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Numerical simulation of the flow of agricultural seeds inside a rotary drum dryer by DEM

S Wangchai

Department of Materials Handling and Logistics Engineering, Faculty of Engineering, King Mongkut's University of Technology North Bangkok.

E-mail: sathaphon.w@eng.kmutnb.ac.th

Abstract. Drying agricultural seeds is a commonly used industrial process. The drying process of the material inside the rotary drum is directly related to the seed movement in the dryer. However, the movement of agricultural seeds inside the rotary drum dryer has never seriously been studied before. This paper adopts a mathematical model for simulating particle flow in rotary drum dryers for agricultural seeds using discrete element methods (DEMs). It is aimed to study the efficiency of the rotary drum dryer and how this is linked to the type and number of vans and positions of vans mounted inside the rotary drum dryer. The study parameters were performed by varying the rotational speed, inclination of the rotary drum installation with minimal impact on the flow of seeds, and segregation of the seeds in a rotary drum dryer. The simulation results show that different operating conditions were the most significant influences on the movement of seeds. Maximum height of the particle falling can be realized when the rotary drums are operating at an optimum condition for particle loading from the bottom drum.

1. Introduction

Rotary drum dryers are widely in many different industrials, with applications for drying granular materials such as chemical process, food processing, and it is relatively simple to design and operate. The rotary drum dryer is built with a large rotating cylinder placed on a slightly steep slope using the force of gravity for material handling. The inner wall of the drum dryer is equipped with a set of multi-vans to control the movement of the material. The motion of each particle is based on rotational and translating motions on the wall surface as the drum rotates during the process under more complex, dynamic movements. Therefore, research is needed to investigate particle movement within the rotating cylinder drum dryer, and how the particle movement controls the direction by the vans. Consequently, the correct position and type of vans installation within the rotary drum dryer are necessary. Therefore, particle movement behavior is essential in controlling the efficiency of the rotary drum dryer and the quality of the product. Prediction of the particle motion and drying processes that occur in the rotary drum dryer need to be correct. The behavior of the particle flow within the system needs to be understood.

Discrete Element Method (DEM) is a numerical technique for simulation analysis and visualisation of particle movement and how particles impact on other particles or impact on the wall of the rotary drum. The principle of DEM is to track any time steps simulation, the rotation of each particle and geometric trajectory in order to evaluate the location of particles, particle orientation and the particle-particle/ particle-wall interactions which are calculated. Commercial software has been used: EDEM (Version 2018) a general purpose DEM package. Many applications have already been analyzed using the DEM method, including; dryer machines [1] comparing the results between experimental and simulation methods [2, 3].

This paper reports on the application of DEM to simulate particle flow in the radial direction and axis along the rotary drum dryer. Particles of a spherical shape were injected into the inlet channel of each rotating drum dryer with the mass flow rate of 0.05 kg/sec. The particle flow in the rotating drum dryer was evaluated with different types, number of vans, as well as the velocity of the drum rotations and friction coefficient.

2. Model of the rotary drum dryer

The geometry shows a three-dimensional model representation of the rotating drum dryer set at an inclination angle equal to 1, 3 and 5 degrees was used in this simulation work, as presented in figure 1. The rotary drum consists of a cylinder 1100 mm in length and comprised of six sections: one (100 mm long) is dedicated to the inlet area for materials, while all of the other five sections are 200 mm in length with diameters of 300 mm. The drum is stirred by 8, 12, 15 and 18 baffles, each of 20 mm in length and 10 mm in width.

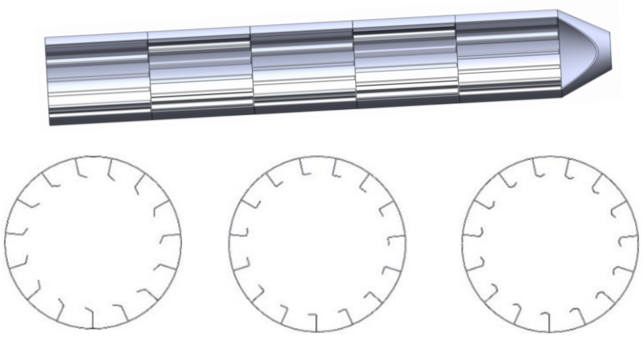

Figure 1. Rotary drum dryer model.

