Particle Motion in Screw Feeder Simulated by Discrete Element Method

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Abstract

It is desired that toners and carriers are mixed well and charged appropriately in the two-component developers of electrophotography. Further these two kinds of particles should be transported to the latent image on the photoconductive drum steadily and at a proper rate. Screw feeders are often used for this process because it is suitable for dealing with mixing, charging and transporting simultaneously. Unfortunately, it is very difficult to know experimentally details of dynamic behavior of particles affected by complicated geometric conditions in the developers unit. As a method for calculating particle motion, DEM (Discrete Element Method) has been attracting a great attention in various fields related to powder and particles. In DEM motion of individual particles is calculated by using the Newton's equations of motion. DEM was applied in this work to study motion of carriers in a screw feeder. The properties concerning mixing and transporting particles were analyzed.

Introduction

Screw feeders are generally used for transporting powder or particles in powder processes. The flow rate of powder can be controlled easily by changing the rotating speed of its screw.

In two-component developers of electrophotography, screw feeders are often used not only for transporting the mixture of toners and carriers but also for mixing and charging them. Therefor it is desired to know their behavior to improve the quality of printing, because it largely depends on the quality of charging. There are many studies on screw feeders*[1-2,] but they intend to study the function of transportation rather than the motion of particles.

In the present work, DEM(Discrete Element Method)*[3] is applied to motion of particles in a screw feeder. DEM first proposed by Cundall and Strack*[3] is a numerical method to calculate individual particle motion based on the equation of motion of a particle by using a contact force model which consists of basic mechanical elements. This calculation method requires us to deal with motion of all particles in a calculation domain, so it is difficult to treat a system which contains a large number of particles. But this limitation is getting lower under the continuing improvement in capacity of computers, and it is possible to treat more than a hundred thousand particles. DEM has been applied to wide range of powder operations.

In this work, only the motion of carriers in a screw feeder is calculated, *i.e.,* the existence of toners is neglected. Motion of carriers dominates motion of the mixture of toners and carriers, because the size of toners is much larger than carriers' one and toners only follows carriers' motion. Consequently, it is possible to analyze the motion of the mixture by neglecting toners. It was investigated the effects of filling fraction of particles and the screw pitch on the flow rate and the mixing rate.

Calculation Method

To calculate the motion of particles, we used a contact force model*[3]. This model expresses contact force acting between particles with springs, dashpots and a friction slider. Several models have been proposed to determine the properties of elements in the model. We use the model by Tanaka et al.*[4], which keeps the coefficient of restitution constant. Spherical monosized particles were assumed, and it was neglected the force caused by liquid bridge, van der Waals force and electrostatic force.

Fig. 1 shows the calculation domain. The sizes of the domain is shown in Fig. 2. The diameter of the cylinder is fixed to 2.0e-3 m, and the rotating speed of the screw, 120 rpm. Periodic boundary condition is assumed in the axial direction, and the axial length of the domain P is set equal to one pitch of the screw. The diameter of the particles is 250 μm, and the particle density, 5000 kg/m^3. The particle flow rate and the degree of mixing were evaluated. The particle flow rate was calculated by

$$W=(N_{OUT}-N_{IN})v\rho_p/dt. \quad (1)$$

N_{out}: the number of particle flowing out from the right boundary
N_{in}: the number of particle flowing in from the right boundary
v: particle volume
ρ_p: particle density

