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Study Horizontal Screw Conveyors Efficiency Flat Bottomed Bins EDEM Simulation

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Abstract: It describes the development history flat bottom silo, characteristics and testing system, composition. For the poor current theory and computer simulation study on horizontal spiral conveyor in the system, Using Solidworks to establish a reasonable three-dimensional model of flat bottom silo Horizontal Screw Conveyors, to import the model into EDEM software, simulation. By setting parameters and the model material parameters, draw motion vectors of the material along the helical axis, horizontal screw conveyor average number of transported materials particles, The results with experimental results compared to abroad, Flat bottom silo systems used EDEM software for the efficiency study of horizontal screw conveyors is authenticity and reliability, at the same time, the simulation makes the screw conveyor filling rate to identify more specific , Save time on flat bottom bunker system design, shorten the development cycle. *Copyright © 2013 IFSA.*

Keywords: Flat bottomed bin, Horizontal screw conveyor, Solidworks, EDEM simulation.

1. Introduction

Flat bottomed bin is also called the mammoth bin or giant bin (see Fig. 1) [1], its development can date back to the 1960s. The earliest flat bottomed bin was set up by ESI Eurosilo company, installed in the Netherlands AVEBE starch company, used to solve the problem of a large number of long-term storage for potato starch, thus protecting it from seasonal fluctuations.

Flat bottomed bin has been widely used in

Europe in the 1970s, between the end of the 20th century to the beginning of the 21st century, Japan determined to realize the industrialization and modernization for potato starch products, and the storage capacity of potato starch were improved significantly.

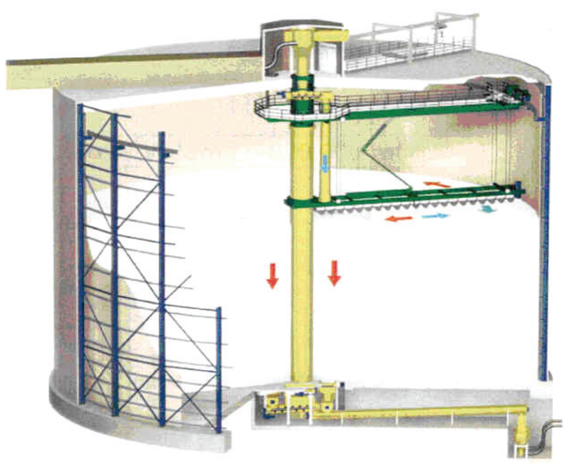


Fig. 1. Flat bottom silo structure.

With the development of science and technology, by installing special spiral rotary devices in bins, makes flat bottomed bin not only suitable for storage of liquid loose material, but also applicable for adhesiveness.

Now, flat bottomed bin has been widely used in energy, chemical industry, agriculture and other fields for storage bulk material, compared with the traditional way of storage, flat bottomed bin has the following advantages [2].

1) The enclosed design protects the internal material, no pollution to the environment;

2) It has a high storage capacity, covers a very small area;

3) The loading process realizes automatic precise control, without the artificial site operation;

4) The high degree of integration, can integrate dehydration, storage and discharging in a fully automated system;

5) The internal structure adopts modular design, can replace components easily.

6) It is not only suitable for access to a single material, but also applied to homogenize a variety of materials.

Flat bottom silo system (shown in Fig. 2) is mainly composed of flat bottomed bin, reversible belt feeder, wavy guard ring rail crane, corrugated wall belt conveyor, rotation/revolution of screw conveyor automatically loading /unloading device, general belt conveyor, transfer device and electric control, etc.