3. Computation Models

DEM is a numerical modelling technique used to simulate the motion of each individual particle and numerical interaction is calculated based on Newton's second law of motion and force-displacement law [4]. The motion of particle i is based on the particle translational and rotational motions in the rotary drum dryer. The equations are as follows.

$$m_i \frac{dv_i}{dt} = \sum(F_{ij}^n + F_{ij}^s + m_i g) \quad (1)$$

$$I_i \frac{d\omega_i}{dt} = \sum_j(R_i \times F_{ij}^s - \mu_r R_i |F_{ij}^n| \widehat{\omega_i}) \quad (2)$$

where m_i, I_i , v_i and ω_i are the mass, the moment of inertia, translational velocities and rotational velocities of particle i , respectively. F_{ij}^n, F_{ij}^s and $m_i g$ represent the normal contact force, the tangential contact force imposed on particle i by particle j and gravitational force, respectively. R_i represents a vector from the centre of the particle to the surface contact point, μ_r represents the coefficient of rolling friction and $\widehat{\omega}_i$ is a unit vector equal to ω_i divided by its magnitude. The contact force models between the particles and particle-wall are based on a spring-dashpot model, which is proposed by Cundall and Strack [4]. The collision forces are calculated using the Herz–Mindlin no-slip contact model to calculate the contact force between particles, including the normal force and normal displacement in the normal direction, and Mindlin and Deresiewicz [5].

4. DEM Model Parameters

A 3D model was created using CAD software and imported into the EDEM Simulation software. The simulations were conducted at a rotational speed of N=10, 20 and 30 rpm. To produce accurate DEM simulations, the material properties of the materials (paddy) and the drums (steel) have been used to aid in the determination of the interaction properties. In terms of the particle shape and size of paddy, there were more dimensions making it more difficult to determine by measuring the materials. The simulated mass of the particle model was matched with the experimental data for the mass of material, bulk density and angle of repose [6]. Subsequently, particle models in the DEM simulations were set with a fixed particle size and particle shape. All particles were generated from an injection plane into the inlet channel and were allowed to fall under the force of gravity alone to the bottom of the rotary drum. The particle size and particle shape of the paddy model, material properties and interaction between particle-particle and between particle-wall selected for simulation by DEM software have all be shown in a previous study [6]. The base particle shape used in the current DEM simulations is spherical with the principal dimensions, d = 4.5 mm. Paddy was chosen as the test material for investigation of the flow mechanisms of the particles within the rotary drum dryer. The coefficient of friction included in the materials test because the purpose of the investigation was to visualise the particle flow in the rotary drum dryers, to measure the flow pattern, and particle segregation. However, this study is to investigate the effects of the segregation of particle movement in the rotating drum. The parameters of the spherical particles model and interaction between particle-particle and particle-wall. The density of the particles of regular paddy were determined according to a previous study [6], including particle shape and particle size of the particle model used in the DEM simulations. The particle movement in the rotary drum dryer was simulated using different van shapes.

The DEM simulations were performed using an HP Z240 workstation, with a 16 GB RAM and 8 processor cores. In the first part of the rotary drum, the particles were fed into the rotary dryer with a fixed particle size and the filling rate was set to 0.05 kg/second; all particles fell down to the bottom surface of the rotary drum under the natural force of gravity and corresponding speed. Table 1 shows that the properties of the materials used in the EDEM simulation software can be divided into two groups, namely interaction properties and material properties (physical and mechanical).

The total simulation time is 100 seconds and it takes about 10 to 18 hours to process, depending on the number of particle movements in the rotary drum dryer model. An examination of the flow of materials in the rotary drum dryer was conducted via DEM simulation using various parameters of static friction coefficients for simulation. The simulated material was randomly generated by allowing the particles to fall under the force of gravity without initial velocity from the injection plane, the particle motion in the rotary drum dryer.

The computation of the particle flow required a DEM mesh applied in the drum model as an unstructured orthogonal mesh with approximately 204,000 cells for the rotating drum. The walls of the drum were set as rigid bodies that were able to rotate around the axis along the drum. The DEM simulation time step was calculated by the Rayleigh time step [1].

Table 1. Physical and numerical parameters of paddy

DEM Input Parameters	Particles	Stainless Steel
Particle Solid density (kg/m^3), (ρ_p)	1193	8000
Particle Poisson Ratio (ν)	0.4	0.29
Particle Shear Modulus (Pa), (G)	1E+7	7.75E+10
Particle Coefficient of Restitution, (e)	0.5	0.65
Particle Coefficient of Static Friction, (μ_s)	0.6	0.3
Particle Coefficient of Rolling Friction, (μ_r)	0.1	0.1
DEM simulation time step, (t_{DEM})	4E-05	-