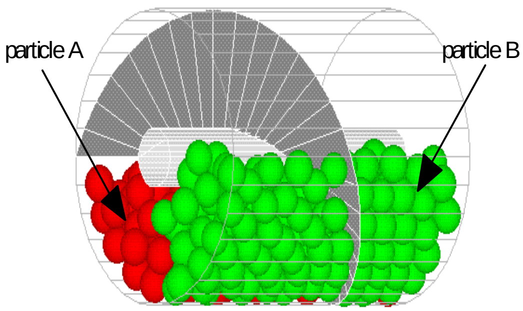

Figure 1. Calculation domain

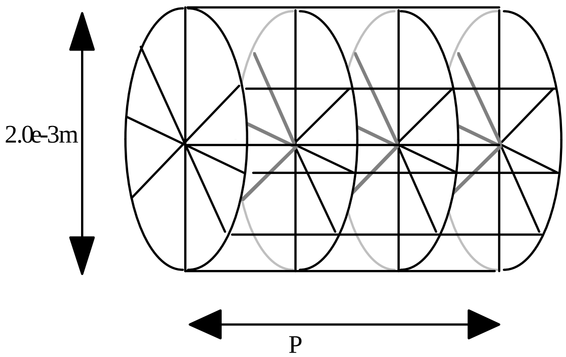

Figure 2. Division of cells

The degree of mixing was calculated as the following way. First, the particles are divided into two classes, which are denoted by A and B, according to the initial position in the cross section of the cylinder. A snapshot of the initial condition is shown in Fig. 1, in which particles are colored to make a distinction between particles A and B. Secondly, the number of particles A and B was counted respectively in each cells, which are shown in Fig. 2 , at the every time step and the number fraction of particle A was calculated. The degree of mixing is defined by the following equation (2).

$$M = \sqrt{\sum_{1}^{N} (c_i - c)^2} \Big/ \sigma_0 N \qquad (2)$$

c: mean number fraction of particle A
c_i: number fraction of particle A in each cell
σ_0: standard deviation of number fraction of particle A at the initial condition.
N: total number of particles

Results and Discussion

As the basic data for optimizing the mixing and transporting characteristics, the influences of the filling fraction and the screw pitch on them were studied. These are the important characteristics of screw feeders used in the electrophotographic process.

Influence of Filling Fraction

Fig. 3 shows the relationship between the filling fraction and the flow rate of particles in the case of *P* =3.0e-3 m. The ideal flow rate of particles is defined as the flow rate when the particles have the same axial velocity as the superficial axial motion of the screw and is also shown in Fig. 3. If no particle run over the center shaft in the transverse direction, the particle flow rate exactly agrees with the ideal one. The flow rate of particles increases with increasing the filling fraction in the range of the present conditions, but the tendendency largely changes when it exceeds 50%. When the filling fraction is less than 50%, the flow rate of particles is nearly equal to the ideal one. On the other hand, when it exceeds 50%, the difference becomes large. This difference is caused by large numbers of particles which run over the center shaft.

The predicted variation of the degree of mixing with time shown the linear profile on the semi-log plot, which is well known law in the mixing theory. The rate coefficient of mixing*[5] was evaluated by using the method of least square. Fig. 4 shows the effect of filling fraction on the rate coefficient of mixing. As the result, it is revealed that there is an optimum rate coefficient of mixing around 50% of filling fraction.

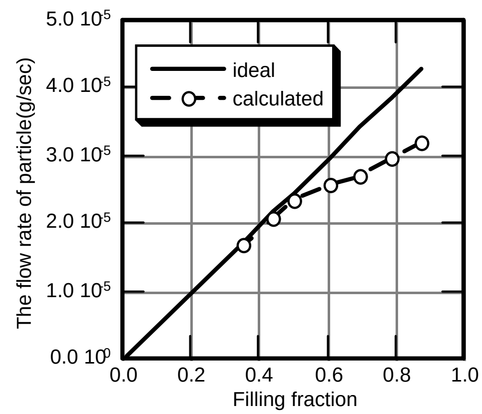

Figure 3. Relation between the flow rate of particle and filling fraction.

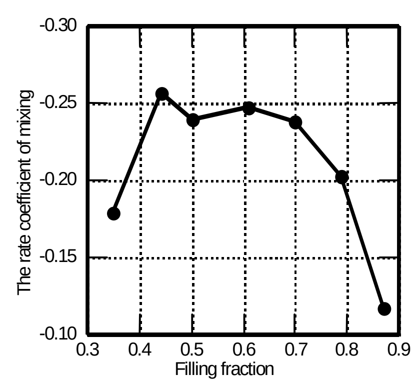

Figure 4. Relation between the rate coefficient of mixing and filling fraction.

