Simulation Analysis of Materials Motion in Rice Whitening Machine Based on Discrete Element Theory

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Abstract: Based on the Discrete Element Theory, this paper explores the dynamic variation process of the group particle material system in the rice whitening machine through simulation analysis of the motion trail, velocity, pressure and distribution of the material particle group in the working process with the help of EDEM. The results indicate that the simulation analysis allows the real time observation of brown rice motion status in the whitening chamber, including the streamlines, velocity and pressure vector, etc.; it also generates the rule of how the particle and particle group velocity vary with time, and how the average resultant force of the particle and particle group vary with time.

1 INTRODUCTION

Rice, as the traditional grain for Chinese residents, its yield, processing volume and consumption in China rank first in the world. The rice processing industry has significant influence on the national economy and people's livelihood. In the rice processing process, whitening is regarded as the most important procedure, and the processing properties of the rice whitening machine directly affect the process effect of rice production. Experts from both home and abroad have already made researches on the rice whitening theory; however, the complete theoretical system of rice whitening is not yet established due to the complexity of the mechanical physical interaction in the whitening process, as most researches are qualitative and quantitative analysis are relatively few. The long-term production practice and theoretical studies proved that the kinematic velocity and the pressured status of the group particle material in the whitening chamber are the key factors that affect the process effect, and also the essence of the whitening theory. Besides, the critical component affecting the working performance of the rice whitening machine is the whitening chamber. This paper has built a parameterized model for the whitening chamber, and made numerical simulation analysis for the motion of group particle material in the whitening chamber with the help of the simulation software EDEM to explore the motion trail, velocity, pressure and distribution of the material flow in the whitening process, in order to provide theoretical foundation for the design of rice whitening machine.

2 WORKING PRINCIPLE

Rice whitening machine is the kernel equipment for rice processing with the task of wiping off the surface layer of brown rice. To be specific, the mechanical component in the whitening chamber will continuously act on the materials to realize the function of wiping off the bran through abrasive action, frictional action, impacting, rolling, and axial pushing, etc. Figure 1 shows the structure of vertical emery roll whitening machine: the materials are conveyed from the feeding hopper to the whitening chamber by the screw iron roll; then with the continuously impaction, compression and abrasive, frictional action of the emery rolls, screens and the huller blade, the materials are rolled by the high-speed revolution of the emery rolls and the particles are uniformly whitened. The post-whitening bran powder will be collected and discharged by the bran discharging system (Jinglan and Wenbin, 2017).

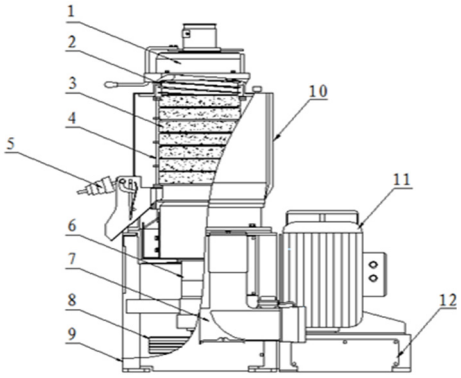


Figure 1: Structural diagram of the vertical emery-roll rice whitening machine.

1 Feeding mechanism 2 Screw iron roll 3 Emery roller 4 Screen frame 5 Pressure gate 6 Bearing bracket 7 Bran discharge hose 8 Spindle pulley 9 Frame 10 Encloser 11 Electrical motor 12 Pedestal

3 MODELING AND SIMULATION ANALYSIS

Discrete Element Method (DEM) is an effective numerical method developed for dealing with the non-continuum mechanics in the particle flow analysis. EDEM is the first simulation software in the world specialized in the particle mechanics based on DEM technology to provide a solution for the particle system simulation and analysis in the engineering field. With the help of EDEM, a parameterized model of the particle system can be built easily to study and explore the mechanical property, material property and other physical properties of the particles, and further control and manage the information of each particle (e.g. quality, temperature, velocity, etc.) and the force acted on it. In recent years, the application scope of EDEM is expanding with the development of the technology and theory (Jie and Wenjun, 2014). Since grain particle group is a kind of granular mixtures, it is suitable for EDEM to be applied in the research of food machinery.

