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Numerical study on collision characteristics for non-spherical particles in venturi powder ejector

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A R T I C L E I N F O

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A B S T R A C T

The venturi ejector forms vacuum causing by venturi effect which makes particles enter into ejector. The conveying process of two kinds of non-spherical particles in the venturi powder ejector was respectively simulated with using CFD-DEM coupling approach, and the collision characteristics among particles were analyzed. The influence of the particle impact on the wall stress was analyzed, and the changed reason of the wall stress from collision behaviors among particles was deeply discussed with using DEM-FEM coupling approach. The present analyses show that hot spots of particle-wall collision occur around the ejector nozzle, both the particle-particle and particle-wall collision frequencies for the cylinder-shaped particles are larger than those for the tablet-shaped particles, and the force strength by collisions for the cylinder-shaped particles is larger than that for the tablet-shaped particles.

1. Introduction

Pneumatic conveying technology of dry powder materials has merits, such as flexible layout, no dust pollution, low operation cost and simple maintenance [1–3]. Thus, pneumatic conveying technology is widely used in petroleum, chemical, metallurgical, pharmaceutical, food and mineral processing industries [4,5]. Venturi powder ejector is the key device for pneumatic conveying system, and studying the collision characteristics of particles is of great significance for decreasing the breakage and optimization of transport performance of particles. Liu et al. [6] carried out a series of experiments of both single-phase gas and gas-coal mixture flows through the venturi, the results showed that a sharp decrease in static pressure and volumetric loading ratio was observed inside the venturi. Ji et al. [7] conducted experimental and numerical studies of the jet tube based on venturi and analyzed the relationship between the different parameters by experiments and simulations.

Computational Fluid Dynamics-Discrete Element Method (CFD-DEM) coupling has been successfully employed in complex gas-solid flow systems. Zhou et al. [8] adopted the CFD-DEM method to model the gas-particle two-phase flow, the gas phase was treated as a continuum and modeled using computational fluid dynamics (CFD), particle motion and collisions were simulated using the DEM code. Traore et al. [9] adopted the CFD-DEM approach to simulate the dense gas-solid flow, DEM was employed to model the granular particle phase and classical CFD is used to simulate the fluid flow. Ayeni at al [10]. presented CFD-DEM simulations of a gas-solid fluidized bed and proposed a new drag model. Karimi et al. [11] developed a new method for validation of the simulation of a gas-solid fluidized bed via CFD-DEM. Qian et al. [12] applied the CFD-DEM coupled method to simulate the gas-solid flow characteristic within the fibrous media to study the influences of the fiber structure and particle properties on particle deposition and agglomeration on characteristics in the filtration process. At present, the discussion of particles inside venturi ejector using DEM is only confined within spherical particles, however, there are few studies on non-spherical particles. As a matter of fact, for industrial applications, most of the materials to be transported are non-spherical particles, such as wheat and catalyst granule. That will be bound to cause greater errors if replacing them with spherical particles [13]. Therefore, the numerical simulation study of the non-spherical particles is of great importance. In order to understand the stress change of ejector walls due to the particle impact, the Finite Element Method (FEM) has been used just like the reference [14].

In this paper, the conveying process of two kinds of non-spherical particles inside venturi powder ejector was respectively

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simulated by using CFD-DEM coupling approach to discuss the collision characteristics among particles. The stress change of walls due to the impact of particles inside venturi ejector was also analyzed by using DEM-FEM coupling approach.

2. Physical problems

2.1. Geometric model

The structure of venturi ejector is shown in Fig. 1(a). As is shown in Fig. 1(b), the computation model for numerical simulation was created by meshing the fluid region, and the ejector is consisted of nozzle, suction chamber and venturi tube. The air flow with high speed jets from the nozzle of venturi ejector, which forms vacuum causing by venturi effect [15] and makes particles enter into suction chamber under the influence of gravity and entrainment. Then, particles are transported with the airflow along the venturi tube.

2.2. The generation of particles

In recent years, some methods were studied to model the non-spherical particle in DEM. The simplest non-spherical particle shapes to be incorporate into the DEM are ellipses in 2D [16] and ellipsoids in 3D [17]. A more general approach to describe mathematically non-spherical particles is super-quadrics equation that allows the description of particles of convex and concave shapes [18]. In nature many solids contain sharp edges or flat surfaces, hence, particle shape representation via polygons and polyhedrons have been applied both in two-dimensional [19] and three-dimensional [20] systems. Besides, the composite spheres method, to construct non-spherical particles is popular in DEM [21]. In the composite spheres method, a non-spherical particle is constructed by gluing a certain number of spheres together, which is called multi-sphere. The multi-sphere method was used in this paper. The objects of two sets of simulation are the tablet-shaped and the cylinder-shaped particles, respectively. The multi-sphere approximations are shown in Fig. 2. Each non-spherical particle was consisted of 4 spherical particles whose diameter was 1.6 mm, and the related details can be seen in Fig. 2.

