 220 mm. There were four stirring blades with the same length and uniform distribution on the central axis in the tank. The structure of the mixing device is shown in Figure 2. The mixing device was made of steel. Its physical parameters were density of 7800 kg/m^3, the tank shear modulus of 7×10^{10} Pa, and the tank Poisson's ratio of was 0.30.



a. Short particle model inblade brown rice germination device



b. Long particle model in blade brown rice germination device

Figure 1 Elliptical particle model (two filled particle models in blade brown rice germination device)

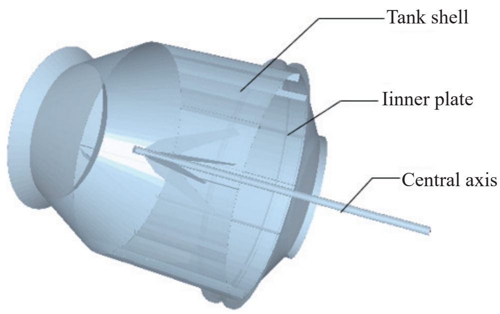
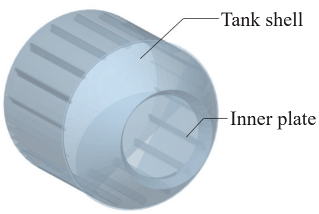


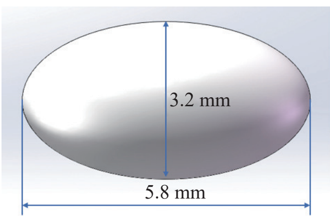
Figure 2 3-D model of blade brown rice germination device

2.1.2 Numerical simulation system of drum brown rice germination device

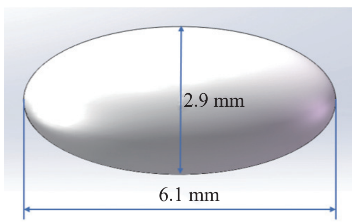
The drum brown rice germination device was composed of tank shell and inner plate, as shown in Figure 3a. The diameter of the drum brown rice germination device was 2000 mm, and the main mixing area length was 1490 mm. The number of inner plate was 18, which was evenly distributed inside the tube germination brown rice tank. The thickness of the plate was 20 mm, the length was



a. Three-dimensional model of drum brown rice germination device



b. Short particle model indrum brown rice germination device



c. Long particle model indrum brown rice germination device

Figure 3 Numerical simulation structure

1400 mm, and the cutting angle of the plate and the tank was 45°. The baffle was evenly distributed inside the drum cylinder. The simulated particle prototype was brown rice. The short particle model and the long particle model of its brown rice particles are shown in Figures 3b and 3c. The physical parameters of the particles and the mixing device are the same as those described in 2.1.1.

2.2 Numerical simulation method

The software used in the simulation experiment was EDEM developed by the British Dem Solutions. The EDEM version used in this article was 2020. The wet moisture content of the simulated ellipsoid particles was less than 12%, so the adhesion force and the liquid bridge force between the simulated particles are ignored. The soft ball collision model was adopted, and the Hertz-Mindlin (no slip) contact mechanics model was used[22]. Based on the above contact model, the ellipsoid particles in the brown rice germination device were divided into independent units in the simulation. According to Newton's second law, iterative calculation was carried out to determine the force and displacement of each element in each time step. Then, the translation and rotation relationship of each unit at each time step was obtained, and the unit position is updated in real time. Through the force-displacement tracking calculation of each unit, the macroscopic motion law of the particle group in the machine was finally obtained[23,24]. According to the above analysis, the translational motion equation of a single ellipsoidal particle unit i in the machine at a certain time step was:

$$m_i\frac{\mathrm{d}\boldsymbol{v}_i}{\mathrm{d}t}=m_i g+\sum_{j=1}^{n_i}(\boldsymbol{F}_n+\boldsymbol{F}_n^d+\boldsymbol{F}_t+\boldsymbol{F}_t^d) \tag{1}$$

where, v_i represents the particle moving speed, m/s; m_i is the mass of the particle, g; g is the acceleration of gravity, m/s²; n_i is the total number of particles in contact with particle i; $\boldsymbol{F}_n$ is the normal collision contact force between ellipsoid particles, N; $\boldsymbol{F}_n^d$ is the normal damping; $\boldsymbol{F}_t$ is the tangential collision force; and $\boldsymbol{F}_t^d$ is the tangential damping, N.

