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ScienceDirect
Powder Technology 186 (2008) 130–136
POWDER TECHNOLOGY
www.elsevier.com/locate/powtec

Numerical analysis of agitation torque and particle motion in a high shear mixer

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Received 26 March 2007; received in revised form 11 November 2007; accepted 12 November 2007
Available online 31 December 2007

Abstract

Numerical simulation of particle motion in a high shear mixer was conducted using a three-dimensional discrete element method (DEM). Torque of an agitator blade, particle velocity profiles and forces acting on a particle were calculated under various agitator rotational speeds. The agitation torque showed a good correlation with the agitator rotational speed and reflected the particle motion in the mixer. The simulated results revealed that particles received greater forces near the bottom of the vessel, as compared to the upper or middle height in the mixer. The particle flow changed with the agitator rotational speed, as experimentally observed, and indicated different velocity profiles. Particle kinetic energy determined the agitation torque and the particle behavior, regardless of the complexity of the changes in the particle flow. A significance of monitoring of the agitation torque in the mixer is also discussed here from the perspective of the particle kinetic energy.

Keywords: Agitation torque; Particle motion; High shear mixer; Kinetic energy; Discrete element method

1. Introduction

Powder mixing and granulation in a high shear mixer are fundamental operations in the pharmaceutical, agriculture, food and chemical industries. They have great advantages that the operations can be completed in a relatively short time and the equipment is very simple in construction.

Contrary to the remarkable advantages, powder behavior in the high shear mixer is sensitive to the operational conditions and has a great influence on quality of the product obtained. Process monitoring and control, therefore, are essential for the stability of product quality and improvement of the process efficiency. So far, a number of investigations have been carried out for process monitoring using different methods, such as measurement of agitation toque [1,2], power consumption [3,4] and vibration of probe [5].

Torque measurement of the agitator blade (main impeller) [1,2] has been often used to monitor and control the processes in the high shear mixer. The agitation torque arises as a result of load from powder against the agitator blade, reflecting changes in powder behavior in the mixer. Despite the widespread measurement of the agitation torque, its physical meaning has not been well understood, because the powder behavior in the mixer is so complicated and has not been well studied yet.

Several researches using a high-speed camera have been reported in order to understand powder flow in the high shear mixer. Lister et al. [6] measured powder surface velocities at different agitator rotational speeds. Nilpawar et al. [7] investigated the effect of binder type on granular flows as well and found that binder viscosity influenced granular-bed velocities. However, this technique provides only information on surface velocities of powders, therefore, it is not sufficient to investigate a correlation between the powder behavior and the agitation torque.

Recently, numerical simulation based on a discrete element method (DEM) has been utilized to study powder flows in powder handling processes. The DEM was originally proposed by Cundall and Strack [8], and has been applied by many researchers [9–12] to obtain the detailed information on powder

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doi:10.1016/j.powtec.2007.11.028

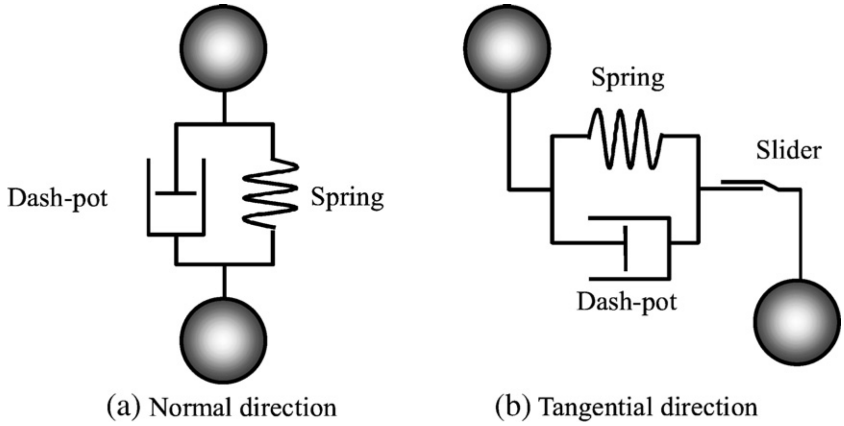

Fig. 1. Models of contact force.

behavior in different manufacturing processes. There are a few reports [13,14] with respect to particle motion in high shear mixer, however, no investigation is made on the effect of the particle motion on the agitation torque.

