Chemical Engineering Science 122 (2015) 565–572

Contents lists available at ScienceDirect

Chemical Engineering Science

journal homepage: www.elsevier.com/locate/ces

Effect of stator geometry of impact pulverizer on its grinding performance

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HIGHLIGHTS

- Effect of stator geometry on performance of an impact pulverizer was investigated.
- Size of the ground powder was clearly influenced by the stator geometry.
- Particle–stator collision at various stator geometries was analyzed by CFD–DPM.

ARTICLE INFO

Article history:
Received 24 July 2014
Received in revised form
29 September 2014
Accepted 9 October 2014
Available online 23 October 2014

Keywords:
Impact pulverizer
Stator geometry
Numerical simulation
Computational fluid dynamics
Discrete phase model

ABSTRACT

An impact pulverizer is widely employed for dry milling of powders in many industrial sectors. However, effect of the equipment geometry on grinding performance of the impact pulverizer is still unknown. This paper presents systematic analysis of effect of the stator geometry of an impact pulverizer on its grinding performance. Three types of stators with different concave angles were investigated. Effect of the stator concave angles on grinding performance of the impact pulverizer was investigated through both experimental and theoretical approaches. As the theoretical approach, a computational fluid dynamics (CFD)–discrete phase model (DPM) coupling simulation was conducted and the particle–stator collision properties were analyzed. The grinding experiment demonstrated that size of the ground powder was reduced with a use of stator with smaller concave angle. A CFD–DPM simulation revealed that the cumulative impact energy per particle became higher at smaller concave angle, because stator with smaller concave angle lead to longer particle residence time and higher total number of the particle–stator collision. In summary, this work revealed effect of the stator geometry on grinding performance of the impact pulverizer; the stator concave angle mainly affects the particle residence time and total number of the particle–stator collision. This results in change in the cumulative impact energy, leading to change in grinding performance of the impact pulverizer.

1. Introduction

Impact pulverizer, also called as hammer mill and atomizer mill, is widely employed for dry milling of powders. The impact pulverizer basically consists of a high speed rotating rotor and a concavo-convex-shaped stator on its grinding chamber wall. Raw powder is continuously fed into the grinding chamber, and the particles are broken by particle–stator collision, particle–rotor collision, and particle–particle collision. The impact pulverizer has advantages such as relatively high grinding performance, high throughput due to continuous operation, simple equipment construction, and less contamination. Due to these advantages, impact pulverizers have been extensively employed in many industrial sectors such as mineral processing, coal processing, pharmaceutical, cosmetics, food, ceramics, and electronics. Some impact pulverizers specially designed have been applied not only for grinding but also for producing composite materials (Li et al., 2001, 2003) and dry particle coating (Pfeffer et al., 2001; Ouabbas et al., 2009). Although the impact pulverizer is widely used, improvement of its performance is still needed due to requirements of higher functionalities of powder products. For improvement in the performance, design and optimization of the impact pulverizer via detailed understanding of particle motion and fluid flow inside the equipment is necessary.

It is hard to analyze the particle motion and fluid flow in the impact pulverizer by experimental approaches due to their complexities. One powerful way to analyze the particle motion and fluid flow is a computer simulation. So far, computer simulations of impact pulverizers have been reported. Some works (Anagnostopoulos and Bergeles, 1997; Bhasker, 2002; Shah et al.,

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http://dx.doi.org/10.1016/j.ces.2014.10.011
0009-2509/

2009; Vuthaluru et al., 2005, 2006) conducted computer simulation studies of impact pulverizers for coal processing. An impact pulverizer for food powder processing was also analyzed through a computer simulation (Akiyama et al., 2003, 2004a, 2004b). We conducted computer simulations of an impact pulverizer for analyzing the particle motion, fluid flow, and particle breakage mechanism inside the grinding chamber (Takeuchi et al., 2012, 2013). Through these studies, the following mechanism was clarified: (1) the particles fed into the grinding chamber are accelerated by high-speed air flow caused by high-speed rotating rotor; (2) the accelerated particles then impact to a wall of the grinding chamber; (3) the particles are broken by the impact stress; (4) these are repeated until the particles are discharged from the grinding chamber. Moreover, it was revealed that main location where the particle–wall collision and resulting particle breakage occur is the stator concaves, not the rotor.

Our finding suggests that geometry of the stator can be a critical factor which determines grinding performance of the impact pulverizer. Importance of geometry of the stator in design of the impact pulverizer can also be implied from a variety of unique stator geometries of impact pulverizers commercially supplied. However, despite its potential importance, effect of the stator geometry on grinding performance of the impact pulverizer is unknown.

Here, we reported systematic analysis of effect of the stator geometry of an impact pulverizer on its grinding performance. Three types of stators with different concave angles were investigated. Grinding experiments were initially conducted using the stators with different concave angles. A computer simulation using a computational fluid dynamics (CFD)–discrete phase model (DPM) coupling model was then conducted to analyze the particle–stator collision properties at different stator geometries. Based on the experimental and simulation results, influence of the stator geometry on grinding performance of the impact pulverizer was discussed.