According to the force synthesis and the energy loss in the particle contact collision, the collision contact force and damping of each ellipsoid particle were decomposed into normal and tangential directions in the model. The calculation formula of the normal collision contact force F_n is as follows:

$$F_n=\frac{4}{3}E^*\sqrt{R^*\alpha^3} \tag{2}$$

where, E^* is the equivalent elastic modulus, Pa; R^* is the equivalent radius, mm; α is the amount of normal overlap. E^* and R^* are obtained from the elastic modulus, Poisson's ratio and the radius between the particles in contact with each other. The normal damping F_n^d can be calculated by Equation (3).

$$F_n^d=-2\sqrt{\frac{5}{6}}\frac{\ln\varepsilon}{\sqrt{\ln^2\varepsilon+\pi^2}}\sqrt{S_n m^*}v_n^{\mathrm{rel}} \tag{3}$$

where, ε is the coefficient of restitution, m^* is the equivalent mass (calculated from the mass of the contacting particle), v_n^{rel} is the normal relative velocity. S_n is the normal stiffness (calculated from the elastic modulus, particle radius and collision overlap), N/m.

The equations for the tangential collision force F_t and the tangential damping F_t^d between ellipsoid particles are as follows:

$$F_t=-S_t\delta \tag{4}$$

$$F_t^d=-2\sqrt{\frac{5}{6}}\frac{\ln\varepsilon}{\sqrt{\ln^2\varepsilon+\pi^2}}\sqrt{S_t m^*}v_t^{\mathrm{rel}} \tag{5}$$

where, δ is the tangential overlap, S_t is the tangential stiffness (calculated from the elastic modulus, particle radius and collision overlap), and v_t^{rel} is the tangential relative velocity.

At a certain time step, the rotation equation of a single ellipsoid particle unit i in the tank is,

$$I_i\frac{\mathrm{d}\boldsymbol{\omega}_i}{\mathrm{d}t}=\sum_{j=1}^{n_i}(\boldsymbol{T}_t+\boldsymbol{T}_r) \tag{6}$$

where, $\boldsymbol{T}_t$ and $\boldsymbol{T}_r$ are the tangential moment and rolling friction moment received by the particle unit i, N·m; I_i is the moment of inertia, kg·m²; $\boldsymbol{\omega}_i$ is the angular velocity, rad/s; t is the time, s. The tangential torque $\boldsymbol{T}_t$ and the rolling friction torque $\boldsymbol{T}_r$ can be determined by Equations (7) and (8).

$$T_t=\boldsymbol{R}_i(\boldsymbol{F}_t+\boldsymbol{F}_t^d) \tag{7}$$

$$T_r=-\mu_r\boldsymbol{F}_n\boldsymbol{R}_i\hat{\boldsymbol{\omega}} \tag{8}$$

where, $\boldsymbol{R}_i$ is the distance (vector) from the center of mass of particle i to the contact point, mm. $\hat{\boldsymbol{\omega}}$ is the unit angular velocity (vector) of the object at the contact point, and μ_r is the rolling friction factor.

In order to reduce the amount of simulation calculations, other structures such as feeding and discharging of the brown rice germination device were ignored, and only the tank body was retained. The initial boundary parameters and physical and mechanical parameters of the mixer and elliptical particles required for the simulation are listed in Table 1[22,25].

