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APPLICATION OF DISCRETE ELEMENT METHOD FOR THE TRANSPORTAT OF SEED IN SCREW CONVEYOR

PRIMENA MODELA DISKRETNIH ELEMENATA NA PROTOK ZRNASTOG MATERIJALA U PUŽNOM TRANSPORTERU

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ABSTRACT

Fifteen horizontal single-pitch screw conveyors with modified geometry and the different lengths were investigated for premixing action, during the transport of materials. All investigations were performed experimentally and numerically, by using Discrete Element Method (DEM). The influences of screw length, observed geometry variations and different types of screw design, on the performances of the screw conveyor-mixer during material transport were explored. The auxiliary mixing action was achieved during the transport of the material. The geometry of the screw conveyor is changed by adding three complementary helices oriented in the same or the opposite direction from screw blades. The particles of the material being transported tumble down from the top of the helix to the next free surface, and that segment of helix was used for additional mixing action. According to DEM analysis, particle path length is increased, and the improved geometry could be determined for increasing the quality of mixing.

Key words*: DEM model, seed, screw conweyor, premixer.*

REZIME

Pužni transporteri imaju široku primenu u prehrambenoj industriji, građevinskim i rudarskim kompanijima, u hemijskoj, poljoprivrednoj i prerađivačkoj industriji, uglavnom za podizanje i / ili transport rasutih materijala na kratkim i srednjim rastojanjima. Uprkos njihovoj očiglednoj jednostavnosti, poboljšanje transportnih parametara je veoma zahtevan zadatak i inženjeri obično moraju da se oslanjaju na podatke dobijene empirijskim istraživanjima. U ovom radu, ispitivano je petnaest horizontalnih pužnih transportera sa konstantnim korakom pužnice, različite dužine, sa modifikovanom geometrijom. Ovi puževi su ispitivani radi mogućnosti pomoćnog mešanja tokom transporta materijala. Sva ispitivanja su rađena eksperimentalno i numerički, pomoću metode diskretnih elemenata (Discrete Element Method - DEM). Uticaji dužine puža, kao i predložene modifikacije geometrije u dizajnu pužne spirale, ipitivani su radi pomoćnog mešanja, tokom transporta granulisanog materijala kroz pužni transporter. Pomoćno mešanje (koje se koristi se za poboljšanje finalnog procesa mešanja) je postignuto tokom transporta materijala. Geometrija pužnog transportera se menja dodavanjem tri komplementarne spirale orijentisane u istom ili suprotnom smeru od pužne spirale. Čestice materijala se transportuju padaju dole sa vrha spirale do sledeće slobodne površine, i taj segment spirale je korišćen za dodatnu akciju mešanje. Prema eksperimentima i DEM analizema trajektorija čestice se povećava, sa primenjenim modifikacijama transportera, a ovakva geometrija može se koristiti za povećanje kvaliteta finalnog mešanja.

Ključne reči: *DEM model, zrnasti materijal, pužni transporter, predmešač.*

INTRODUCTION

Screw conveyors are widely used for transporting and/or elevating particulates at controlled and steady rates. The modern conveyor consists of a helical screw rotating in a U-shaped trough or enclosed pipe. Screw conveyors are not efficient as belt conveyors. The reason for low efficient is friction between the solids and the flights of the screw. But, they are cheaper and easier to maintain. A summary of current design methods and problems experienced for screw conveyors can be found in *Bortolamasi and Fottner, 2001*. Numerical models based on DEM (Discrete Element Method) showed to be reliable and useful in catching particle interactions and predicting mixing process for investigation of solids mixing. The soft-sphere method originally developed by *Cundall and Strack, 1979*, was the first granular dynamics simulation technique published in the open literature. DEM is a numerical technique used to predict the behavior of collision dominated particle flows. Each particle in the flow is tracked and all collisions between particles and boundaries are modeled. The particles are allowed to overlap and the extent of overlap is used in conjunction with a contact force law to give instantaneous forces from knowledge of the current positions, orientations, velocities and spins of the particles, *Cundall and Strack, 1979*. DEM of particulate flow in a screw conveyor was first reported in *Shimizu and Cundall, 2001*. In this work, the performance of horizontal and vertical screw conveyors were examined and compared with the results of empirical equations. In article *Owen et al., 2003*, the use of a periodic slice model was introduced to explore the performance of a long screw conveyor. *Cleary, 2004*, used DEM to study draw down patterns from a hopper by a 45° inclined screw conveyor.