5. Results and Discussion

The movements of the particles within the rotary drum dryer are shown in figure 2 to figure 5. The movement of the particles can be considered using three characteristics, consisting of; First, particles behave in different forms. The behavior of the particle in the rotating drum is shown to segregate after the particle moves out of from the vans and falls to the bottom surface of the rotating drum. Secondly, particles accumulate on the vans and all of the particles that fall from the vans will be presented in this study. Third, it can be seen that multi-particle collisions consisted of collisions between each of the particles, collisions between particles and vans, and collisions between particles and the wall of the rotary drum dryer. figure. 2 presented the movement of the particles in the rotary drum dryer. The movement of particles within the rotary cylinder drum appears to go in two directions; in the axial direction (according to the length of the rotary cylinder drum) and the transverse direction (both of which are shown in figure 2 to 5). When the drum is rotated, all of the particles are subject to movement under the friction that is created between the wall of the drum and particles, and the particles moving by the vans. After that, the particles are lifted to a higher level until the vans are not able to accommodate them. The particles move out of from the vans and fall to the bottom surface of the rotary drum dryer. This whole process is repeated continuously. At the same time, after the particles have fallen to the bottom of the rotary drum dryer, there is a movement along the axis of the drum. The installation of a rotary drum dryer with a slope will result in the movement of the particles in the axial direction of the rotary cylinder drum.

The effect of the type of vans is illustrated in figure 2. Three different types of vans (figure 1) were installed in the rotating drum with a slope of 3 degrees and 15 vans. (1 and 5 degrees not shown). The segregation of particles in the rotary drum dryer shows a similar trend of particles falling to the lower surface. Where there is a segregation of particles at a low speed (10 rpm), it can be seen that there is a sparse number of particles moving out from the vans when compared to the increased rotation speed (30 rpm). The particles will collect as a heap on the bottom of the drum between the space of vans at a low speed and will decrease when the speed is increased. Therefore, the distribution of suitable particles is deemed to be in the range of speed of about 20 rpm. In general, the rotation speed is high, allowing the particles to have a similar dormancy time. During the process, the rotation speed of the drum should be set with the appropriate values.

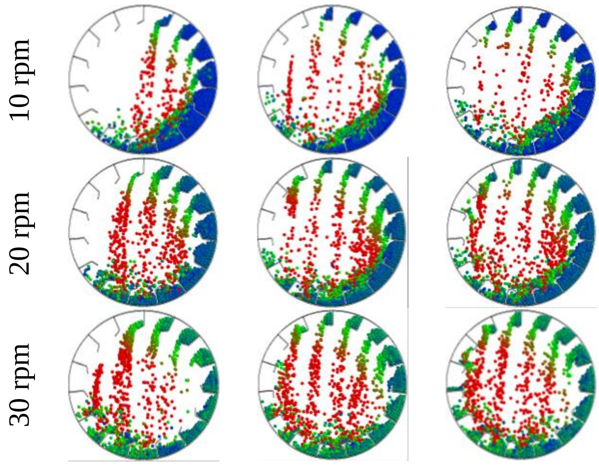

Figure 2. Transversal motion of particle flow inside the rotary drum dryer.

The effects of the rotation speed of the drum dryer are shown in figure 2. There are three different rotation speeds, i.e. 10 rpm, 20 rpm and 30 rpm with drum slope angle of 3 degrees and 15 vans are installed inside the drum. For the velocity of particles in the axial direction, there is distribution along the rotary drum dryer system, as to the depth of the particle heaps and the number of particles in the cross-section. There are differences in each position along the different axes, resulting in the velocity of particles becoming inconsistent throughout the axis of the rotary drum; the velocity of particles increases in the axial direction of the rotary drum. This is due to the reduction of particle heaps in the rotary drum dryer.

The effect of the number of vans is illustrated in figure 3 and it is presented that the influence of particle flow in the rotation of the rotary drum where the number of vans is 8, 12, 15 and 18, and rotated at a speed of 10, 20 and 30 rpm. It can be seen that the particles fall to the bottom and are segregated across all of the cross-section area an increasing number of vans. When the rotation speed of the drum increases, the number of particles living on the vans decreases and the residence time will decrease. The number of vans must be sufficient for the segregation of particles at the full cross-section area of the product in the rotary drum dryer. The number of vans below this range results in the particles becoming packed, falling and impacting on one another in the particle heap in the rotary drum and the values above this range of particles fall and impact on the other vans at the bottom of the drum.

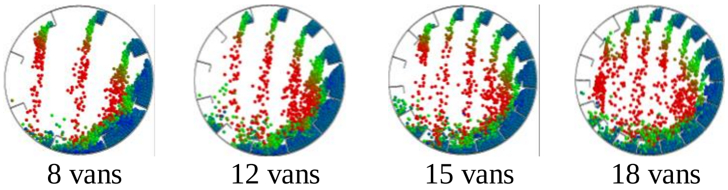

Figure 3. Transversal motion of particle flow inside the rotary drum dryer.