Table 1 Parameters required for simulation

Parameter	Value
Particle density/kg·m^{-3}	1538
Particle Poisson's ratio	0.4
Interparticle recovery factor	0.6
Coefficient of static friction between particles	0.43
Coefficient of kinetic friction between particles	0.01
Coefficient of static friction between particles and inner wall	0.3
Coefficient of kinetic friction between particles and the inner wall	0.01
Coefficient of restitution of particles and the inner wall	0.6
Mixer density (steel)/kg·m^{-3}	7800
Tank Poisson's Ratio	0.3
Mixer shear modulus/Pa	7×10^{10}
Particle shear modulus/Pa	1.1×10^{7}

In order to determine the gradient range of the rotational speed parameters in the simulation experiment, simulation experiments were carried out under different rotational speed conditions. And the gradient range of the rotational speed parameter was determined according to the particle mixing state at the end of the simulation experiment. The particles were divided into upper and lower layers after filling. The upper particles were blue and the lower particles were red. The number of particles was the same for both colors. The mixing time parameter of the simulation experiment was set to about 35 s. The specific mixing time was determined according to the final mixing state of the two colors of particles. Among them, the filling degree φ is calculated as follows:

$$\varphi=\frac{V_p}{V} \tag{9}$$

where, V_p is the total volume occupied by the particle-filled tank; V is the total volume inside the tank. Based on the relationship between the number of particles and the filling degree under different rotational speed conditions, the mixing parameters were determined, as listed in Table 2.

Table 2 Mixing parameters of two kinds of brown rice germination devices

Mixer type	Particle type	Filling degree/%	Number of particles	Rotational speed/r·min⁻¹
Blade brown rice germination device	Long particle	33.83	4700	10 20 30 40
		44.59	6400	
		55.23	7600	
	Short particle	40.16	4800	
		50.5	6000	
		60.83	7600	
Drum brown rice germination device	Long particle	37.9	4800	10 20 30 35
		44.2	6000	
		53.7	7200	
	Short particle	38.5	4800	
		45.8	6000	
		55.8	7200	

3 Verification tests of the mixing process of brown rice particles

In order to verify the accuracy of the discrete element simulation results, the mixing motion mode of brown rice in the tank of the drum brown rice germination device was observed through experiments in this study. The mixing law of brown rice particles in the simulation experiment results and the verification test results were compared.

3.1 Validation of experimental equipment and programs

The author of this paper designed and built a set of mixing experimental device of drum brown rice germination device, as shown in Figure 4.

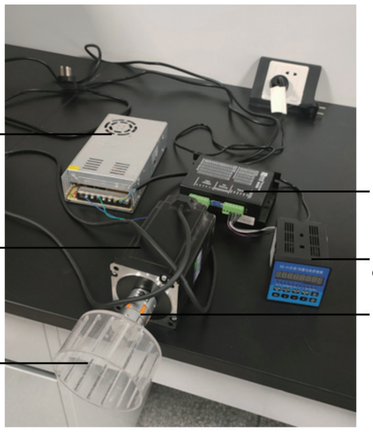


Figure 4 Experimental setup diagram

The mixing drum was placed horizontally and rotated around the central axis. The main geometric parameters included diameter and length. Its main operating parameters included rotational speed and filling degree. The diameter of the drum was 100 mm and the length was 75 mm. The research object was japonica brown rice, which was dyed red and blue respectively with vegetable dyes. The lower layer was filled with blue and the upper layer was filled with red. The number of brown rice particles of both colors was consistent. The material of the mixing drum was acrylic plate. During the experiment, the mixing motion state of the brown rice particles inside the drum could be clearly observed. A high-speed camera was used to photograph and video the mixing process of brown rice particles inside the mixing drum for the convenience of experimental recording and analysis. The design of the verification test scheme is listed in Table 3.

Table 3 Validation test scheme design

Mixer type	Rotational speed/r·min⁻¹	Filling degree/%
Drum brown rice germination device	10 20 30 35	32 45 55

3.2 Comparison of particle mixing morphology between verification test and simulation experiment of mixing drum

In this study, the conditions of three different rotational speeds, filling degree of 45% were taken as examples. Mixing motion images of the verification test particles and motion vector diagrams of the simulation experiments were displayed, as shown in Figure 5.