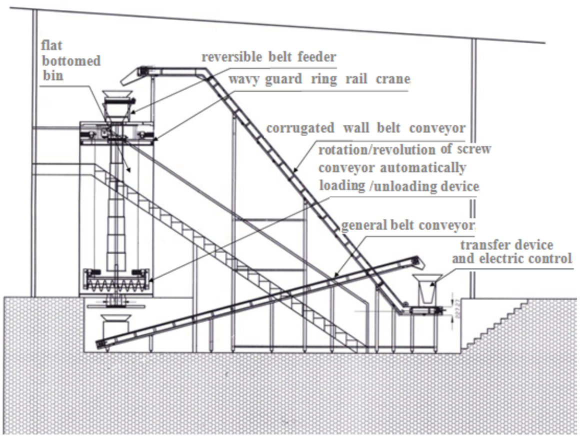


Fig. 2. Flat bottom silo systems.

2. Flat bottom Silo System Horizontal Screw Conveyor

2.1. Horizontal Screw Conveyor

Inside the flat bottomed bin was decorated a rotation/ revolution of screw conveyor automatically layout/feed system (see Fig. 3), its principle is to put the two screw conveyor in a line, through motor's positive and negative rotation to realize the screw conveyor's rotation, so that the material move to the middle or around, realizing the role of auxiliary unloading and loading.

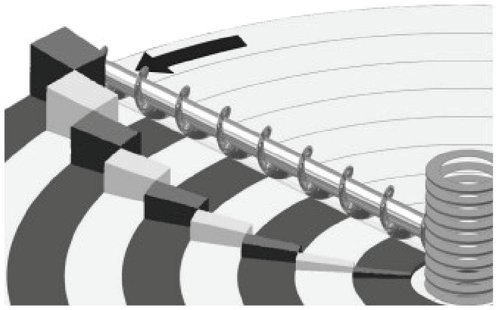


Fig. 3. Flat bottom silo systems.

Screw conveyor is a conveying machinery, which do not have flexible traction components , open horizontal screw conveyor is mainly composed of spiral blades, shaft and drive [3], see its structure in Fig. 4. Its operating principle is: screw conveyor insert material surface, the axis drives helical blade rotation, due to the effect of material's gravity and its internal friction , makes it not rotate with the spiral, but under the effect of spiral thrust, it moves along the axial , the direction of feeding and discharging is in a horizontal angle of 90 degrees [5].

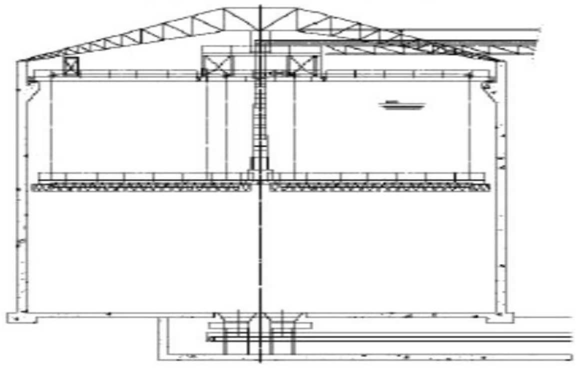


Fig. 4. Open horizontal screw conveyor horizontal screw conveyor's layout drawings.

The transmission capacity of horizontal screw conveyor which owns physical helical surface is [6]:

$$Q = 470\psi k_2 \gamma n D^3 \text{ (t/h)},$$

where ψ is the filling coefficient of the material, k_2 is the screw pitch and screw axis diameter ratio, γ is the packing density of the material to be delivered [kg/m^3], n is the speed of screw [rpm] and D is the screw diameter [m].

We find that when the horizontal screw conveyor conveys certain material, increasing the filling coefficient ψ of material, screw speed n and screw diameter D can also increase the productivity. In order to reduce the cost and self-weight of the conveyor and meet delivery capacity while does not affect the efficiency of the case, we try to reduce the screw axis diameter d, however, the increase of material filling coefficient ψ and screw speed n make the material rolling around the screw axis in the process of delivery, reducing conveying efficiency, thus to meet the transmission efficiency of horizontal screw conveyor, the filling coefficient ψ of material, screw rotational speed n and other parameters must be reasonable designed.

In this paper, the studies on flat bottom silo with opened horizontal screw conveyor, its conveying capacity is not only related to screw diameter, screw speed, but also related to the filling coefficient. To determine reasonable parameters, we must apply advanced design method to determine the constraint relationship between the parameters and their effects on the conveying process.