Examination of the effect of installing a rotary drum dryer at a sloped angle and considering the motion of the particles when the drum is rotated at speeds of 10, 20 and 30 rpm. figure 4 shows the particle drop characteristics after they are moved out of the van and similar dispersion for particle flow with all of the different slopes showing trends. The average lifespan of the particles will decrease when the slope of the rotating drum is increased from 1 degree to 5 degrees. It shows that the particles are stacked up at the slope of a small drum (1 degree) to 2 times when compared to particles that are rapidly dispersing where there is a large slope (5 degrees). In other words, the movement speed of the particles in the axial direction will increase when the slope angle is increased up to 5 degrees, which will be 2 times higher than the slope angle at all times.

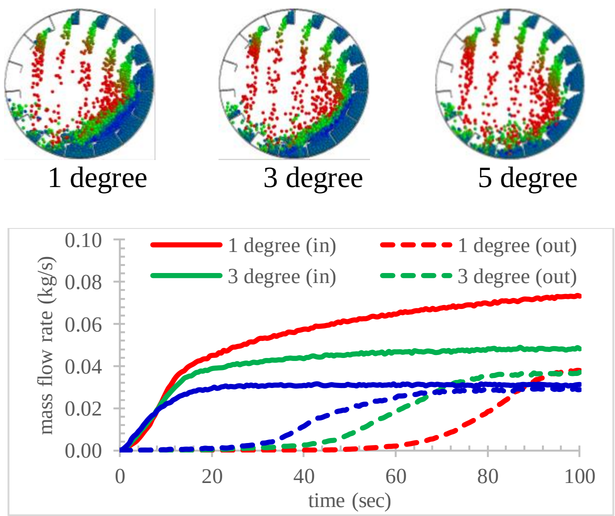

Figure 4 (a) shows particle flow patterns at 1,3, 5 degree and average mass flow.

The effect of friction coefficient (μ) is shown in figure 5, as well as the presence of three values of friction, such as the friction coefficient between particle-particle and particle-wall of the rotary drum dryer. It can be seen that where there is a lower friction coefficient, the angle in which the particles slide on the vans decreases when compared with a higher coefficient of friction. Therefore, particles heaped on the vans and distribution after the particles move out from the vans and falling to the bottom. The amount of particle movement in the axis of the rotary drum dryer. It can be seen that the number of particles at the feeder and to the left of the rotary drum dryer is a little different.

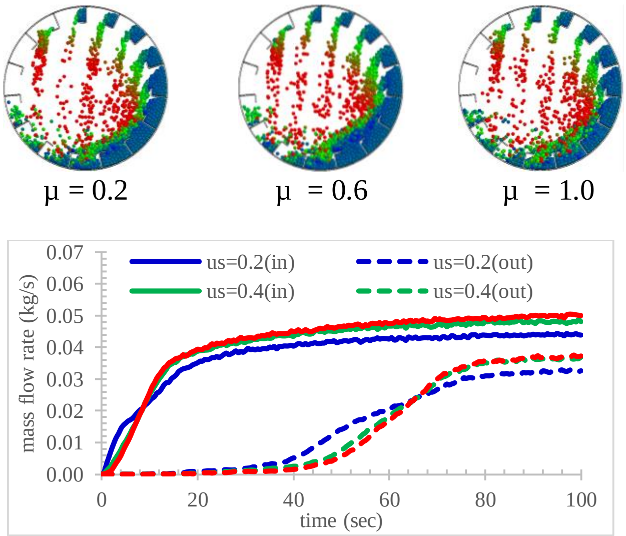

Figure 5. Shows particle flow patterns at friction coefficient (μ = 0.2, 0.6 and 1.0) and average mass flow.

6. Conclusions

Continuous particle movement has been studied by applying a 3D numerical simulation of a rotary drum dryer with three different van types. There are three different rotation speeds and three slope angles of the rotary drum dryer. The movements of the particles are shown to collide between particles-particles, between particles-vans and between particles-walls of the drum. The particles dispersed within the rotary drum dryer, which is discussed in terms of important parameters, such as rotation speed, slope angle of the drum, type of vans and the number of vans. The results clearly show that all proposed variables have a significant impact on particle movement behavior in rotary dryers. The highlighted results can have significant benefits for controlling the production process and the engineering design type of vans with the rotary drum dryer, which can be used as relevant data for the further study of particle motion in the future. This is a preliminary review on the type of vans in order to investigate the flow of particles. Following research should investigate the movement of particles that are subjected to hot air flow in a rotary drum dryer for agricultural seeds.

7. References

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