It could be seen from the verification test images that the brown rice particles moved in a circular motion with the tank. The moving area of brown rice particles was divided into active area and fixed area under the rolling mechanism[26]. The lower area of particles was a fixed area, and there was no relative movement between particles. The free surface flow on the mixing upper surface is called the active area. Brown rice particles rolled down from the top right corner of the tank and mixed with the particles in the lower fixed area. The higher the rotational speed, the more brown rice particles falling down could be observed. It meant that the mixing speed was faster and the mixing efficiency was higher. And when the rotational speed was the same, the drop height of brown rice particles in different experimental groups was also basically the same.

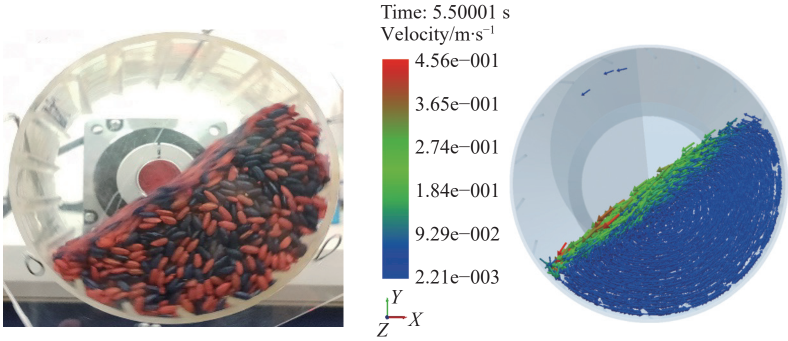
Through the mixing morphological image of the comparative verification test and the simulation experiment particles in Figure 5, it could be seen that the flow state of brown rice particles was rolling. And the mixing morphology was highly similar. Under the same conditions of rotational speed and filling degree, the verification test images and the simulation images showed the same drop height of brown rice particles. There was no significant difference in the flow range of brown rice particles in the drum.

4 Analysis of numerical simulation results

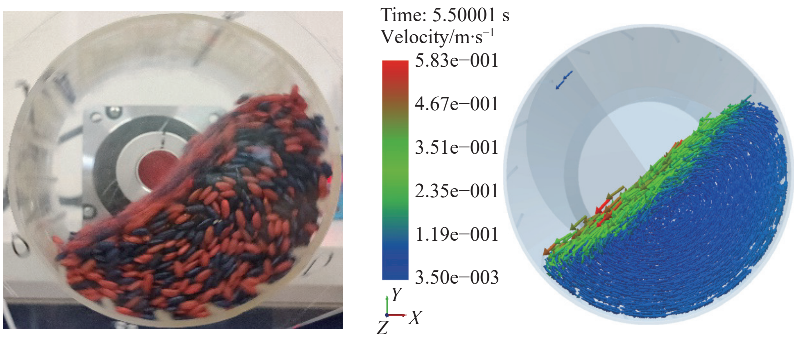
4.1 Particle mixing process

At present, the stirring and mixing mechanisms mainly include convective mixing, diffusion mixing and shear mixing[27]. The mixing process was roughly divided into three stages: the initial stage of mixing, the middle stage of mixing, and the later stage of mixing[28]. The whole mixing process of different experimental groups was basically similar. The mixing process of particles in the tank was described by taking the tank body of the blade brown rice germination device, the speed of which was 30 r/min and the number of short particles was 7600. Figure 6 shows the radial mixing state of particles of two colors at different time points. The direction of the arrow shown in the figure is the direction of rotation of the drum.