The purpose of the present study has been to investigate powder and agitation toque behavior in a high shear mixer. Particle motion and torque of the agitator blade were numerically analyzed using a three-dimensional discrete element method (DEM). The agitation torque, particle velocity profiles and forces acting on a particle were calculated under different agitator rotational speeds. The agitation torque behavior was characterized based on the obtained results. A significance of monitoring of the agitation torque in high shear mixer is also discussed.

2. Numerical simulation

2.1. Numerical model

A three-dimensional discrete element method (DEM) was employed to analyze particle motion and torque of an agitator blade in a high shear mixer. The DEM calculates location, velocity, and acceleration of an individual particle as well as forces acting on the particle based on the following Newton's second law:

$$m\frac{d^2\boldsymbol{X}}{dt^2} = \boldsymbol{F}_{\mathrm{c}} + m\boldsymbol{g} \tag{1}$$

$$\frac{d\omega_{\mathrm{p}}}{dt} = \frac{\tau_{\mathrm{c}}}{I} \tag{2}$$

where, $\boldsymbol{X}$, m, t are position vector, mass of a particle and time, and $\boldsymbol{F}_{\mathrm{c}}$, $\boldsymbol{g}$, show contact forces acting on a particle and gravitational acceleration, respectively. Also, ω_{p}, τ_{c} and I indicate angular velocity, torque for rotational motion and inertia moment of the particle. Each particle in the mixer receives the contact forces against other particles, agitator blade and vessel wall.

A contact model shown in Fig. 1 proposed by Cundall and Strack [8] was applied here to calculate the contact forces. This model expresses the contact forces by using mechanical elements such as spring, dash pot and friction slider. The spring provides a repulsive force upon collision of a particle. The dashpot and the friction slider represent an energy dissipation and a friction characteristic, respectively, for the collision. The contact forces of normal and tangential direction, $\boldsymbol{F}_{\mathrm{cn}}$ and $\boldsymbol{F}_{\mathrm{ct}}$, are given as follows:

$$\boldsymbol{F}_{\mathrm{cn}} = (-k\delta_{\mathrm{n}} - \eta\boldsymbol{V}_{\mathrm{rn}}\cdot\boldsymbol{n})\boldsymbol{n} \tag{3}$$

$$\boldsymbol{F}_{\mathrm{ct}} = (-k\delta_t - \eta\boldsymbol{V}_{\mathrm{rt}}) \qquad (\text{if } |\boldsymbol{F}_{\mathrm{ct}}| \le \mu|\boldsymbol{F}_{\mathrm{cn}}|) \tag{4}$$

$$\boldsymbol{F}_{\mathrm{ct}} = -\mu|\boldsymbol{F}_{\mathrm{cn}}|\frac{\boldsymbol{V}_{\mathrm{rt}}}{|\boldsymbol{V}_{\mathrm{rt}}|} \qquad (\text{if } |\boldsymbol{F}_{\mathrm{ct}}| > \mu|\boldsymbol{F}_{\mathrm{cn}}|) \tag{5}$$

where, δ, k, η and μ are displacement between contact particles, spring stiffness, damping and friction coefficient, and $\boldsymbol{V}_{\mathrm{r}}$ shows

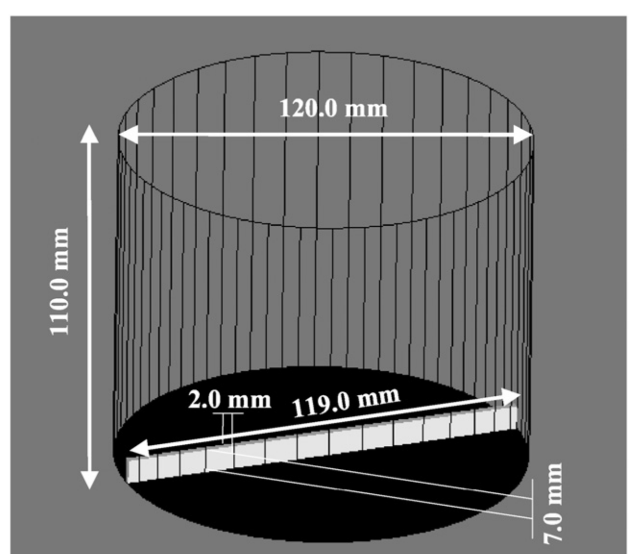

Fig. 2. Schematic diagram of high shear mixer.