2.2. The Comparison of traditional Design Method and Advanced Design Method

The traditional mechanical design methods are analogy design method, test algorithm, Table, Fig., etc. These methods are based on experience, sensibility, static manual labor. The design workload is massive; design cycle is long and can not obtain ideal results easily.

The design method of advanced computer simulation is a scientific, rational, dynamic computerized process, through the analysis of original data, adopting the technical means and methods to draw the most economic and reasonable parameters, makes design results more optimal.

EDEM is global CAE software which is based on the discrete element method simulation, analysis particle system process and the production operation. EDEM solves the movement of particles, momentum and energy transfer. Now a lot of industries, such as chemicals, food, minerals, raw material processing and so on all, apply EDEM design analysis software to design and analysis quickly, so the application of EDEM reduces development time and costs.

3. Simulation of Loading/unloading Efficiency

Shimizu and Cundall first describes the DEM simulation of screw conveyor motion state of the material, they studied the performance of the screw conveyor and according to the experience of the previous work they compared the DEM simulation and actual test results. Owen, etc employ a single spiral blade model to explore the performance of the screw conveyor. But the research content is the study of vertical screw conveyor, and for the simulation of horizontal screw conveyor is more a lack of, especially the flat bottomed silo horizontal screw conveyor in the loading/unloading problem.

This article uses Solidworks to fulfill modeling and simulated with EDEM software, getting a result of unloading efficiency, particle velocity and mass flow rate, energy loss and power consumption of the horizontal screw conveyor in the flat bottomed silo, meanwhile analyzes the inside flat bottomed silo of the horizontal screw conveyor' change of the internal material flow state under different conditions.

3.1. Modeling for the Flat Bottomed Silo Horizontal Screw Conveyor

The establishment of model references Ekke Oosterhuis's test method which is used to study flat silo screw conveyor unloading efficiency , converted the screw conveyor's rotation motion to horizontal motion, placed the horizontal screw conveyor in the bin, by adding rectangular particle plant in the bin to feed screw conveyor, and by giving different heights of particle plant to realize the different filling rate, finally made the screw conveyor do rotation and horizontal motion at the same time. Modeling with Solidworks was shown in Fig. 5.

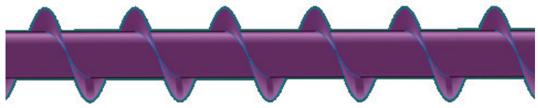


Fig. 5. Analog unloading model to flat mammoth silo.

The content mainly research conveying material under different fill rates for open screw conveyor, there are three main parameters: (1) the unloaded particles amount, namely the comparison of the unloading efficiency; (2) the comparison of particle velocity, including four aspects, such as average speed variation, average axial velocity, average rotational speed and average speed; (3) the comparison of mass flow rate. Importing the entity model which was built by Solidworks software into EDEM software, simulation by setting movement parameters, it provides unlimited flexibility for both the specified 3D geometric model and the interaction among the particles.

The simulated horizontal screw conveyor is standard pitch, single screw blade, when turn a circle around the shaft, the length is defined as a pitch. Due to the simulation results should be compared with the abroad experimental results [4], the parameter of horizontal screw conveyor model is set to: screw diameter D = 300 mm, screw pitch S = 300 mm, screw axis diameter D = 150 mm, screw length L = 1500 mm. To build a model for horizontal screw conveyor as Fig. 6.

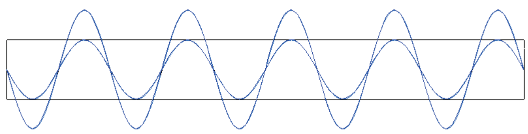


Fig. 6. Horizontal screw conveyor model.

This article treats the coal ash which its packing density is 500 kg/m^3 as the research object, the particle size of coal ash is among 0 to 1000 μm, evenly distributed on the quality of a uniform.

