Simulation and Analysis of Vertical Screw Conveyor Based On EDEM

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Abstract: Screw conveyor is a major equipment for bulk delivery and the vertical screw conveyor is one of its key components. Research on the vertical-screw conveyor helps to optimize the design and increase the efficiency of bulk transportation. The theory of Bulk Mechanics, analysis tool (EDEM) with discrete element and a setting periodic boundary model are applied in this work to simulate the vertical screw conveyor's grain (e.g., coal) delivery condition under different fill levels and screw rotational speeds and analyze the conveying process, state, and performance of bulk materials in the vertical conveying of the screw ship unloader under different filling rates and speeds.

1. Introduction

With the rapid development of the national economy and foreign trade, China has become a major country in port loading, unloading and transportation. As of 2020, China's port throughput capacity has ranked first in the world for 17 consecutive years. In the field of bulk cargo logistics, bulk unloading operation is the bottleneck link that influences the pier working efficiency, and the ship discharged technology has become a core technology of bulk cargo professional wharf. Vertical screw ship unloader is expected to become the mainstream equipment of bulk unloading operation in the future with its characteristics of energy conservation and environmental protection. [1]

Due to the complex mechanical properties of the material particle group, the complexity of the movement of the material in the vertical transportation process, and the idealized assumption of theoretical analysis, it is difficult to fully simulate the stable motion state of materials in vertical spiral conveying at present. However, the discrete element simulation analysis method provides an effective tool for this type of research. In this paper, discrete element simulation software is used to model the vertical spiral under different filling rates and speeds. Through simulating and analyzing the conveying process of materials, we can find out the influence of different filling rate and speed on the material movement and vertical screw conveying performance. The simulation results show that the mass flow rate of the new vertical screw shaft is slightly decreased, while the driving torque is slightly increased, and the material axial conveying speed is basically not affected, but the requirements for manufacturing and installation accuracy are greatly reduced.

2. Vertical screw simulation model based on EDEM

Shimizu and Cundall first proposed the use of DEM to model the particle flow in a screw conveyor and they used it to study the performance of horizontal and vertical screw conveyors and compared the results with previous work and empirical formulas. Owen et al [2-3] introduce periodic boundary model to explore the performance of long screw conveyor. Cleary uses DEM to study the model that material is settling-down from 45° Angle of screw conveyor of the hopper [4], and have a further research on the influence that particle shape has on the subsidence flow and the characteristics of screw conveyor transport [5]. Refer to previous research, this paper uses discrete element method (DEM) and setting periodic boundary model to simulate the vertical screw conveyor's materials delivery condition under different fill levels and screw rotational speeds and analyze the flow state of material particles in the vertical screw conveyor, and the influence of different filling rates and rotating speeds on the productivity and power of the vertical screw conveyor.

2.1 Vertical screw model

Based on the relevant dimensions of the vertical conveyor of the screw ship unloader with a rated productivity of 1200T/h, the milling formula screw feeding device is selected to provide stable materials for the vertical screw conveying section. The modeling of the vertical conveying screw is based on the characteristics of the vertical screw structure, considering the simulation scale and calculation time, and intercepting a section of the vertical conveying screw to simulate the vertical conveying process of the screw ship unloader more completely. The specific modeling dimensions are: the vertical spiral is double-headed right-handed, its diameter is 820mm, the blade thickness is 10mm, the spiral length is 7000mm, the inner diameter of the conveying pipe is 844mm, and the wall thickness is 10mm. The three-dimensional modeling is drawn with SOLIDWORKS mechanical modeling software. Figure 1 shows the EDEM simulation model of the vertical conveying section.

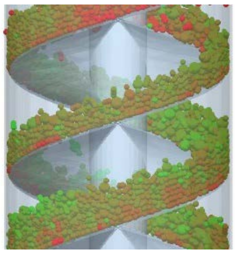

Figure. 1 EDEM simulation model of vertical conveying section   Figure. 2 EDEM simulation of material vertical conveying process

Figure 2 shows the EDEM simulation diagram of the material movement state during the vertical conveying process. The EDEM simulation video of the vertical conveying process of materials can visually inspect the conveying process of materials in the vertical screw.