The main idea in this paper was to analyze the transport process in the screw conveyor and to evaluate the contribution of modified geometry of screw blades on premixing process, before material enters the main mixer. DEM analysis was used to investigate the influence of these modifications in screw geometry on transport path on pre-mixing process, during the transport of particles, with the intention to keep the material flow unspoiled, (*Cundall and Strack, 1979*). The trajectories of the characteristic particle during the pre-mixing process were presented and analysis of the influence on screw geometry on path of the particle, duration and the quality of the mixing process were investigated. All numerical simulations were verified by appropriate experimental results. The quality of the mixing process is analyzed using well known relative standard deviation (RSD) criteria, (*Jovanović et al., 2014a*).

MATERIAL AND METHOD

Experimental method

Fifteen screw conveyors were assembled and tested for mixing capabilities during the transport of bulk material. Five types of modified screw transporters (single flight screw conveyor, modified screw conveyor-mixer with three additional helices oriented in the same direction as screw blades, modified screw conveyor-mixer with three helices oriented in the opposite direction from screw blades, screw conveyor-mixer with three truncated additional helices oriented in the opposite direction as screw blades, and modified screw conveyor-mixer with additional straight line blade), and each modified screw conveyor type was tested in length of 400, 600 or 800 mm. All screw transporters-mixers used in experiments were made from transparent Plexiglas. Each experiment was performed with different type of modified screw transporter, and the different length of transporter. The upper inlet segment was divided into two compartments with a barrier and a mobile panel. Painted spherical granules made from zeolite are placed in both compartments, red granules in the first compartment and blue granules in second compartment. In the following, we considered fifteen different representative cases (five types of modified screw conveyors and three different lengths of screw transporter). Each experiment was repeated for 6 times, and the results of the experiments were averaged.

Model description

The contact between two particles occurs on a finite area due to the deformation of the particles, which is equivalent to the contact of two rigid bodies allowed to overlap slightly in the DEM analysis (*Jovanović et al., 2014a*). The contact traction distribution over this area can be decomposed into a component in the contact plane (or tangential plane) and one normal to the plane, while the evaluation of the total force and torque acting on a particle is related to many geometrical and physical factors such as the shape, material properties and movement state of particles, (*Cundall and Strack, 1979*). DEM analysis generally adopts simplified models to determine the forces and torques resulting from the contact between particles. According to DEM model, the translational and rotational motions of a particle at any time, t, can be described by Newton's law of motion, (*Cundall and Strack, 1979*):

$$m_i \frac{dv_i}{dt} = F_{n,i} + F_{s,i} + m_i g \quad I_i \frac{d\omega_i}{dt} = R F_{s,i} \tag{1}$$

where m_i, I_i, v_i and ω_i are, respectively, the mass, moment of inertia, translational and rotational velocities of particle *i*.

The forces acting on particle *i* are normal force $F_{n,i}$, shear force $F_{s,i}$ and gravitational force $m_i g$, (*Jovanović et. al., 2014b*).

For particle–wall contacts, the maximum shear force is defined with μ_w which represents the coefficient of friction for the wall. The wall has been defined as helix, and to solve particle–wall contact forces it was necessary to describe helix with appropriate mathematical model, (*Jovanović et al., 2015*). Contact detection at the helical flight requires the most computational operations in the model, due to the nature of the helix.

Description of screw modeling

To solve numerically described problem, it was necessary to approximate screw conveyer with appropriate geometric shape. The screw can be described as helix. Parametric description of a helix in cylindrical coordinates is given by:

$$\vec{r}\left(\theta\right) = R\cos\theta\vec{i} + R\sin\theta\vec{j} + \frac{p}{2\pi}\theta\vec{k} \tag{2}$$

where *p* is the pitch of helix, *R* radius and θ angle from *x* axis to *xy* plane.