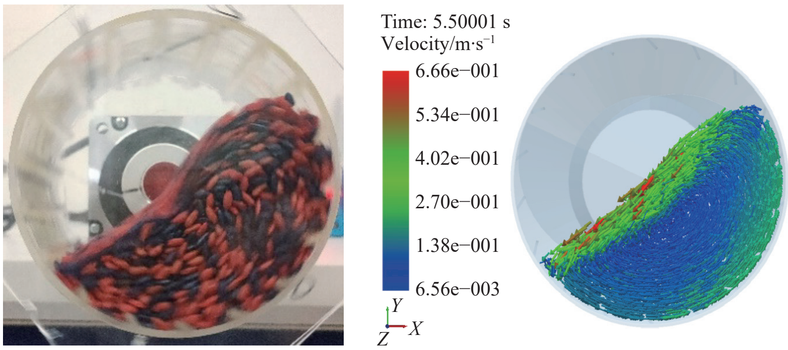
Figures 6a-6d show the images of the mixing state of two color particles at four mixing time points, respectively. It could be seen at the time of T=3 s and T=3.5 s, the mixing of the particle group was in the initial stage of mixing. It was called the fast mixing stage[29]. In the initial stage, the particles were distributed up and down the tank with minimal mixing. After the mixing time reached 3.5 s, the particle group moved greatly under the driving of the tank. The particle of two colors changed from the upper and lower layers to the left and right layers, mainly because the convective mixing worked[30]. At this time the mixing speed was very fast, but the degree of uniformity of the mixing was not high. When the mixing



a. Rotational speed: 10 r/min, filling degree: 45%

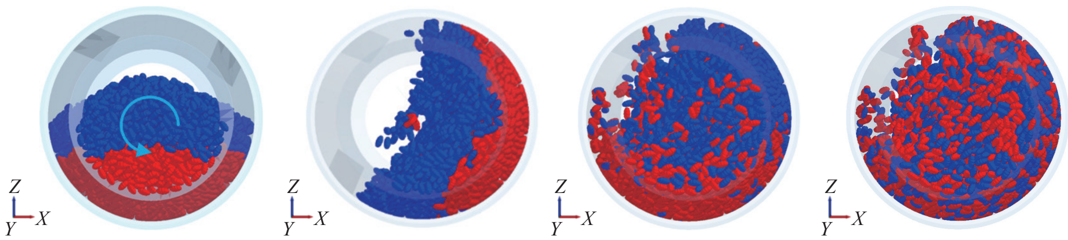


b. Rotational speed: 20 r/min, filling degree: 45%



c. Rotational speed: 30 r/min, filling degree: 45%

Figure 5 Comparison of particle mixing morphology between verification test and simulation experiment



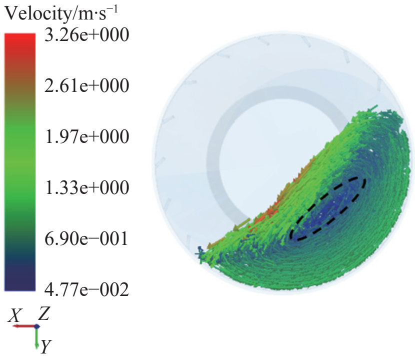
a. T=3 s b. T=3.5 s c. T=10 s d. T=35 s

Figure 6 Mixing state of particle groups at different time points (blade brown rice germination device, short particle, 30 r/min, 60.83%)

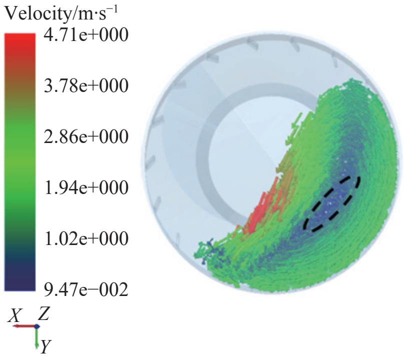
time reached 10 s, the mixing process had reached the middle stage. This stage was called the slow mixing stage and was mainly diffusion mixing and shears mixing. The more the two particles infiltrated each other, the higher the degree of mixing. Then their overall relative slip would gradually decrease. The mixing speed was slowed down and convection was reduced accordingly. When the mixing was carried out for 35 s, it could be seen that the mixing of the two particles was very uniform. At this time, the binary particles were still in periodic motion. The two particles still flowed and exchanged stably in the tank, but the final mixing degree of the particles remained unchanged. It showed that the mixing between particles had reached the later stage of mixing, which was also called the fluctuation mixing stage.

