Modeling of Mixing of Toners with DEM and Continuum Models

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Abstract

Computation of mixing of toners in mixers with complex geometries requires extensive computational effort. Continuum models are more practical for such problems in comparison with DEM models due to the size of the problem. Use of continuum models requires appropriate material properties for modeling such flows. Discrete element model is used to determine the material properties for the continuum model. A simple problem is solved first by both DEM and continuum models. By comparing the results of these to solutions, material properties of the toner for continuum model are determined. In this paper, a summary of the formulations is provided and examples of a simple experiment of toner flow are illustrated.

Introduction

Proper mixing of toners is a critical problem for improving the quality and life of a toner supply. Proper mixing of old and new toners have to be continued in parallel to the printing process. In general a mixing cartridge may contain billions of particles. Although it would be desirable to calculate the motion of each toner particle, computation of such a problem is not practical for design. Toner particles can be of different shape and size; they could be charged at different levels.

Computation of toner flow in mixers with complex geometries requires extensive computational effort. On the other hand, use of continuum models for such problems requires appropriate material properties for modeling such flows. Material properties for toners under different flow conditions are difficult to measure.

In this paper, determination of material properties for continuum modeling of toner mixing process is presented. Appropriate modeling of toner as a continuous fluid is considered. Depending on the properties of the toner and flow conditions, toner particles do not behave like an ideal fluid. The motion of toner particles occur only after certain level of shear stresses are achieved between two toner particles themselves or between the toner particles and the walls. Different types of forces such as VDW forces play critical role in determining the above characteristics of toner flow.

Material properties are usually defined from experiments. Here, material properties are defined by comparing the simulation of toner flows for small samples by both continuum and particle modeling. Discrete Element Method (DEM) is used to solve the same problem solved by the continuum model. Obtained results are compared to determine the material properties for the continuum model. This approach also provides a detailed understanding of contribution of particle forces to the overall flow patterns. Since the objective is to predict overall mixing of considerable number of particles of different shape and size, it is expected that continuum model should provide a statistically accurate representation of the mixing process.

Mathematical Models

Two models are used in this analysis: DEM model and the continuum model.

DEM Model

For each toner particle, equations of motion in three-dimensions are integrated in time.

$$m\ddot{x} = \Sigma F_x \text{, and } m\ddot{y} = \Sigma F_y$$

$$I\ddot{\theta} = \Sigma M \qquad (1)$$

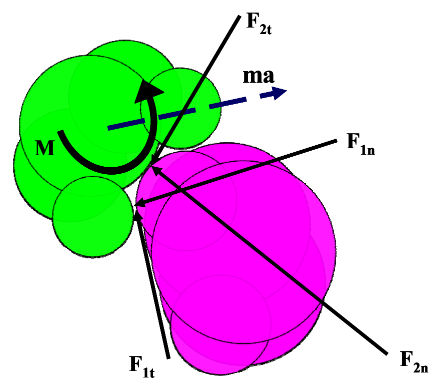

Figure 1. Forces and Moments on Toner Particles

Irregular geometry of the toner particles is represented by an assembly of spherical particles as shown above. During the motion of the particles, contact between two particles is detected and normal and frictional forces are calculated.

In addition, Coulombic forces between particles and the electric forces due to an electric field are included. VDW forces and image forces add added. Finally, the charging of the toner particles are calculated by detecting the contact of different points on the surface of toner particles. The results of this analysis, shows the position of each toner particle at each time step of the numerical integration.

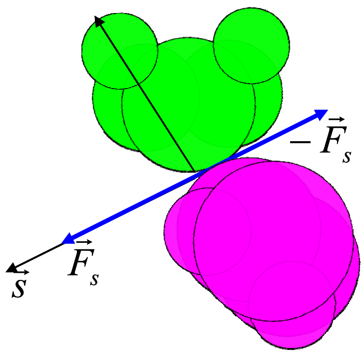

Figure 2. Friction and Contact Forces

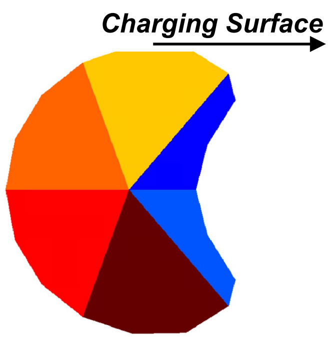

Figure 3. Charging of particles by Contact

Continuum Model

For the analysis of continuum model we have to solve three-dimensional Navier-Stokes equations. The main issue is how to model the toner in this continuum model. We start with the power law model for viscosity.

$$\eta = K\dot{\gamma}^{(n-1)}$$

Where K is a constant, n is the power index, γ and η are shear rate and apparent viscosity respectively. The power law is then modified to incorporate different flow conditions such as when the toner is flowing, when the toner is stationary and when the toner is yielding according to the local stress conditions. The boundary conditions are also modified for stick-slip and non-contact boundaries.

The specification of material properties for modified power law and boundary conditions for different surface conditions are obtained by running PASSAGE® DEM codes and comparing results with the continuum models.

Numerical Examples

Flow of Toner on an Inclined Plane

As a first simple experiment, toner particles are placed on an inclined plane, initially held by a plate placed downstream. When the plate is removed, flow of the particles are calculated from both DEM and continuum models. Under different slopes of the incline, flow profiles change in both models. By matching the results of Passage® DEM and continuum material model for these cases, material properties are determined for the continuum model. Figure 4a, 4b and 4c shows the comparison of Passage® DEM and continuum models for determining material properties.