3.2. Determination of Simulation Parameters

In EDEM simulation, reasonably determine the mechanical properties for materials is a key factor to ensure the simulation results, material for all the parts of the structure which was involved in the simulation are shown in Table 1 and Table 2 [7].

Table 1. Material properties table.

Material	Poisson ratio	Shear modulus /(pa)	Density /(kg/m3)
coal ash	0.5	1e+08	500
steel	0.3	7e+10	7850

Table 2. Contact property table.

Interaction	Coefficient of restitution	Static friction coefficient	Rolling friction
coal ash-coal ash	0.5	0.6	0.05
coal ash-steel	0.5	0.4	0.05
Steel-coal ash	0.5	0.4	0.05

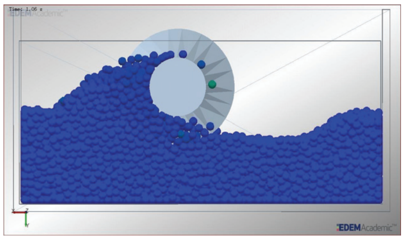
The simulation refers to foreign experimental parameters [4], screw shaft speed was set to 300 rpm, horizontal movement speed was set to 10 mm/s, and set up three different filling rate, such as 8 %, 15 %, 30 %, [8] (the three values is set up to compare with the abroad experimental data, to verify the simulation's accuracy and feasibility of EDEM software, while it does not represent the fill rate's actual optimal value of screw conveyor).

3.3. Results of Simulation

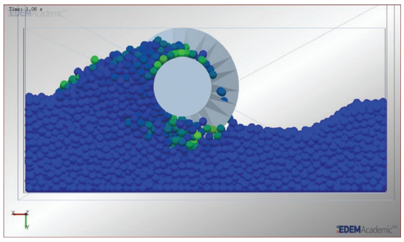
3.3.1. Particles Distribution in the Process of Conveying for Horizontal Screw Conveyor

We specified that the right-hand of screw was the unloading area, screw speed was set to 300 rpm, the material's initial filling rate is 8 %, 15% and 30 % respectively (as shown in Fig. 7, screw conveyor submerged into different depth of materials was satisfied for different fill rates). According to the material's speed, we pained material particles, the particle which moves slowest was pained blue, speed is of slightly higher was painted green, speed is of the highest was painted red; then applied breakout section view command in the EDEM to analysis the material's conveying status when the horizontal screw conveyor stably operated, and through breakout section, the longitudinal section for the particle distribution of internal material was shown in Fig. 7-a and 7-b, 7-c, transverse sections was shown in Fig. 8-a, 8-b, 8-c.

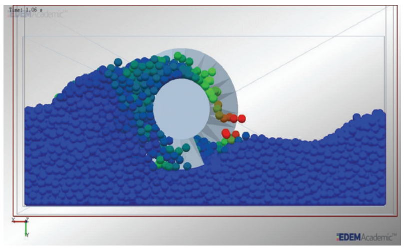
From Fig. 7, we find that the actual and expected conveying effect of open screw conveyor are the same, in the process of operation, with the improvement of filling rate, there will be a part of material particles cannot do axial movement along with the screw conveyor, but get over the screw shaft to the material inflow side, they can not be conveyed, and when fill rate of screw conveyor is higher, the more material particles get over the screw axis.



(a) Fill rate in 8 %.



(b) Fill rate in 15 %.



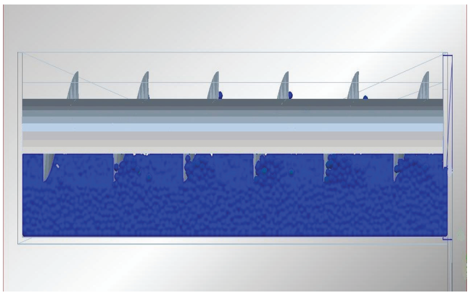
(c) Fill rate in 30 %

Fig. 7. Screw conveyor longitudinal cross-sectional of material particle distribution in three fill rate.

