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Translated Paper

Effect of paddle rotational speed on particle mixing behavior in electrophotographic system by using parallel discrete element method

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ABSTRACT

The objective of this paper is to investigate the effect of paddle rotational speed on the mixing behavior in an agitation process of an electrophotographic system by using parallel DEM. The mixing behaviors of beads with different sizes and densities were measured at various paddle rotational speeds by using a high-speed video camera, and were compared with the simulation results. A good agreement in the mixing behavior was obtained and the changes in particle velocity during the mixing were comparable. The simulation for mixing behavior of larger carrier particles suggested that the radial particle mixing was much faster than the axial one. The faster radial mixing is attributed to the fact that there are two radial flows in the system; the one is over the shaft, the other is between the paddle and shaft. The extent of mixing depended on the number of paddle rotations when the rotational speed is larger than 100 rpm, while the mixing under 50 rpm is completed at a smaller number of rotations.

1. Introduction

An electrophotographic system is one of the commonest printing techniques, and widely used for printers and copy machines. The requests for improvement of the printing technology; such as downsizing, high-speed, high quality, high stability, low cost, energy saving and so on, increase more and more with rapid development of information technologies in a past decade. However, it is impossible to satisfy all of the requests and the manufacturing the new machine is very tough work. For example, if the smaller toner particles are started to use for the high quality of printed images, it is difficult to control the toner charge by the present tribo-charging process. It leads to the different toner charge distribution and affects the developing and the transferring efficiency. The temperature of fusing should also be changed when the toner size are changed. Thus, all of processes have to be re-optimized, even if only one condition is changed. Therefore, the development of the simulation tool for helping the designing and optimizing the electrophotographic system is necessary.

The behavior of toner particle in the electrophotographic is controlled mainly by the electrostatic force, thus the amount of toner charge is one of the most important conditions for the high quality of the printed images. The toner particles take the tribo-charges during mixing with the carrier particles in the developer tank of the two-component development system [1]. The objective of this paper is to develop the simulation tool for the analyzing and optimizing the particle mixing behavior in the developer tank by using Discrete Element Method (DEM) [2]. DEM is the one of the most famous and reliable simulation methods for analyzing the particle behavior, and some researches on the electrophotographic system have been already studied [3–8]. However there is huge number of particles in the developer tank, so that the speed-up of DEM calculation is important task for the analysis of mixing behavior in it. The authors had tried to accelerate the DEM calculation by optimizing particle detection process [9–11] and the program tuning [12]. The high-speed DEM cord, which can calculate more than million particles, was developed by the parallel computing using MPI (Message Passing Interface).

In this paper, the analysis of the particle mixing behavior in the developer tank of two-component development system was conducted by using parallel DEM. The particle mixing behavior of beads was compared with the one recorded in the experimental work to validate the simulation result. The effect of the paddle rotational speed on the mixing behavior of carrier particle was investigated to optimize the mixing process in the electrophotographic system. The adhesion force and Coulomb force [13,14] were not considered in this work, because the carrier particles have large density, so that the effect of these forces is negligible.

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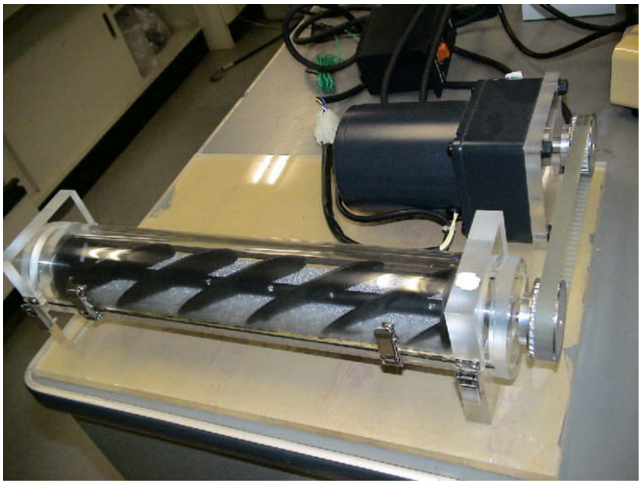

Fig. 1. Experimental apparatus.