3.1 Build Calculation Model for Whitening Chamber

For the convenience of simulation calculation, the whitening roller and screen are simplified and then on this basis, the 3D solid model of the whitening chamber is built for EDEM numerical simulation analysis as shown in Figure 2. Sliding mesh technique is used to divide the computational domain into two parts -- the inside and the outside. Figure 3 shows the simplified fluid region of the whitening machine built by EDEM.

Figure 2: DEM calculation model.

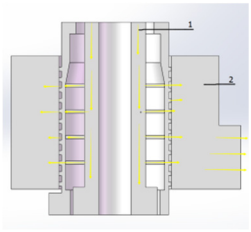


Figure 3: Fluid region of rice whitening machine.

3.2 Build Calculation Model for Brown Rice Particle

The object for the whitening process is the brown rice. The aim of whitening is achieved through the crashing, scrolling and rubbing between the brown rice particles and the emery roller, screen and the particles around to wipe off the surface layer. The brown rice in China can be mainly divided into 3 categories: Japonica brown rice (short and thick), Indica brown rice (long and thin) and sticky brown rice. The related parameters of volume-weight, density and particle size can be seen in Table 1.

As the shape of brown rice particle is similar to an oval, a parameterized model is built by a pre-EDEM processing software through the accumulation of multi-spheres, i.e. using the particle bonding method to build the DEM model for the brown rice particle (Favier and Kremmer, 1999).

Table 1: Related parameters of brown rice particles.

Category	Volume-Weight (g/L)	Density (g/m³)	Particle Size(mm)			Length-width Ration
			Length	Width	Thickness	
Japonica	822.1	1.37	5.4	3.1	2.1	1.74
Indica	802.9	1.4	5.8	2.7	1.9	2.07
Sticky	796.1	1.39	5.5	2.6	2	2.1

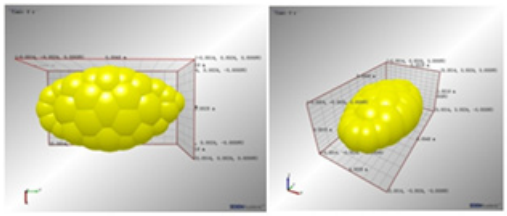


Figure 4: Effect picture of DEM model for brown rice particle.

3.3 Simulation Analysis

3.3.1 Selection of Contact Model and Parameters Setting

Contact model is the basis for DEM simulation analysis. The common contact model for EDEM are Hertz-Mindlin no-slip soft sphere model, Hertz-Mindlin bonding contact model, linear cohesion contact model, and moving plane contact model, etc. which are built according to the simulation object (Yongjun and Shuai, 2017). This paper selected Hertz-Mindlin no-slip soft sphere model according to the contact property of brown rice particles, brown rice particles and the screen or the emery roller in the whitening chamber. Table 2 shows the contact properties of the brown rice particles and the component material properties of the whitening machine. Figure 5 shows the basic physical parameters of the brown rice and the steel, including the desity and the poission ratio, as the gravity is ignored. Figure 6 is the setting for the contact properties between different models according to the information in Table 2.

Figure 5: Parameter-setting for brown rice and steel.

Table 2: Contact properties of materials.

Interaction	Collision Coefficient of Restitution	Static Friction Coefficient	Kinetic Friction Coefficient
Rice Particle-Rice Particle	0.3	0.56	0.015
Rice Particle-Steel Plate	0.52	0.5	0.01
Rice Particle-Emery Paper	0.45	0.61	0.024

c: Property setting for contact between brown rice and brown rice. d: Property setting for contact between brown rice and steel

Figure 6: Property setting for contact between models.

The whitening roller consists of emery, and other components are steel. The motion form of the whitening roller and the screw iron roll is linear rotation around their axis with 900rpm. The brown rice particles will be conveyed to the whitening chamber continuously at 320000 particles/s with the initial linear velocity of 1m/s. The setting of time step is realized through the options of "rayleigh time step" and "fixed time step" (Liying and Yuepeng, 2016).