2.2 Parameter settings of EDEM simulation

The contact models of particles and particles, the models of particles and geometry boundary, the direction and magnitude of gravity acceleration, the physical material of particles and the geometry, the restitution coefficient, static friction coefficient and rolling friction coefficient of particles and particles and particles and geometry. As follows:

(1) Particles and the material of geometry

The particles used in this simulation are coal and the radius (the generalized radius of the particle) obeys a normal distribution, the mean is 1 time the radius, the variance is 1, and the particle radius is 10mm. The screw conveyor is made of Q345 steel.

(2) The physical properties of particles and the geometry

In the simulation of the actual system, the rationality of physical properties of materials is the key to ensure that the simulation results are close to the reality, the physical properties of the materials involved in simulation are shown in Table 1 and Table 2 [6].

Table. 1 Material Properties Table

Material	Poisson’s	Shear Modulus（Pa）	Density（kg/m^3）
Coal	0.4	1.1×10^{7}	1023
Steel	0.3	1.0×10^{10}	7850

In this table, Poisson's ratio, shear modulus, and density parameters are taken from literature [6] and the density of pulverized coal is the actual measured value.

Table. 2 Contact Property Table

Interaction	Restitution coefficient	Coefficient of static friction	Coefficient of rolling friction	The contact models
Coal-coal	0.5	0.6	0.05	Hertz-Mindlin（no slip）
Coal-steel	0.5	0.4	0.05	Hertz-Mindlin（no slip）

(3) The contact models

Discrete Element Method simulates the spreading process of movement in the collection of the particles and the movement of particles would inevitably lead to collision between the particles and generate force. In this simulation, it is no sliding Hertz-Mindlin contact model between particles and particles and particles and geometry.

2.3 EDEM simulation scheme settings

The simulation scheme is: combined with the actual working conditions of the L-shaped screw ship unloader, and considering that the number of particles in the simulation is close to the limit of the EDEM software (1 million) [7] and the single simulation time lasts for nearly one month, in order to simulate the transportation process more comprehensively, the simulation scheme is shown in Table 3.

Table. 3 Working condition simulation program

Group	Mechanism	rpm	Mechanism	rpm	Mechanism	rpm
1	Horizontal screw rotational speeds	80	Horizontal turning speed	0.364	Vertical screw rotational speeds	228
2		80		0.364		252
3		80		0.364		270
4		80		0.364		282
5		80		0.52		300
6		80		0.468		300
7		80		0.416		300
8		80		0.364		300
9		80		0.312		300

Based on the comprehensive consideration of the simulation scale and calculation time, the simulation scheme aims at the two most important parameters of the vertical screw conveying performance of the screw ship unloader-the filling rate and the screw speed and simulates and analyzes the conveying process and performance under different filling levels and screw speeds.

3. The simulation results analysis

After completing the simulation calculation, this paper uses the data analysis module to obtain the simulation calculation results and analyze them.

3.1 Simulation analysis of vertical transportation under different filling rates

1. Changes in the axial conveying speed of particles

Set the vertical spiral speed to 300rpm, the horizontal spiral speed to 80rpm, and the material pile height to 700mm and perform EDEM simulation under five different filling levels by changing the speed of the horizontal reclaiming section.

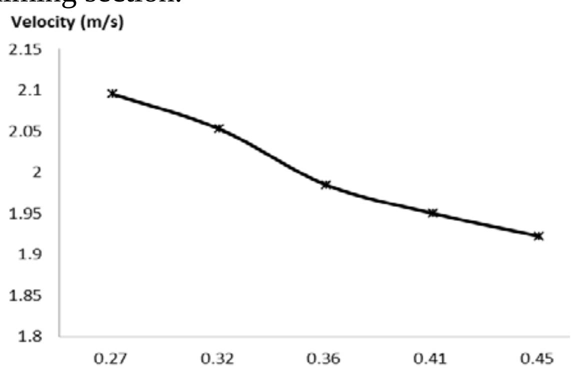

Figure. 3 Trend chart of average axial linear velocity of particles under different filling rates

Figure 3 shows the change of the overall average axial conveying speed of particles in the vertical screw ship unloader. The results show that with the increase of the filling rate, the average axial linear velocity of the particles in the vertical spiral conveying slowly decreases, but compared with the increase of the filling rate, the average axial linear velocity of the material particle group decreases less. When the filling rate increases by 65%, the average axial linear velocity of the material particles decreases by only 8.26%. When the vertical spiral speed is constant, the change of the filling rate has a small effect on the average axial linear velocity of the material particles in the vertical spiral conveying (the maximum is only 8.26%).

