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Characterization of screw conveyor based on discrete element method

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Keywords: Screw conveyor; discrete unit method; simulation; conveying capacity

Abstract: As a key equipment in the field of material conveying, the performance optimization of screw conveyor is of great significance for improving production efficiency and reducing energy consumption. This study is based on the discrete unit method to simulate the screw conveyor conveying process. It is found that at the rated speed, the flow rate increases with the increase of filling rate. At rated filling rate, the flow rate increases with increasing speed. At rated speed, torque increases with increase in filling rate. At rated filling rate, torque increases with increasing speed. This paper provides an important reference for the optimized design, efficient operation and practical engineering application of screw conveyor.

1. Introduction

China is a large agricultural country, and since 2011, the total value of China's agricultural production has been climbing up. Taking agricultural materials as an example, by 2021, the national value of agricultural materials production will be 1,223.41 billion yuan. However, the transportation of agricultural materials consumes a lot of time and manpower, resulting in product backlog and high transportation costs. Agricultural material transportation has gradually become a stumbling block limiting agricultural development. Therefore, by reducing costs in the transportation process, the price of agricultural products can be effectively reduced and the profits of agricultural material processing enterprises can be increased.

The main forms of agricultural material transportation in China at present include package transportation, containerized transportation and vehicle-mounted transportation. Take agricultural materials as an example, vehicle-mounted transportation is the use of special agricultural materials as shown in Figure 1 for agricultural materials transportation. Vehicle-mounted transportation can greatly maintain the integrity and freshness of agricultural materials, compared with packaging and containerized transportation, vehicle-mounted transportation is more convenient and efficient loading and unloading. On the other hand, because the vehicle-mounted transport can make the loading and unloading, transportation and storage process of agricultural materials mechanized, so the use of agricultural materials vehicle conveying, can save manpower and material resources, greatly reduce the transportation cost and improve the transport efficiency, vehicle-mounted agricultural materials transport is currently an important direction of the development of domestic and foreign agricultural materials transportation [1-2].

Agricultural material transporters mostly use screw conveyor as shown in Figure 2. Screw conveyor is a very common transmission equipment, widely used in a variety of industries to transport granular materials. Screw conveyor is an important component of combined grain harvesting, mainly composed of screw shafts, screw blades, casing, bearings, etc. In a series of harvesting operations, the conveyance of the screw conveyor determines the quality of the operation of the subsequent processes (such as screening, cleaning, etc.).

Fig 1 Agricultural Material Transportation Vehicle

Fig 2 Screw conveyor

The process of screw conveying of agricultural materials is very complex. The screw conveyor structure is often closed, and it is not possible to observe and measure the state of motion of the particles inside. In the material conveying process is accompanied by stirring, mixing and other functions, and bulk materials often show solid (wet material), fluid, gas (dust) morphology, as well as the mechanical properties of the various forms of coupling, in the actual transport process shows a very complex behavior of movement and mechanical behavior, at the same time, the characteristics of the material and the geometric parameters of the transport mechanism has a very close correlation and interaction, increasing the difficulty of the study. Therefore, the study of the kinetic properties of the material in the conveying process, analyze the influence of various factors of the conveying mechanism on the material conveying characteristics of the law. It is of great significance to optimize the conveying structure, improve the working performance and reduce the material breakage rate [3-5].

Foreign scholars Roberts [6] and others used millet as a tool for conveying materials, screw conveyor at different speeds, different conveying angles, different gaps under a large number of experimental studies, and came up with the impact of these factors on the screw conveyor conveying capacity and power consumption. However, their experiments only studied the two gaps of 0.39mm and 3.175mm, and could not reflect what kind of trend the conveyor has with the change of gap.Shimizu et al [7] first proposed the application of discrete element model of particles inside the screw conveyor in 2001. Song Qiqun [8] studied the horizontal screw conveyor mechanism, analyzed the material force and material tumbling mechanism in the conveyor, and revealed the influence of material properties on the conveying effect. Zhang Xiliang et al [9-11] conducted a DEM simulation experimental study on the effect of particle size on the quantitative charging performance of screw feeder in order to improve the dosing performance of screw feeder, to solve its conveying efficiency and to solve the problem of unstable charging amount and high energy consumption. This study investigates the mechanical characteristics of agricultural granular materials in screw transportation, and analyzes the influence law of each factor of the conveying mechanism on the conveying characteristics of granular materials. It can provide theoretical basis for the parameter design and structural optimization of screw transport equipment for agricultural materials.