By observing the time series of snapshots, it was found that particle mixing is activated by particles' transverse motion over the center shaft. The increase of the rate coefficient of mixing in the range of low filling fraction is caused by increase of the number of particles run over the shaft. When the filling fraction is increased over 0.5, such the transverse motion becomes smaller. Because the distance of particle transfer on the free surface of the particle bed is restricted by the outer cylinder. This is considered to the reason for the profile of the rate coefficient of mixing in the range of high filling fraction in Fig. 4.

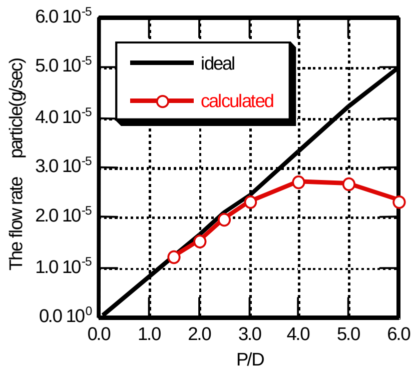

Figure 5. Relation between the flow rate of particle and the rate of the screw pitch to the screw diameter (P/D).

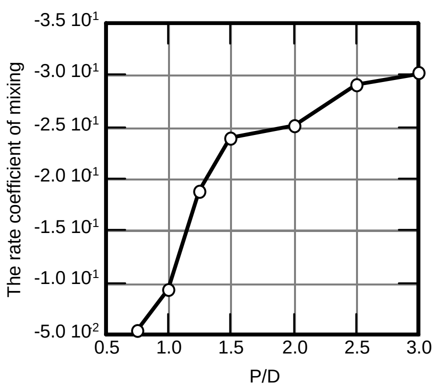

Figure 6. Relation between the rate coefficient of mixing and the rate of the screw pitch to the screw diameter (P/D).

Influence of the Screw Pitch

To analyze the influence of the screw pitch on the particle motion, the screw pitch was varied from 1.5mm to 6.0mm. Fig. 5 shows the relationship between the ratio of the screw pitch to the screw diameter (P/D) and the flow rate of particles in the case of the filling fraction, 0.5. In the range of P/D<1.5 the flow rate of particles obeys the ideal line which is proportion to P/D. The flow rate of particles takes the maximum value around P/D=2.2, and decreases with increasing P/D in the range of P/D>2.5. The difference between the predicted flow rate and the ideal one corresponds to the fraction of particles which run over the center shaft.

Fig. 6 shows the relation between the rate coefficient of mixing and P/D. Increasing the screw pitch, the degree of mixing increases rapidly in the range of small P/D. In the high P/D range the gradient of the profile becomes small.

Conclusion

Discrete particle simulations of particle flow in screw feeders were made, and the effects of parameters, such as the filling fraction and the pitch of screw, on the flow rate of particles and mixing properties. The principal results are as follows;

1. In the case of low filling fraction, the flow rate of particles nearly obeys the ideal transport model. When the filling fraction of exceed about 0.5, the difference from ideal transport model increases with increasing the filling fraction.
2. The predicted rate coefficient of mixing has an optimum filling fraction around 0.5.
3. In the range of small P/D the flow rate of particles obeys the ideal model, and proportional to P/D. The flow rate of particles takes the maximum value, and decreases with increasing P/D in the range of high P/D.
4. The rate coefficient of mixing increases rapidly with increasing the ratio of the screw pitch to cylinder diameter, P/D, in the range of small P/D. In the high P/D range the gradient of the increment becomes small.

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Biography

Kei-ich Tanida received the B.A. of Physics. in 1990 from Kwansei Gakuin University in School of Science and then he joined at the MITA Ind. Co.,LTD. He has engaged in the research and development of toner particles, and numerical simulation of particle motion. He is a member of the Society of Electrophotography Japan. He joines now Ph. D. Student of Tsuji Laboratory, Complex Particulate Systems, Department of Mechanophysicis Eng. of Osaka University.