Distance between center of the granular particle and the edges of the screw can be defined as, (*Shimizu and Cundall, 2001*):

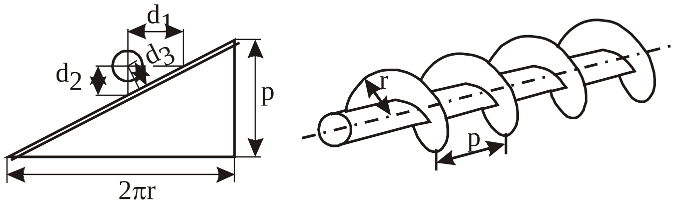

Fig. 1. Scheme of the unfolded figure of the helix- approximation of the helix (θ_p angle from x axis to xy plane)

$$d_1 = \sqrt{\left(R\cos\theta_p\right)^2 + \left(R\sin\theta_p\right)^2} \tag{3}$$

$$d_2 = z_p - p\frac{\theta_p}{2\pi} \tag{4}$$

$$d_3 = \left(z_p - \frac{p}{2\pi}\theta_p\right)\cos\phi_p \tag{5}$$

The distance d_3 must be less than the radius of a particle, *R*, for a contact with the advancing flight to occur. DEM simulations were performed for the same conditions as the experiments (number of particles, size and shape of particles). Numerical evaluations were performed for various screw conveyor configurations. The screw transporter - mixer is filled with approx. 10,000 particles (5,000 red and 5,000 blue particles), while the wall is represented by the other side of the screw conveyor. The influence of the gravity is taken into account and it represents the force which leads the particles to the bottom.

RESULTS AND DISCUSSION

The influence of modified screw conveyor helix geometry on single particle motion and particle path is investigated in this paper. DEM analysis is applied to discover the mutual influence of different design of helix geometry and observed size and shape of particles on possibility of prolonging single particle trajectory during transport. The start of analysis is at the moment when spherical particle enters the screw conveyor and the end of trajectory is at the moment when particle leaves the transporter. In this paper, particle trajectories and particle dispersion coefficients in axial directions were analyzed in order to predict the possible segregation sites. DEM allows us to interrogate the entire collision history for any given particle. A one dimensional dispersive model was used to describe the axial particle mixing, which is assumed to be a random or stochastic process, and that the particle motion can be calculated according the statistical laws and that there is no influence of the past motion of a particle on its future motion. A dispersion coefficient D can be written as follows:

$$D = \lim_{\Delta t \to 0} \frac{\left\langle \Delta x^2 \right\rangle}{2 \cdot \Delta t} \qquad (6)$$

where $\left\langle \Delta x^2 \right\rangle$ is the mean square axial displacement considered during the time interval Δt. The motion of the particle is tracked considering each data point of the data as a starting point, and the subsequent axial displacement of the particle is found after a time *t*. The elements used in numerical mesh were triagonal and the size of the element is less than 10^{-8} m^3. The optimization of numerical grid was performed, and grid refinement tests showed that there is no significant change in results of the simulation for larger number of cells in control volume. The maximum overlap between particle and boundary is determined by the normal spring stiffness. The basic screw conveyor explored in this paper was a standard pitch, single flight screw conveyor with no additional helices, Fig. 2a. This type of screw conveyer is commonly used in processing industry. A standard pitch screw has its pitch equal to the outer diameter of the helical blade. The DEM model was simplified (and the CPU time is significantly reduced) by applying periodic boundary conditions to a single pitch of the screw. Numerical experiments based on DEM simulations were performed for various screw conveyor-mixer geometry. Single flight screw conveyor's with standard pitch was compared with modified screw conveyors with additional flights welded on the periphery of the helix in order to improve premixing during transport. The particle trajectories are plotted in Fig. 2 (red lines). The paths presented are determined for the characteristic particles. This type of trajectory represents the behavior of almost all of particles in observed premixing screw conveyors. Exceptions are particles that were trapped and for some other reason did not come to the outlet. The behavior of those trapped particles has not been discussed in the present paper.