4.2 Vector analysis of particle motion velocity at different rotational speeds

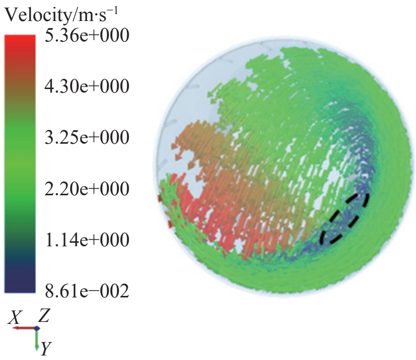
In order to intuitively understand the movement characteristics of particles in the mixer tank and observe the mixing morphology of particle groups at different speeds of the mixer, the long particle model in the tank of the drum brown rice germination device was used as an example to simulate the mixing process at the filling degree of 37.9%. Figure 7 shows the mixing motion analysis of the particle group in a steady state at different rotational speeds.



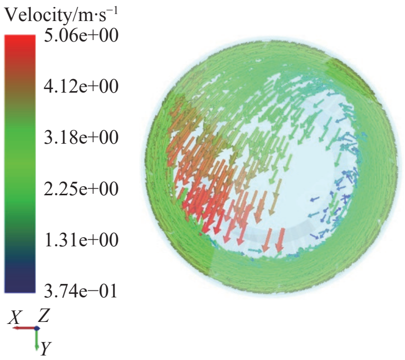
a. Vector diagram of the mixingmotion of the particle group at a rotational speed of 10 r/min



b. Vector diagram of the mixingmotion of the particle group at a rotational speed of 20 r/min



c. Vector diagram of the mixingmotion of the particle group at a rotational speed of 30r/min



d. Vector diagram of the mixingmotion of the particle group at a rotational speed of 35 r/min

Figure 7 Vector diagram of the mixing motion of the particle group at different rotational speeds (drum brown rice germination device, long particle, 37.9%)

It could be seen from Figure 7 that the particle group moved with the rotation of the tank. The velocity of the particles exhibited distinct layering and the velocity of the particles at the bottom of the tank decreased gradually from the outside to the inside. It could be clearly perceived by comparing the mixing motion of the particle groups at different rotational speeds that the motion modes of the particles in the mixer in Figures 7a-7d were rolling, cascading, cataracting and centrifuging[31]. And the greater the rotational speed of the tank, the more particles fell. The higher the linear velocity, the stronger the centrifugal forced on the particles[32], and the more visible the "cascading" and free surface flowed in the falling layer. By comparing and observing the mixing dead area at different speeds, it could be found that the larger the tank speed was, the smaller the area of the mixing dead area was, leading to in a better mixing effect. In Figure 7d, the velocity of the drum was too large, and the particles were greatly affected by centrifugal force. The number of falling particles was smaller than that of the experimental group whose rotational speed was 30 r/min, and the mixing effect became worse. It could be assumed that as the velocity of the tank increased, there would be some differences in the movement of the particles. But as a whole, it still performed periodic movements according to specific phenomena. And when the rotational speed increased within a certain range, the speed of the particles on the free surface flow increased, and the falling particles increased significantly. This increased the rate at which the particles were mixed. When the speed of the drum increased to 30 r/min, the falling particles decreased. It indicated that the centrifugal force on the particles would inhibit the mixing process.