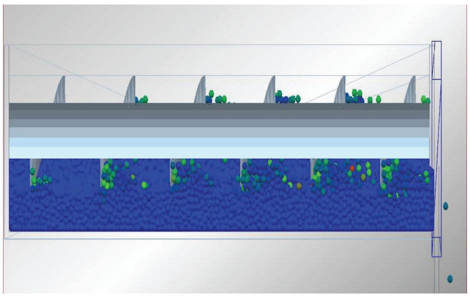
In Fig. 7-a, screw conveyor's filling rate is 8 % which is the minimum, its handling efficiency can reach 85 % or higher, material mainly do axial movement along with the screw conveyor, the average speed of the material is not high, basically is blue, material is mainly in the screw axis side (material handling side). In Fig. 7-b, the screw conveyor's filling rate is increased to 15 %, this time material gets over the screw axis and in the side of material flow into, the quantity of material particle is increased, the handling efficiency decreases about 70

% or so, and you can see the material which close to the screw axis trends to move faster compared with Fig. 7-a. In Fig. 7-c, screw conveyor's filling rate has been increased to 30%, we can see that most of the material is rolling-over, it gets over the screw axis and in the side of material flows into, thus it can't be carried forward, handling efficiency is significantly lower, about 50 %, while material moves evidently faster, especially above the screw axis and the side of material flows into, color has been red, jumping phenomenon is obvious.

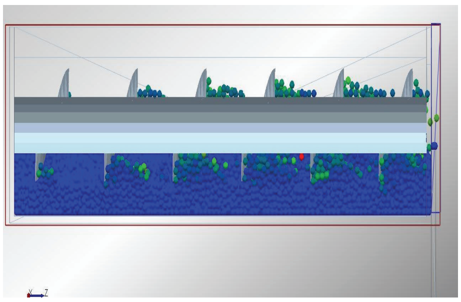
From Fig. 8 we can see material's distribution along the screw conveyor under three different fill rates. While the screw conveyor does translation and rotation, material moves along the screw conveyor, handling from bottom of the conveyor to the unloading end. The material's filling rate is the highest near the unloading end, it shows that the handling is a process of gradual accumulation when in the process of handling material along the screw conveyor axial, and when material’s filling rate increases , material accumulate more obvious near the unloading end (shown in Fig. 8-c).



(a) Fill rate in 8 %.



(b) Fill rate in 15 %.



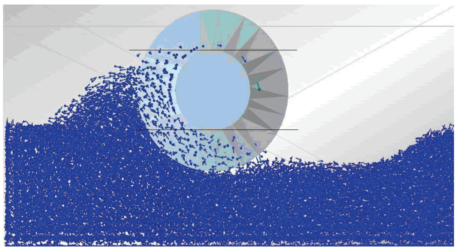
(c) Fill rate in 30 %.

Fig. 8. Screw conveyor transverse cross-sectional distribution of material particles in three fill rate.

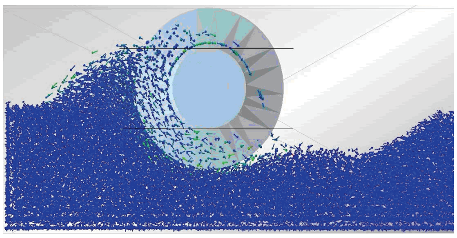
3.3.2. Vector Diagram for Particle Distribution

Longitudinal interface of screw conveyor can be divided into three parts, which are used to analysis material's motion vector. When the filling rate is lower (Fig. 9-a), we find that some of the material in three parts moves along the screw axis, and some of the material moves perpendicular to the screw axis, and the central is the main force for material moving along axial, above the central, the material start to move in all directions, most moves to the left and forms a stack, a few part gets over the screw conveyor to the side of material flow into.