2. Discrete unit method introduction

Discrete unit method is a particle discrete body material analysis method. The basic idea is to simplify the material into a collection of particles with real material properties, and then give some kind of contact mechanics model between particles and between particles and boundaries. The equation of motion of each particle is established, and the motion characteristics of each particle at a specific moment are calculated, so as to reflect the motion performance of the whole system. Simulation and analysis through the discrete unit method can directly obtain a large number of complex and experimentally difficult to measure the information of bulk materials, such as particle velocity, particle force, particle trajectory, mass flow rate, equipment power consumption and so on. Based on the above reasons, this project adopts the discrete unit method to study the characteristics of spiral conveying of agricultural materials.

3. Model Description

3.1 Material parameters

The particles of an object under the action of internal and external forces produce a certain flow, showing the nature of the fluid, and ultimately the formation of particle flow. The common loose materials in daily life are paddy, sand, coal, granules, cement and ore, among which paddy, sand and ore are the most studied loose particles. Since the object of study in this paper is soybean particles, the parameters of the material are set in the specialized discrete element program EDEM, and the corresponding physical properties of soybeans are given in Table 1.

Tab 1 Soybean attribute parameters[12]

Properties	Value
Modulus of elasticity	1.5×108N/m^2
Density	1.9×103kg/m^3
Friction angle	32.5°
Poisson's ratio	0.35
Resistance coefficient	0.20

3.2 Hertz theory

Hertz's contact theory refers to the contact force of non-adhesive spherical particles. According to Hertz's contact theory, the continuous action between two objects is considered to be limited because there is no direct collision between these objects. In addition, this theory assumes that the continuous interaction between two objects is subject to compression and stretching in both directions and that this interaction has an inherent characteristic of both compression and stretching in both directions, and that this interaction is also subject to compression and stretching in both directions.Hertz's contact theory can be used to deal effectively with the interactions of different curved bodies. The theory is applicable to the present simulation model.

Fig 3 illustrates the deformation of the elastic contact between two spherical particles in Hertz's contact theory, where the dashed line represents the position of the surface of the particle that is not affected by the deformation, while a refers to the radius of the contact surface, and α refers to their normal overlap.

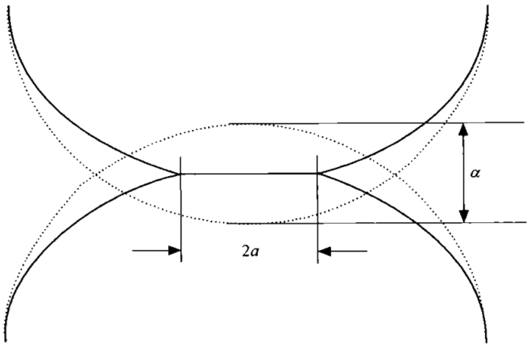


Fig. 3 Schematic of elastic contact deformation of two spherical particles in Hertz contact theory

3.3 Modeling

This design uses EDEM to simulate the inclined spiral transportation model, and in reference to the real test equipment and simulation scale and time interval on the basis of its addition to a certain degree of simplification and improvement, and can more comprehensively record the whole process of inclined spiral transportation. This model uses SolidWorks modeling software, the model is mainly composed of the inlet, the spiral body, the aggregate barrel.

As shown in Figure 4, the transportation process of the simulation model. Among them, the granular material enters through the inlet, passes forward through the screw mechanism, and outputs from the rightmost outlet.

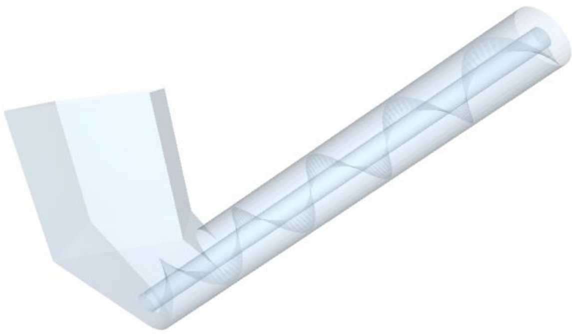


Fig. 4 Single screw conveyor model

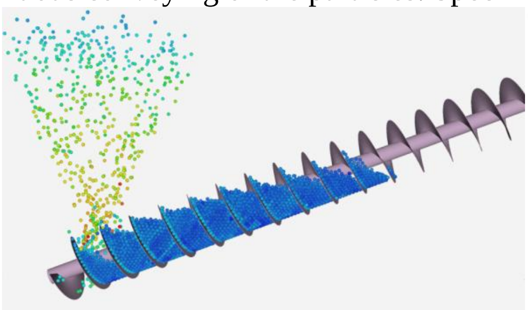
4. Simulation results and analysis

On the basis of mechanical modeling, the amount of flow output as well as the magnitude of torque at different filling rates and the amount of flow output and the magnitude of torque at different rotational speeds were analyzed.