2. Changes in the axial force of the screw axis

Under the same parameter setting conditions as in the previous section, this paper performs EDEM simulation under five different filling rates through changing the rotating speed of the horizontal reclaiming section. Figure 4 shows the change of the average axial force on the vertical spiral blade. The results show that with the increase of the filling rate, the average axial force on the spiral blade increases firstly, but when exceeding a certain value, with the increase of the filling rate, the increase of the average axial force on the spiral blade decreases. When the filling rate changes from 0.40 to 0.46 and 0.53, the average axial force on the spiral blade increases by 16.8% and 15.4%, respectively; however, when the filling rate changes from 0.53 to 0.59 and 0.66, the increase in the average axial force on the blade is only 0.38% and 0.42%, respectively. The simulation shows that when the filling rate is small, it has a greater influence on the average axial force that the spiral blade suffered, but when the filling rate exceeds a certain value, with the increase of the filling rate, the average axial force on the blade increases slightly.

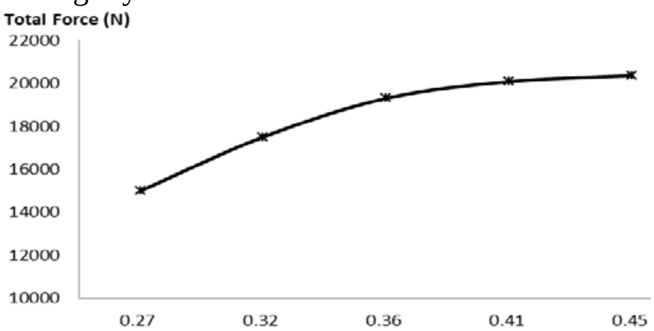

Figure. 4 Trend chart of average axial force that spiral blades suffered under different filling rates

3. Changes in the productivity of vertical screw conveyors

The transportation volume of the vertical screw ship unloader can be analyzed by measuring the mass flow rate of the particles by the quantitative detection method. Mass flow refers to the sum of the mass of particles passing through a section perpendicular to the spiral axis per unit time, which is usually located in the middle of the two boundaries [6].

Using EDEM post-processing to obtain the mass flow rate of the screw ship unloader for vertical conveying under different working conditions. Under the same parameter setting conditions as in the previous section, this paper performs EDEM simulation under five different filling rates through changing the rotating speed of the horizontal reclaiming section.

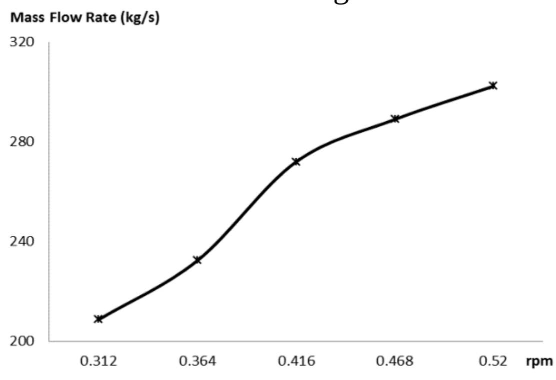

Figure. 5 Trend chart of vertical spiral productivity under different filling rates

Figure 5 shows the change in the productivity of the vertical conveying screw. The simulation results show that with the increase of the filling rate, the average mass flow of particles in the vertical screw ship unloader increases. When the filling rate changes from 0.40 to 0.46 and 0.53, the average axial total torque on the vertical spiral increases by 9.97% and 4.1%; however, when the filling rate changes from 0.53 to 0.59 and 0.66, the average axial total torque on the vertical spiral increases by 4.4% and 6.5%, respectively. Increasing the filling rate can significantly increase the productivity of the screw ship unloader.

3.2 Simulation analysis of vertical conveying under different speeds

1. Changes in the axial conveying speed of particles

Set the horizontal reclaiming screw rotating speed to 80rpm, and the horizontal reclaiming screw turning speed to 0.364rpm, and the material pile height to 700mm. The EDEM simulation is performed by changing the vertical spiral speed under the same filling rate. Figure 6 shows the variation of the overall average axial conveying linear velocity of particles in the vertical screw ship unloader. The simulation results show that with the increase of the vertical spiral speed, the average axial linear velocity of particles in the vertical spiral conveying increases. When the vertical spiral speed changes from 228rpm to 252rpm and 270rpm, the average axial linear velocity of the particles increases by 18.4% and 14.6%; however, when the vertical spiral speed changes from 270rpm to 282rpm and 300rpm, the average axial linear velocity of the particles increases by 3.9% and 6.3%, respectively. Increasing the spiral speed can increase the axial linear velocity of the material in the spiral conveying, thereby increases the productivity of the ship unloader.