DEM considers the contact model as the vibration one for spherical surfaces, as shown in Fig. 3, the collision force and torques are determined by the overlap between particles [22,23].

The vibration movement of the particle during the contact process is decomposed into two components in the normal and the tangential direction, as seen in Fig. 3(a). The normal vibration equation of motion in the contact process is given as:

$$m_{1,2}d^2u_n\Big/dt^2 + \eta_n du_n/dt + K_n u_n = F_n \tag{1}$$

The tangential vibration movement during the contact process manifests as the tangential sliding, as seen in Fig. 3(b), and the particle rolling, as seen in Fig. 3(c), which can be calculated by the following equations:

$$m_{1,2}d^2u_s\Big/dt^2 + \eta_s du_s/dt + K_s u_s = F_s \tag{2}$$

$$I_{1,2}d^2\theta\Big/dt^2 + (\eta_s du_s/dt + K_s u_s)s = M \tag{3}$$

Here, $m_{1,2}$ is the equivalent mass of the particle, $I_{1,2}$ is the equivalent moment of inertia of the particle, s is the radius of gyration, u_n and u_s is the normal and the tangential relative displacement of the particle, respectively, Θ is the rotation angle of the particle, F_n and F_s is the normal and the tangential component of the particle force, respectively, M is the external torque of the particle, K_n and K_s is the normal and tangential coefficient of elasticity, respectively, η_n and η_s is the normal and the tangential coefficient of damping, respectively.

The tangential sliding and the particle rolling are affected by the friction force between particles simultaneously. The judgment equation for the tangential sliding or the particle rolling is given as:

$$F_s = \mu K_n u_n \mathrm{sgn}[K_s(u_s + d\theta/2)] \tag{4}$$

Here, μ is the coefficient of friction, sgn [ ] is sign function, $\mathrm{sgn}(x) = \begin{cases} 1, x \geq 0 \\ -1, x < 0 \end{cases}$.

Although there is the definite difference in shape for two kinds of particles, their volume are approximately equal: $V_{\text{tablet-shaped}} = 6.0274\text{e-}9\ \mathrm{m}^3$ and $V_{\text{cylinder-shaped}} = 5.8489\text{e-}9\ \mathrm{m}^3$, and their surface area are also approximately equal: $S_{\text{tablet-shaped}} = 1.7496\text{e-}5\ \mathrm{m}^2$ and $S_{\text{cylinder-shaped}} = 1.7844\text{e-}5\ \mathrm{m}^2$. The material of the particle is the same. In order to reflect the real image of the particle comprehensively, the shape factors of the particle: such as the flatness (m) and the elongation (n), are used to describe the shape characteristics of the particle [24].

$$m = \frac{b}{h} \tag{5}$$

$$n = \frac{l}{b} \tag{6}$$

Here, b is the minor axis of the particle, h is the thickness of the particle, and l is the major axis of the particle.

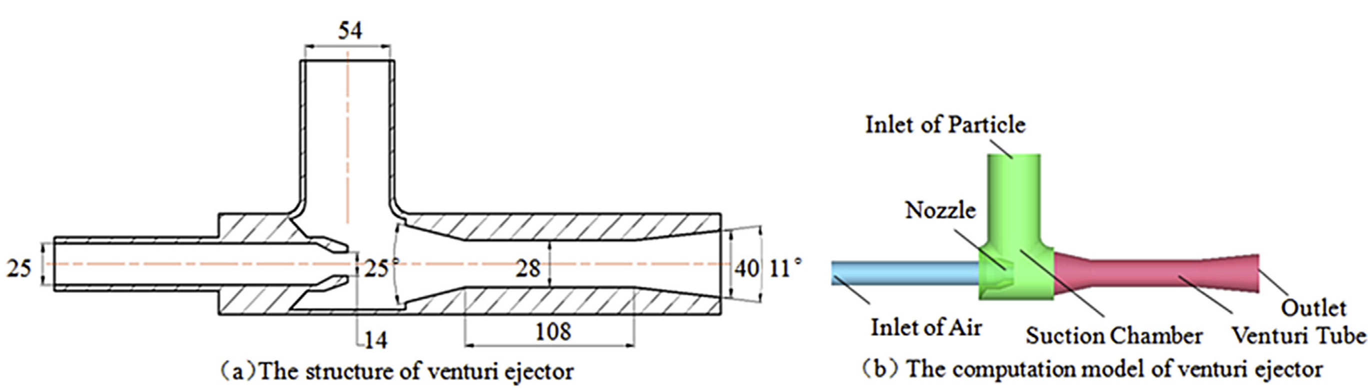

Fig. 1. Geometric structure of venturi powder ejector.