On entering the inclined spiral, relative motion is created between the object and the spiral blade while the object starts moving towards the top. This movement plays an important role in the inclined screw drive. In order to ensure the efficient transfer of material, the screw conveyor must invest a large amount of energy as a way to ensure that the material passes through the conveyor to the mechanism smoothly. In order to investigate the motion effects of particle flow within the inclined screw conveyor, as well as the conveyor conveying performance and condition, this paper, by simulating a screw speed of 250 r/min and a feed rate of 0.3 kg/s, yields a stable conveying region that starts at the third pitch and extends all the way to the penultimate pitch, and all of the particle motions within this region are as expected.

Most of the particles run at a relatively smooth speed during the whole screw conveying process.

Since the rotational speed of this simulation is set at 250r/min, the particle transportation speed shows a low-speed running state during the whole conveying process. The percentage of faster particles in green and very fast particles in red shown in the figure is relatively small, below 8%. The faster particles are mostly concentrated in the vicinity of the inlet and outlet. Secondly, the running direction of the particles can be clearly seen during the conveying process. In the inlet portion, the particles are piled up under the inlet port, which has more particles and facilitates the continuous conveying of the particles. Specifically as shown in Fig. 5 and Fig. 6.



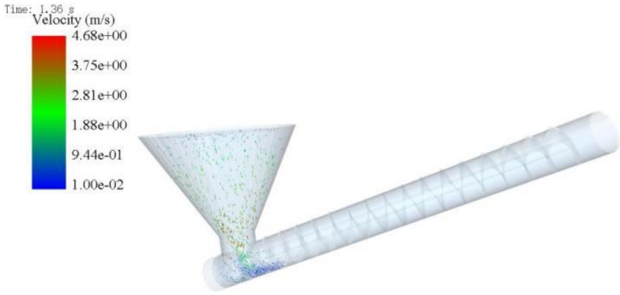
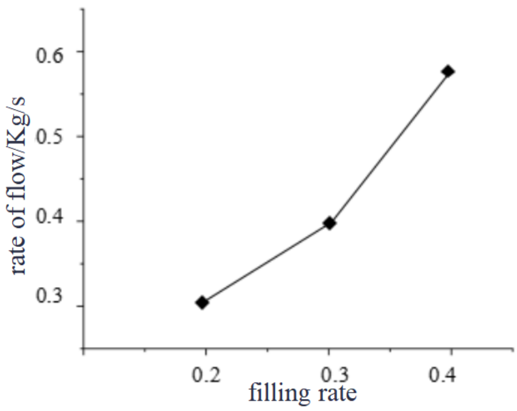


Fig. 5 EDEM model diagram Fig. 6 EDEM material movement schematic diagram

As can be seen from Fig. 7, there is a relationship between fill rate and flow rate. Under the rated speed of 250 r/min, the flow rate increases with the increase of filling rate. When the filling rate is 0.2, the flow rate is 0.31kg/s, when the filling rate is 0.3, the flow rate is 0.39kg/s, and when the filling rate is 0.4, the flow rate is 0.51kg/s. It can be seen from the figure that the flow rate increases more rapidly in the range of the filling rate of 0.3-0.4. Between 0.2-0.3, the flow rate increases by 0.08kg/s when the filling rate increases by 0.1, and between 0.3-0.4, the flow rate increases by 0.12kg/s when the filling rate increases by 0.1.



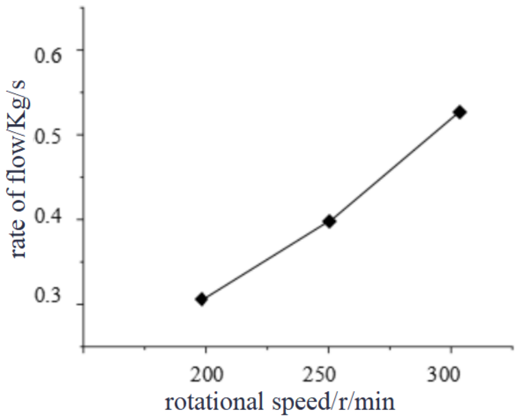


Fig. 7 Flow rate at different filling rates Fig. 8 Flow rate at different rotational speeds

As can be seen in Figure 8, there is a relationship between speed and flow rate. With a rated filling rate of 0.3, the flow rate increases with the increase in rotational speed. When the rotational speed is 200r\min, the flow rate is 0.31kg/s, when the rotational speed is 250r/min, the flow rate is 0.38kg/s, and when the rotational speed is 300r/min, the flow rate is 0.51kg/s. It can be seen that the flow rate increases more rapidly in the range of rotational speeds from 250r/min to 300r/min from the figure. The flow rate increases by 0.07kg/s when the spiral speed increases from 200r/min to 250r/min and 0.13kg/s when it increases from 250r/min to 300r/min.