In this paper, particle trajectories and particle dispersion coefficients (Fig. 3) in axial directions were analyzed in order to predict the possible segregation sites. DEM allows us to interrogate the entire collision history for any given particle. The axial dispersion coefficient calculation as a function of position in the cross-sectional plane is presented in Fig. 3. It shows the local axial dispersion coefficient calculated for a mixing time corresponding to a single rotation. Changing the geometry of the screw conveyor by complementary helices significantly affects the dispersion coefficient calculations, because the particle path length is increased. As it can be seen, the local dispersion coefficient is much lower in the middle regions than that in the free surface region, showing that axial motion occurs preferentially near the free surface.

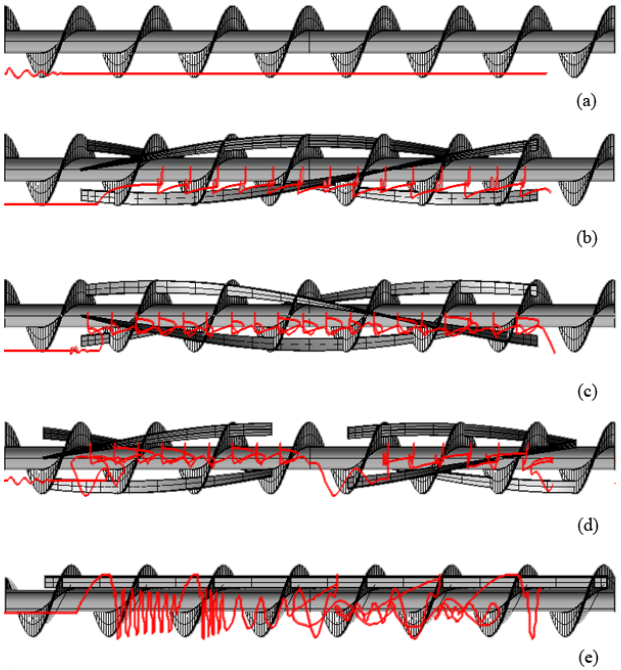

Fig. 2. (a) Single flight screw conveyor, (b) Screw conveyor-mixer with three additional helices oriented in the same direction as screw blades, c) Screw conveyor-mixer with three additional helices oriented in the opposite direction from screw blades, d) Screw conveyor-mixer with three truncated additional helices oriented in the opposite direction as screw blades, e) Screw conveyor-mixer with additional straight line blade

The movement of granular particles and trajectory of the single particle was observed from the initial moment, when single particle enters the modified screw transporter to the moment of leaving the external tube.