2. Experimental

Fig. 1 shows schematic of an impact pulverizer (LM-05, Dalton Co., Ltd.) used in this study. The impact pulverizer consists of following components: grinding chamber with a diameter of 137 mm and a depth of 30 mm; rotor with eight hammers; concavo-convex-shaped stator; classification screen with opening size of 0.7 mm in diameter; collection pot of ground particles. Clearance between tip of the hammer and the stator convex is 0.5 mm. A raw powder is continuously fed into center of the grinding chamber through the front cover. The fed powder was ground between the rotor and stator in the grinding chamber. Ground particles which pass through the classification screen are collected in the pot. Fig. 2 shows schematic of stator concaves used in this study. Stators with different concave angles (θ) were tested. The stator concave angle θ was defined as the angle between surface of the stator concave wall and radial direction of the rotor (dotted line in Fig. 2). Three types of stators with θ=0, 22.5, and 45 deg were used.

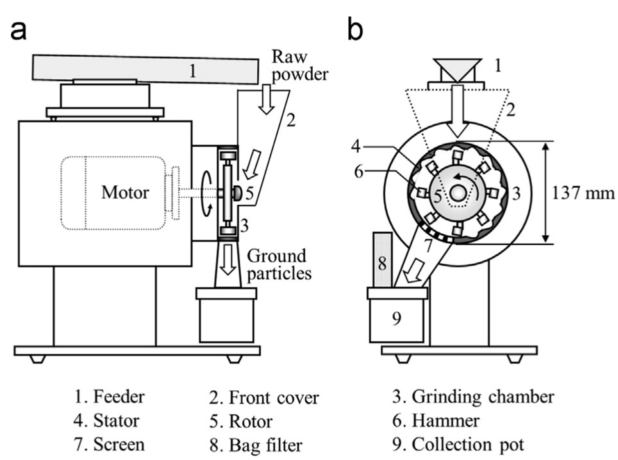

Fig. 1. Schematic of impact pulverizer. (a) side view (b) front view. 1. Feeder, 2. Front cover, 3. Grinding chamber, 4. Stator, 5. Rotor, 6. Hammer, 7. Screen, 8. Bag filter, 9. Collection pot.

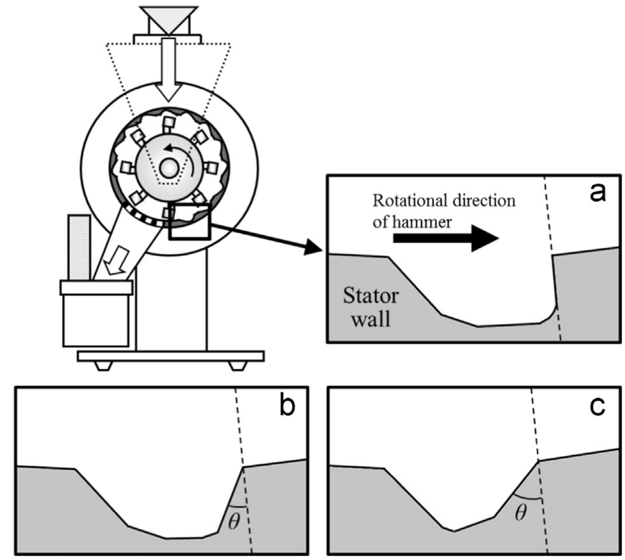

Fig. 2. Schematic of stator concaves with (a) θ=0 deg, (b) θ=22.5 deg, and (c) θ=45 deg.

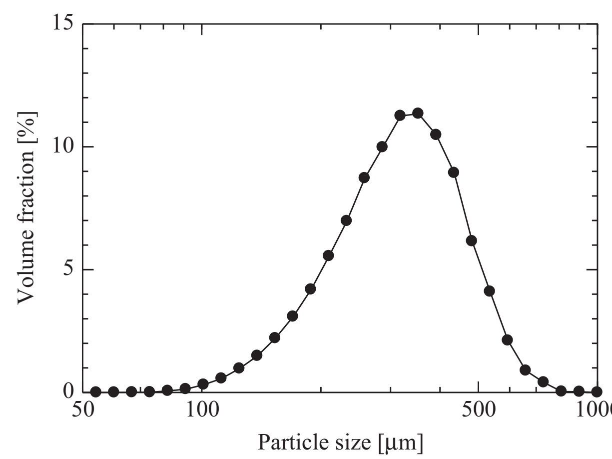

Fig. 3. Particle size distribution of experimental material.

A calcium carbonate (#16, Nittofunka Kogyo, Japan) was used as an experimental material. Fig. 3 shows a particle size distribution of the experimental material. Median particle diameter was 287 μm. Operating conditions of the impact pulverize were as follows: hammer rotational speed was 267 rps, feed rate of powder was 5 g/min, and operating time was 6 min. Particle size distributions of ground particles were measured by a laser diffraction particle size analyzer (SALD-2100, Shimadzu Co., Ltd.).

3. Computer simulation

To analyze the particle–stator collision in the impact pulverizer, a computer simulation was conducted. For this purpose, both the