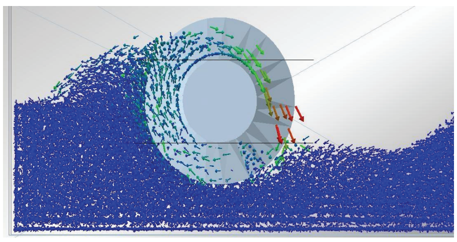
When material's filling rate increased to 15 % (Fig. 9-b), the lower material moving along the screw axis becomes very few, they basically move perpendicular to the screw axis, while the central material is still the main force for material moving along axial, the number of particles which handled along the axial is lower than the low filling rate, the number of upper material particle also significantly increases, most material particle moves perpendicular to the screw axis, and turns to the non-handling direction. When the filling rate increased 30 % (Fig. 9-c), the movement directions of the three parts are mostly perpendicular to the screw axis, and velocity is improved obviously.



(a) Fill rate in 8 %.



(b) Fill rate in 15 %.

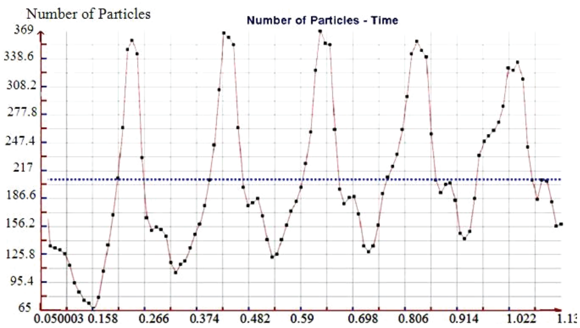


(c) Fill rate in 30 %.

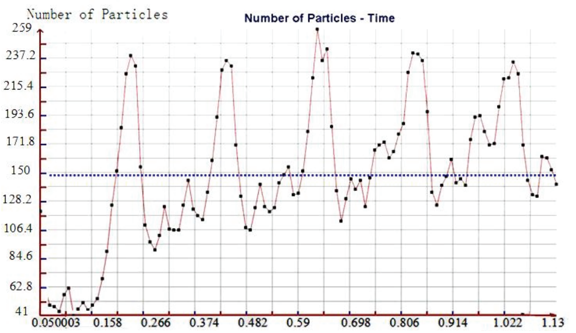
Fig. 9. The material particle motion vector in three fill rate.

3.3.3. Handling Efficiency of Horizontal Screw Conveyor

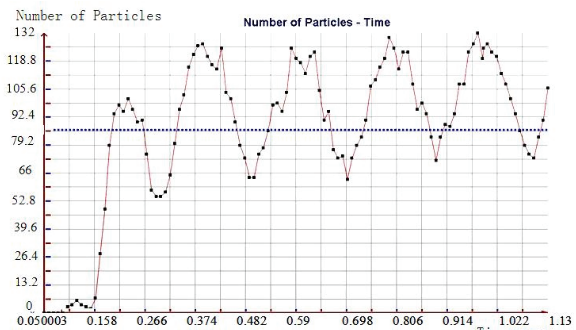
From Fig. 10, we find that when the filling rate is 8 %, the average number of conveying particles is about 210, when the filling rate is up to 15 %, the average number of conveying particles will reduce about 150, when the filling rate is up to 30 %, the average number of conveying particles is down to about 86. In Ekke Oosterhuis trial, when the fill rates are 8 %, 15 % and 15 %, the conveying efficiency is 85 %, 68 % and 45 %, respectively. We can find that the results which get by computer simulation and experimental are basically identical. It has concluded that simulation results and experimental results are basically consistent, and namely that computer simulation can replace physical experiment, it both saves the cost and shortens the research time.



(a) Filling rate in 8 %.



(b) Filling rate in 15 %.

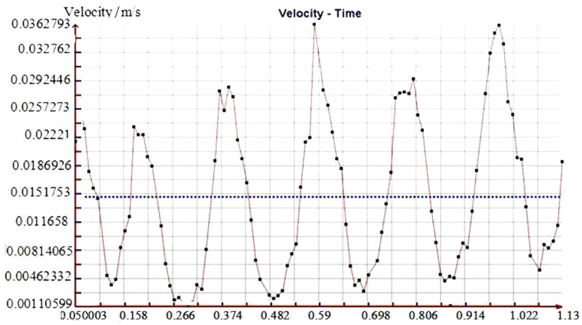


(c) Fill rate in 30 %.