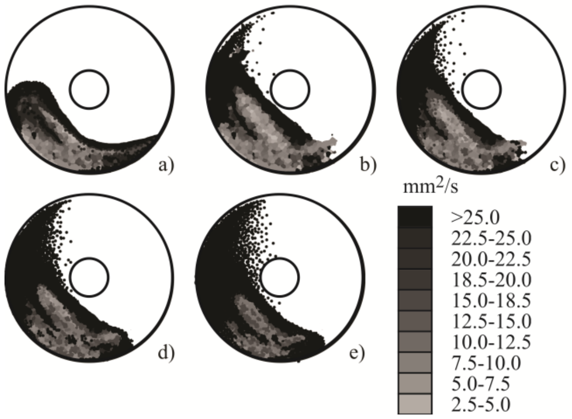

Fig. 3. Axial dispersion coefficient calculated in the cross-sectional view

The purpose of this analysis is to improve the geometry of the standard screw transporter with additional elements, welded on the periphery of the helix that enables the prolonging of trajectory for a single particle within the screw conveyer. Also, the increase of the particle velocity could be expected. The effect of prolonging the path of single particle leads to enhance the interferences between observed particles and increase probability of particles being mixed during the transport. In the first case, screw transporter acts only as a simple conveyor, the particle path is almost a straight line (Fig. 2a), while in all other cases the particle is moving on a much longer path which was particularly evident in the case of screw conveyor-mixer with additional straight line blade (Fig. 2e). In case of single flight screw conveyor (Fig. 2a), the total particle path is only 436.1 mm, according to DEM simulation. Initial small perturbation was observed, as the particle enters the screw conveyor, and afterward particle moves along the straight lined path, caused by screw conveyor transporting action. Screw conveyor-mixer with three additional helices oriented in the same direction as screw blades (Fig. 2b), significantly enlarges the total particle path, calculating more than a three times longer trajectory of 1612.2 mm, for the same transport time of 26.5 s. The velocity of the particle is also increased more than three times with the enlargement of the particle path. After reaching the top of the screw the particle tumbles down from the top of the helix. The particle falls down, led by gravitational force, to the next free surface on the heap and that segment of the path can be used for auxiliary mixing action. When using screw conveyor-mixer with three additional helices oriented in the opposite direction from screw blades (Fig. 2c) for transporting and auxiliary mixing action, transporting path enlarges even more, to 1949.1 mm, which was expected, because these helices are oriented to the opposite of the particle path, and return the particles a bit backward, as can be seen from Fig. 2c. The particle path is being shortened by truncation of three additional helices oriented in the same direction as screw blades (Fig. 2d), due to the breakage of helices at the middle of screw conveyor. In this case, total path is 1887.2 mm, according to DEM simulation. Modified screw conveyor-mixer with additional three straight line blades exerts the longest single particle path in DEM simulation (Fig. 2e): 2240.4 mm, which is a bit more than five times compared with single flight screw conveyor. The degree of mixing and the time needed to achieve an acceptable mix can be predicted using here presented DEM algorithm and experimental measurements. The literature has proposed several tools and indices to evaluate the degree of homogeneity of a mixture (*Zhong and O'Callaghan, 1990*). The results of numerical simulations and experimental processes are presented in Fig. 4. Mixing begins as soon as the mobile panel is removed, enabling the granules to fall toward the screw conveyor. The particles are rapidly blended if the modifications were performed, as seen from the figure, reaching the mixing degree between 90-95 % at the outlet for the screw length of 400 mm. Modified screw conveyors with length of 600 mm reached a bit better mixing result (80 %-85 %), while the screw transporters with screw length of 800 mm achieved the best mixing result (63-74 %).

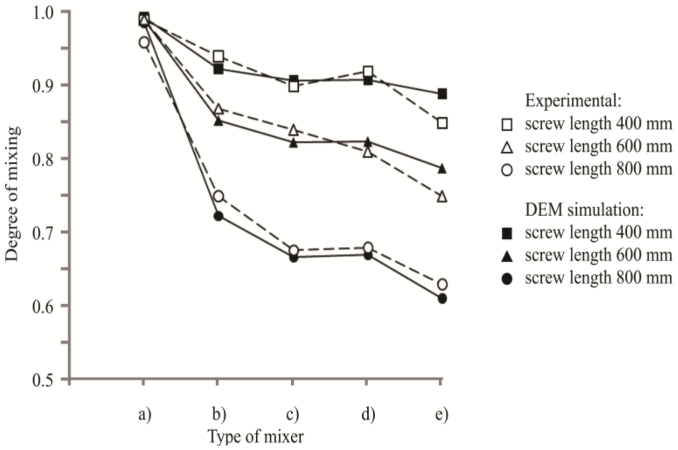

Fig. 4. RSD mixing criteria for modified screw transporters, signs a) - e) are the same as for Fig. 2

CONCLUSION

In this work the influences of the modified geometry of screw conveyor on the premixing process were analyzed. The main idea was to improve mixing quality and homogeneity of the mixture before entering the main mixer, by inserting additional helix or helical strips, on the periphery of the screw helix, in the same or in the opposite direction of material flow. Fifteen screw conveyors with five different geometries and three different screw lengths were tested for mixing capabilities during the transport of bulk material. Experiments with screw conveyors made from transparent Plexiglas were performed for this analysis. Discrete Element Method was used for an investigation of the effects of differences in screw geometry and the influence on transport trajectory, during the transport of particles, with an intention to use a screw conveyor as transporter, but also as the continuous premixer. The longest path result obtained in DEM simulation was with the screw conveyor with additional straight line blade, which is a less more than five times compared with single flight screw conveyor.

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