3.3.2 Simulation Result and Analysis

When the simulation is running, the motion simulation of brown rice particles in the whitening chamber at 0.36s, 5s, 8s can be seen in Figure 7. The particles in the whitening chamber will accumulated with time and the brown rice particles will move forward under pressure. As shown in the figure, the high speed region is where the particles just left the screw iron roll to the whitening roll, and at the discharge hole.

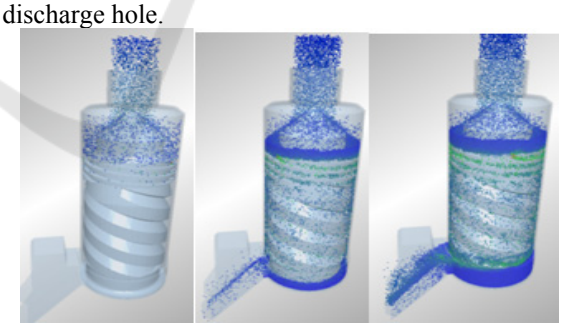


Figure 7: Motion of brown rice particles in whitening chamber at 0.36s, 5s, 8s.

In Figure 8, the brown rice particles are moving spiral downward along the whitening roller in the form of streamlines, which is corresponding with the actual flowing direction. If it is showed in the form of velocity vector, the flowing direction of the brown rice flow is also in accordance with the reality, moving spiral downward along the whitening roller.

In the simulation of group particles, Figure 9a refers to the time-vary situation of the average velocity of all particles in 0s to 6.5s; Figure 9b refers to the time-vary situation of the average velocity of the specific particle labelled No.1. The velocity of No.1 particle is stable between 3.5s to 5.6s, reached the peak at 5.6s and then become stable again.

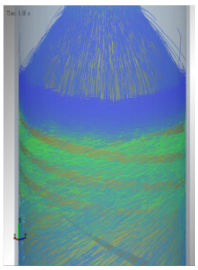
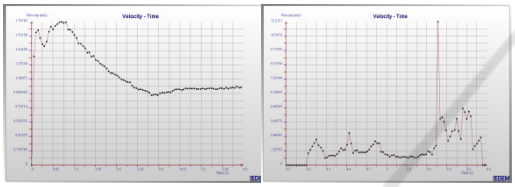


Figure 8: Motion of brown rice showed in streamlines.



a: Time-varying velocity of brown rice particle flow.
b: Time-varying velocity of brown rice particle No.1.

Figure 9: Time-varying velocity of brown rice particle.

Figure 10 indicates the time-vary situation of the average resultant force of the brown rice particle flow in the whitening chamber. The pressure increases as the brown rice particles moving from the feeding end to the discharging end, but the total value of the resultant force is not big. That is because emery roller whitening machine is a speed type which wipes off the surface of brown rice by the high speed abrasive action of the emery roller. Therefore, to a great extent the effectiveness of the abrasive action is depending on the velocity rather than the stress of the particles.

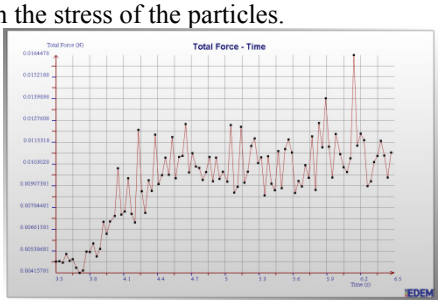


Figure 10: Time-varying average resultant force of particle flow.

4 CONCLUSIONS

In the DEM simulation analysis, a DEM model of brown rice particle in the shape of oval is built through the particle bonding method. And the Hertz-Mindlin no-slip soft sphere model is chosen according to the contact property between the brown rice particles, brown rice and screen, brown rice and whitening roller. After the numerical simulation analysis, the motion status of the brown rice particle group in the whiteing chamber (including the streamlines, and the velocity vector direction) is generated. It comes to a conclusion that the velocity of the brown rice particle flow and its individual particle varies with time; the average resultant force of the particle flow varies regularly with time.

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APPENDIX

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