Torque is an important index for judging the power of inclined screw conveying, and it can be seen from Fig. 9 that there is a relationship between filling rate and torque. Under the premise that the rated speed is 250r/min, the torque increases with the increase of filling rate. When the filling rate is 0.2, the torque is 2.55N/m, when the filling rate is 0.3, the torque is 3N/m, and when the filling rate is 0.4, the torque is 3.35N/m. It can be seen from the figure that the torque increases more rapidly in the range of the filling rate of 0.2-0.3. Between 0.2-0.3, the torque increases by 0.45N/m when the filling rate increases by 0.1, and between 0.3-0.4, the torque increases by 0.35N/m when the filling rate increases by 0.1.

Torque is an important index for judging the power of inclined screw conveying, and it can be seen from Fig. 10 that there is a relationship between rotational speed and torque. Under the premise that the rated filling rate is 0.3, the torque increases with the increase of rotational speed. When the rotational speed is 200r\min, the torque is 0.75N/m, when the rotational speed is 250r/min, the torque is 1.05N/m, and when the rotational speed is 300r\min, the torque is 1.45N/m. It can be seen from the figure that the torque increases more rapidly in the range of rotational speeds of 250r/min-300r/min. Between 200r/min-250r/min, the torque increased by 0.3N/m when the rotational speed increased by 50r/min and 0.4N/m when the rotational speed increased by 50r/min between 250r/min-300r/min.

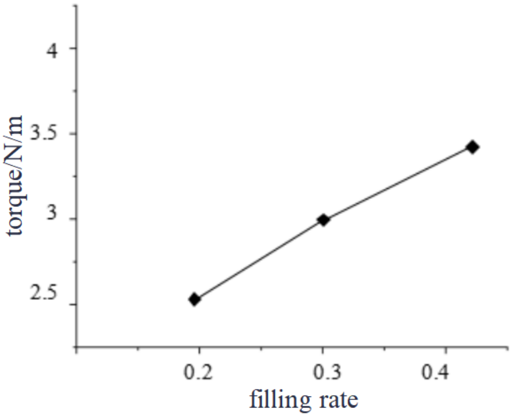


Fig. 9 Torque at different filling rates

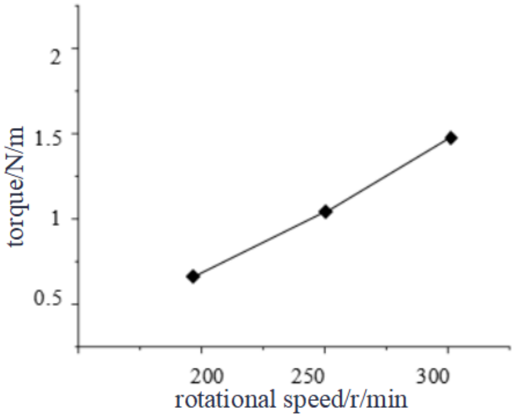


Fig. 10 Torque at different speeds

The test platform selected for this paper is an acquired screw conveyor, as shown in Fig. 11. The screw conveyor is structurally identical to the simulation model. In order to effectively reduce the interference of harvesting, threshing and other aspects of the test assessment indicators, in the test process, with the help of the power machine through the transmission device to drive the spiral conveyor. At the beginning of each test, 5 kg of quantitative soybean particles are uniformly conveyed to the horizontal conveyor, and the conveying mode is consistent with the simulation process as much as possible.

Verified by the conveying test, the screw conveyor is basically consistent with the simulation results in terms of the relationship between filling rate and flow rate, rotational speed and flow rate, filling rate and torque, and rotational speed and torque. Specific performance: in the rated speed, the flow rate increases with the increase in filling rate, filling rate in the 0.3-0.4 filling rate interval, the flow rate growth trend is rapid. At the rated fill rate of 0.3, the flow rate increases with speed. In the rated speed range, the flow rate increases significantly. Torque increases with filling rate, and at the rated filling rate of 0.3, torque increases with rotational speed, with significant torque growth in the 250-300 r/min rotational speed range. However, due to the limitation of the accuracy of the measuring instrument, the specific parameter change amount could not be verified in this test, and relevant research work will be carried out for this in the future.

Figure 11 Screw conveyor experimental prototype

5. Conclusion

1) Based on EDEM and discrete element method, the magnitude of material flow and torque of screw conveying is analyzed at different filling rates and at different rotational speeds.

2) In the simulation of screw conveying, most of the particles are running smoothly, and the overall speed is low due to the set rotational speed, and a few high-speed particles are concentrated near the inlet and outlet. The accumulation of particles below the inlet facilitates continuous conveying. There is a correlation between filling rate and flow rate, speed and flow rate, filling rate and torque, speed and torque, which shows that when one side increases, the other side also increases, and the growth is more rapid in a specific interval.

3) Using the screw conveyor prototype for experimental verification, it is learned that in the process of screw conveying, the filling rate and flow rate, speed and flow rate, filling rate and torque, and speed and torque of the relationship between the law, which is basically consistent with the simulation results.

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