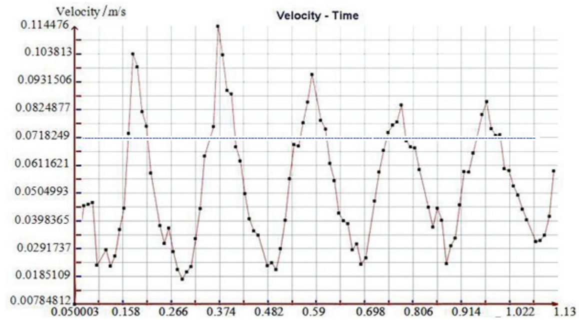
Fig. 10. The material particle number conveyed by screw conveyor versus time in three fill rate.

3.3.4. Average Speed of Particle Movement

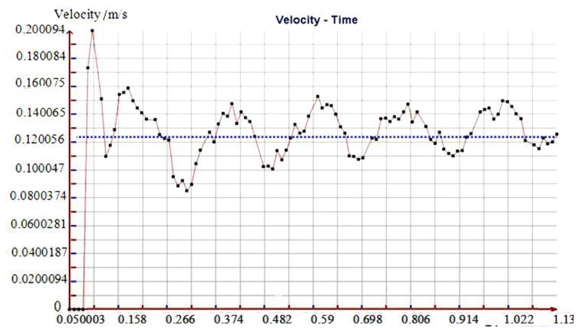
In Fig. 11, we can see that it is a curve of average speed over time when material under different filling rates does circumferential motion, and we also find that when the filling rate increases, material's speed will also increases. Combining with Fig. 8 we concluded that speed increasing was mainly due to the increasing speed of perpendicular to the axial, while the speed along the axial did not increase, it illustrates that increasing the filling rate doesn't improve the conveying efficiency.



(a) Filling rate in 8 %.



(b) Filling rate in 15 %.



(c) Filling rate in 30 %.

Fig. 11. The material particle motion average speed versus time in three fill rate.

4. Conclusion

In this paper, firstly it introduced the composition, characteristics and working principle of flat bottomed bin system, then it used Solidworks software to establish three-dimensional model for flat bottomed bin's unloading part and horizontal screw conveyor, imported the model into EDEM software, by setting model and different motion parameters, we studied the simulation and get the following conclusions:

1) While the filling rate of material increases, material's motion vector along the screw axis is reduced, vector of perpendicular to the screw axis increases, so it makes the material particles along the screw axis running forward trends abate, but rotates with a screw axis and does reverse movement.

2) The average conveying number of material particles for screw conveyor is different when materials under different filling rates, the average conveying number of material particles reduces while the filling rate increases.

The results which get from computer simulation are basically identical with experimental results. Foreign experimental results are follows: when filling rate < 8 %, the speed of material particles along the axial is the largest, the material particles' conveying number is the highest , conveying efficiency reached more than 80 %; While the filling rate increases, axial velocity of material particle does not increase, and radial velocity perpendicular to the axial increases, material particles starts rotating with the screw axis, the number of conveyed material particles is reduced, also conveying efficiency is reduced, when the filling rate > 40 %, conveying efficiency is below to 50 %.

The research fills the domestic blank in the research of simulation for flat bottomed bin opened horizontal screw conveyor. The simulation makes the filling rate of screw conveyor more specification. At present, the existing theory is: for the horizontal screw conveyor, the filling coefficient of material can not increase without limit, instead small values have advantages, generally adopts the value less than 50 % [6]. By simulating with EDEM software, it provides a reliable and efficient mean to reasonably determine the best filling rates for material. At the same time, to a certain extent, it is also verified that it is an authenticity and feasibility research for loading/unloading efficiency of flat bottomed bin system. It both saves time for design flat bottomed bin systems and shortens the construction cycle.

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