2. Experimental

Fig. 1 shows the experimental apparatus, which was used in this work. The elliptic paddles (100 mm × 50 mm) were installed in a shaft with 30°, and its rotation radius was 25 mm. The pitch of each paddle was 50 mm, and the diameter of chamber, d_C, was 58 mm. Steel (diameter; $d_b = 1.0$ or 1.5 mm), polystyrene ($d_b = 1.0$ mm) or zirconia ($d_b = 0.5$ mm) beads were charged in the agitation chamber, and their filling-ratios were about 50%. The paddle rotational speed was changed from 99.3 to 195.4 rpm. The agitating behavior of beads was recorded by using a high-speed video camera (MotionPro HS-4, NIPPON ROPER Co., Ltd.) under 1000 or 2000 fps. The beads velocity field during agitating was measured from the recorded images by PIV (Particle Image Velocimetry) using DIPP-FLOW ver.1.13 (DITECT Co., Ltd.). The resolution of image was 512 × 512 pixels, and the grid size was 10 × 10 pixels. The detailed experimental conditions are tabulated in Table 1.

3. Simulation

3.1. Discrete element method

Three dimensional mixing behavior in the agitation system was simulated by using Discrete Element Method (DEM) [2]. DEM is one of the most famous and reliable simulation methods for the numerical analysis of solid particle behavior. This simulation method consists of the idea of determining the kinematic force to each finite-sized particle. All forces acting on each particle are

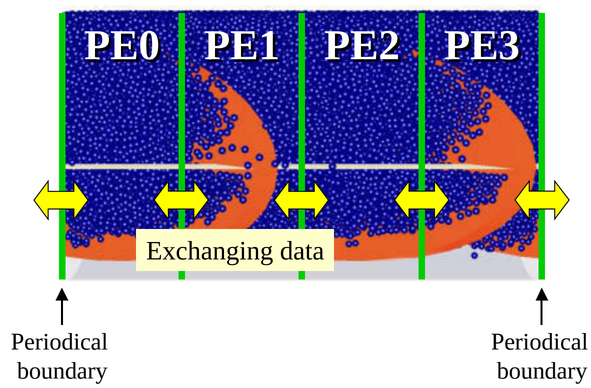

Fig. 3. Schematic diagram of parallel computing by using MPI.

Table 1
Experimental conditions.

Beads	Diameter (mm)	Mass (kg)	Rotational speed (rpm)	Frame rate (fps)
Steel	1.5	1.49	99.3, 195.4	1000
Steel	1.0	1.49	159.2	2000
Polystyrene	1.0	0.21	157.5	2000
Zirconia	0.5	1.10	143.9	2000

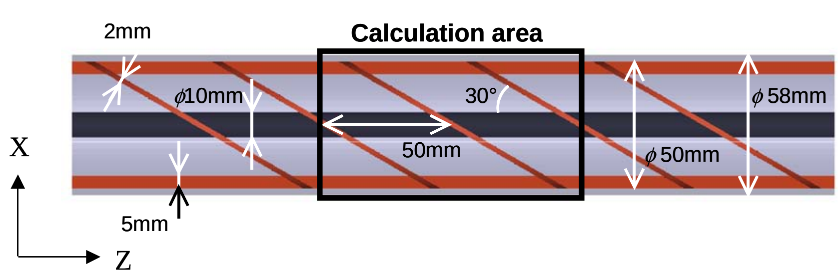

Fig. 2. Schematic diagram of agitation paddle.

Table 2
Particle conditions in the simulation work.

Beads	Diameter (mm)	Number of beads (–)	Young's modulus (GPa)	Poission's ratio (–)	Density (kg/m^3)	Frictional coefficient (–)
Steel	1.5	43,560	210	0.30	7800	0.23
Steel	1.0	146,778	210	0.30	7800	0.23
Polystyrene	1.0	131,916	3.5	0.34	1050	0.68
Zirconia	0.5	1,011,396	200	0.30	6000	0.23