4.3 Vector analysis of particle motion velocity at different filling degrees

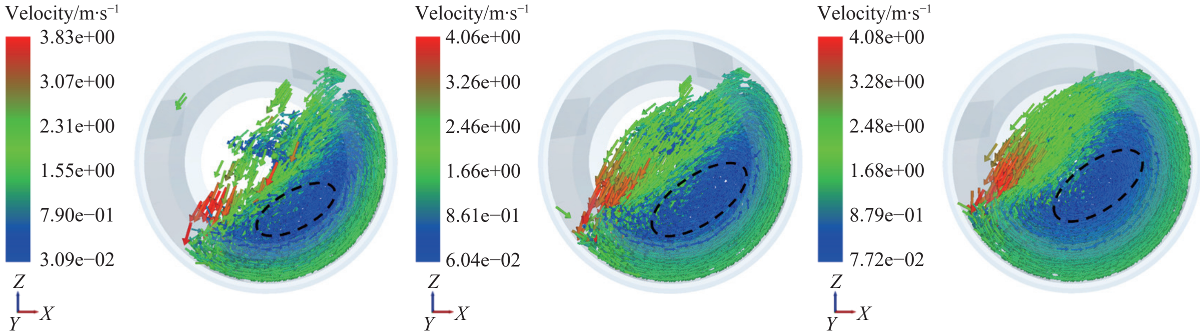
The effect of filling degree on the mixing characteristics of particles in the tank was analyzed by using the short particle model in the blade brown rice germination device at a rotational speed of 20 r/min. The mixing motions of the particle group in the steady state are shown in Figure 8.

It could be observed from Figure 8 that the drop height of the particles was almost the same for the tank with the same rotational speed. The higher the filling degree, the more falling particles and the more obvious free surface flow could be observed. In addition, the proportion of the three regions in the particle group with different filling degrees was roughly unchanged. Therefore, it could be considered that there was no significant difference in the final mixing degree of the particle groups with different filling degrees. At the same tank speed, the smaller the number of particles, the greater the range of flow during the mixing process. The mixing effect brought by convection was more obvious, and the mixing was more sufficient. As a result, it could be considered that the mixing efficiency of the particle group with a smaller filling degree was higher.

4.4 Single particle trajectory analysis

In order to clarify the particle movement in the tank of the blade brown rice germination device, a single particle in the particle group was randomly selected when the filling degree was 44.59%. The movement trajectory diagram of the particle in the whole process was made, as shown in Figure 9.

Figures 9a-9c are the motion trajectories of the particles in the tank under the conditions of three tank rotational speeds. The movement of the particles in the tank is reflected from the *Y*-axis direction and the *Z*-axis direction, respectively. From the characteristics of the movement process of a single particle, it could be inferred that the trajectory of the particle rotating in the tank had certain regularity[33]. From the *Y*-axis direction, its motion trajectory was elliptical and gradually shrank from the outermost ring inward. The whole movement process was like a spiral advance, which was random and regular. This was due to the upward lifting force on the particles during motion. After following the rotation of the tank to the highest point and falling, the speed of the particles became slower due to being squeezed by other particles and being subjected to various forces such as friction and shearing force. So the trajectory of the movement shrank every time. And because of the collision with other particles during the movement, the plane of each rotation of the particle changed. And the smaller the rotational speed of the tank, the narrower the movement range of the particles and the less movement trajectory.