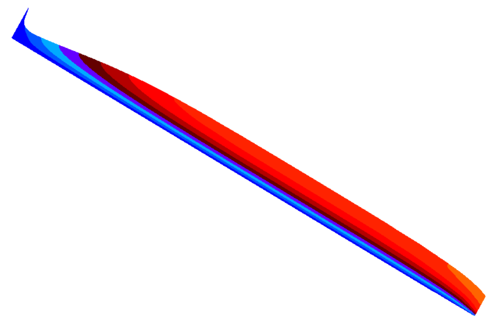

Figure 4a. Continuum Model Results

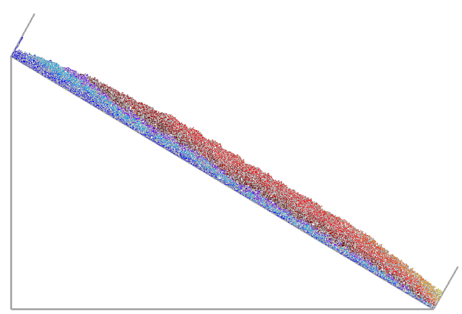

Figure 4b. Passage® DEM Model Results

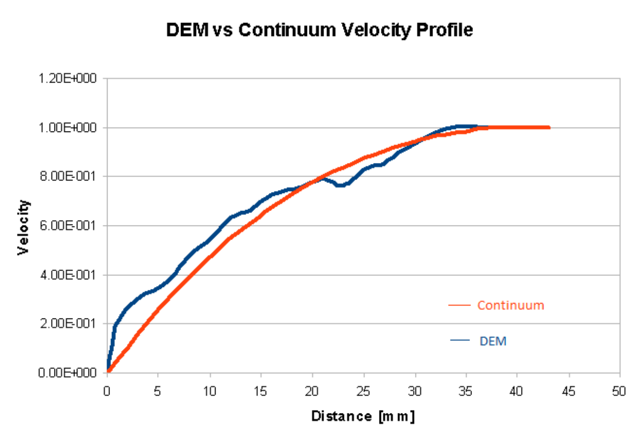

Figure 4c. Comparison of Velocity Profiles

Mixing of Toner in a Rotating Drum

Mixing of toner in a rotating drum is used as an experiment to determine the material properties and boundary conditions for toner flows. In the following example, two types of toner particles are placed in a cylindrical drum and rotated. The mixing of the particles depends on the rotational speed of the drum as well as material properties. At low speeds toner acts more like a viscous fluid. At high speeds more mixing occurs. For different levels of material and different amount of charging the conditions differ. Also the boundary conditions vary for low and high rotational speeds. The stick and slip behavior between the wall and the toner changes drastically. By checking the material model for all such conditions, one can determine the material properties for toner under different conditions. Figure 5 shows the comparison of Passage®DEM and continuum for determining material properties.

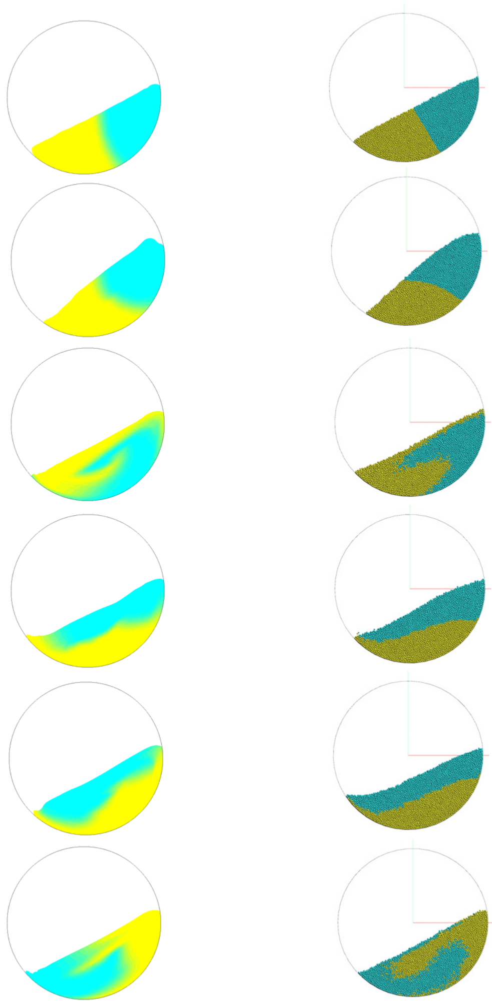

Figure 5. Continuum and DEM Model Results

Auger Mixing

Once, the material properties for the continuum model is determined from the drum experiment, the continuum model can be used to model auger mixing for design of practical configurations. Again, in the case of augers, many different boundary conditions occur and material properties change based on the flow conditions. A typical case of the mixing of two toners in an auger configuration is shown in Figure 6.

Figure 6, Continuum Model Results of Auger Mixing- Concentration of New Toner

Conclusion

A continuum model for analyzing mixing of toners is presented. The material properties and the boundary conditions for the continuum model is obtained by simple experiments.. By comparing the results of DEM models with continuum models of these experiments for several cases, properties of continuum models are defined. These models can then be used typical toner mixing problems where billions of toner particles are mixed.

References

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Biography

Dr. Ecer received his Ph.D. from University of Notre Dame. He is the President of Technalysis and Professor Emeritus of Mechanical Engineering at Indiana University – Purdue University (IUPUI)

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