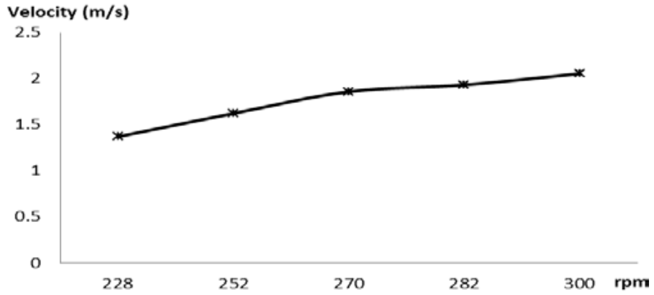

Figure. 6 Trend chart of average axial linear velocity of particles at different speeds

2. Changes of the axial force that the screw shaft suffered

Under the same parameter setting conditions as in the previous section, this paper performs EDEM simulation through changing the vertical screw rotational speed. Figure 7 shows the change of the axial average resultant force experienced by the vertical spiral. The simulation results show that with the increase of the vertical screw rotational speed, the average axial force on the vertical spiral shaft also increases. When the vertical screw speed changes from 228 rpm to 252 rpm and 270 rpm, the increase of the average axial force that the screw shaft suffered is 5.58% and 4.3%, respectively. Nevertheless, when the vertical screw rotational speed changes from 270 rpm to 282 rpm and 300 rpm, the increase of the average axial force experienced by the screw shaft is 2.8% and 5.3% respectively. With the increase of the vertical spiral rotational speed, the average axial force on the spiral shaft increases slightly, but compared with the increase of the average axial force caused by the change of the filling rate, it shows a trend of smaller first and then larger.

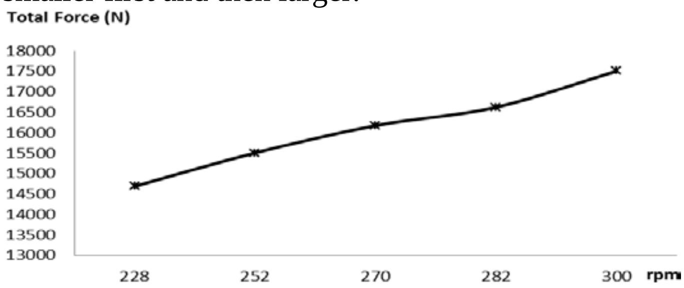

Figure. 7 Trend chart of axial force that screw shaft suffered under different speeds

3. The change of the axial average total moment of the screw shaft

Under the same parameter setting conditions as in the previous section, this paper performs EDEM simulation through changing the vertical screw rotational speed. The simulation results show that with the increase of the vertical screw rotational speed, the average axial force on the spiral shaft also increases. When the vertical screw speed changes from 228 rpm to 252 rpm and 270 rpm, the increase of the average axial force that the screw shaft suffered is 1.8% and 0.7%. However, when the screw rotational speed changes from 270 rpm to 282 rpm and 300 rpm, the increase of the average axial force on the screw shaft is 3.7% and 5.2%, respectively. With the increase of the vertical spiral rotational speed, the average total axial torque the screw shaft suffered increases slightly, but the increase is smaller than that caused by the change of the filling rate.

4. Conclusions

Based on the discrete element method, this paper carries out EDEM modeling and simulation on the vertical spiral shaft under different filling levels and rotational speeds and simulates the conveying process of materials based on the original design and actual situation. According to the results of the EDEM simulation analysis and comparing the particle axial average linear velocity, mass flow rate, average total energy of particles and average axial total moment experienced by the spiral blade of the vertical spiral shaft, the results in this paper show that the mass flow rate (vertical screw conveying capacity) of the new vertical screw shaft machine with the middle spoke structure is slightly reduced, the torque required to drive the screw shaft (the driving power of the vertical screw shaft) is slightly increased, and the material axial conveying speed is basically not affected.

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