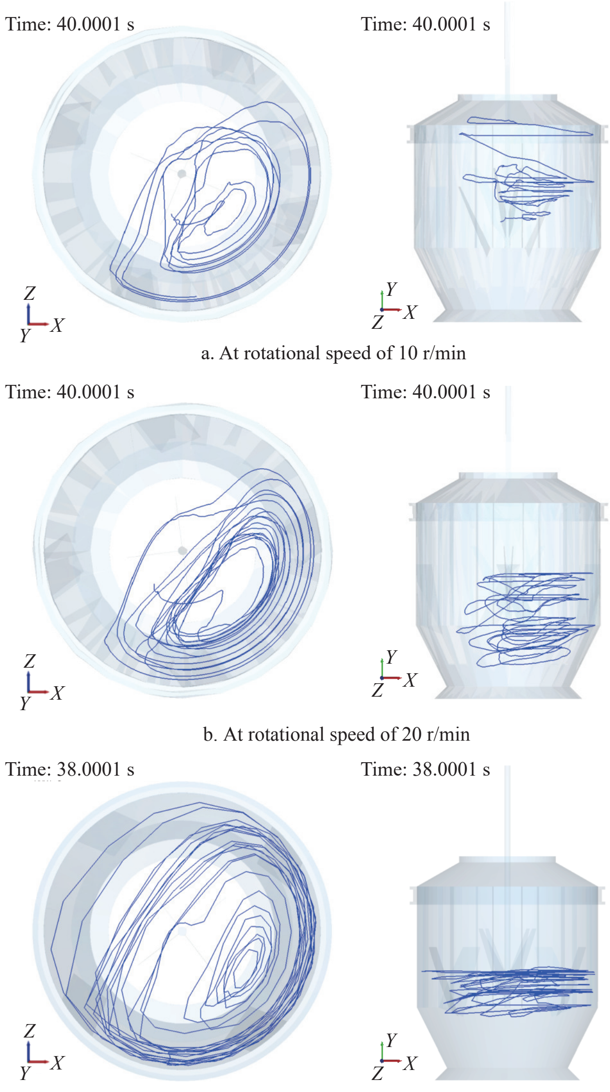


a. Mixing motion vector diagram of the particle group at a filling degree of 40.16%

b. Mixing motion vector diagram of the particle group at a filling degree of 50.5%

c. Mixing motion vector diagram of the particle group at a filling degree of 60.83%

Figure 8 Mixing motion vector diagram of particle group at different filling degrees (blade brown rice germination device, short particle 20 r/min)



a. At rotational speed of 10 r/min

b. At rotational speed of 20 r/min

c. At rotational speed of 30 r/min

Figure 9 Distribution of single particle motion trajectory at different rotational speeds (blade brown rice germination device, long particle, 44.59%, left: *Y*-axis direction, right: *Z*-axis direction)

4.5 Comparison of the mixing process analysis of the two types of brown rice germination devices tank body

This paper mainly studies the mixing characteristics of two types of brown rice germination devices at different speeds and different filling degrees. Both the two kinds of mixer equipment were sporty. The blade brown rice germination device had a central shaft. The drum brown rice germination device was a type without a central shaft. There were three mixing processes in the particle mixing process of the two mixers: the fast mixing stage, the slow mixing stage and the fluctuation mixing stage. The mixing mechanisms included convection, shear and diffusion. When the velocity vector analysis was performed on the mixing process of the particles, the particle system would appear in six motion states with the different velocity of the tank. And in the stable mixing stage, three mixing regions could be observed according to the mixing motion characteristics of the particles. This was consistent with the results of other scholars in the study of particle group mixing[15]. The centrifugal motion state for the drum brown rice germination device appeared at the speed of 35 r/min, while for the blade brown rice germination device, it occurred at 40r/min. It showed that the rotational speed had a greater influence on the mixing state of the particles in the tank of the drum brown rice germination device. When analyzing the particle movement trajectory, the particle trajectory in the tank of the two brown rice germination devices was an elliptical spiral that gradually narrowed from the outer circle to the inner circle. The degree of shrinkage depended on the effect of particle mixing. The better the mixing effect, the more obvious the change of particle motion trajectory.

5 Conclusions

In this study, discrete element simulation was used to study the mixing motion process and motion law of particles in two typical brown rice germination device tanks. And the reliability of simulation experiments was verified through physical experiments. The research results indicated that under the same conditions of rotational speed and filling degree, the mixing motion state of brown rice particles in the verification test and the simulation experiment was consistent. In the discrete element simulation experiment, the mixing state of the particles was significantly different at different rotational speeds. The lower the filling degree, the higher the mixing efficiency of the particle system. The trajectory of a single particle in the *Y*-axis direction was an elliptical spiral that gradually shrank from the outer ring inward, and the particle movement range was related to the rotational speed.

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