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Fluidization of non-spherical particles: Sphericity, Zingg factor and other fluidization parameters

Baiqian Liu *, Xiaohui Zhang, Ligang Wang, Hui Hong

School of Mechanical Engineering, University of Science and Technology Beijing, Beijing 100083, China

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Abstract

A comparison of sphericity and Zingg factor for particle morphology and description of fluidized-bed dynamics are presented. It is found that Zingg factor $F_z = LH/B^2$ (where L, H and B are, respectively, the length, breadth and height of a particle) well describes the effect of particle morphology. Experimental results show that non-spherical particles give poor fluidizing quality as compared to spherical particles in terms of pressure drop, U_{mf}, etc. With the same volume-equivalent diameter, non-spherical particles have lower U_{mf} and fluidizing coefficient δ. Some smooth curves have been obtained between the parameters δ, U_{mf} and F_z. The quality of fluidization could be evaluated by fluidizing coefficient, which has been correlated to the Zingg factor and minimum fluidizing velocity in this paper.

Keywords: Particle morphology; Fluidized-bed; Sphericity; Non-spherical particle

1. Introduction

Most industrial gas–solid systems do not consist of spherical particles, and their performance characteristics depend greatly on particle morphology. Theories on fluidization, gas–solid transportation and gas–solid reaction, too, depend on particle morphology, which is generally denoted as particle sphericity.

As early as in 1950, Brown (and later in 1996, Zou & Yu) studied the relationship between sphericity and porosity of a packed bed, and Dolejs and Machac (1995) proposed a fixed-bed pressure-drop equation for non-spherical particles. Eriksson, Alderborn, Nystrom, Podczeck, and Newton (1997) measured the aspect ratio. Xie and Zhang (2001) presented an equation of sphericity and a dynamic shape factor. Endo, Chen, and Pui (2002) gave the fixed-bed pressure drop for non-spherical particles. Bouwman, Bosma, Vonk, Wesselingh, and Frijlink (2004) compared nine parameters for non-spherical particles: the aspect ratio, the circularity, the projected shape factor, the shape factor, the radial shape factor, the critical stability in one plane, the Stokes shape factor, the mass shape factor and the roughness factor. Chhabra and coworkers (Venu Madhav, & Chhabre, 1995; Ferreira, & Chhabra, 1998; Chhabra, Agarwal, & Sinha, 1999; Chhabra, Rami, & Uhlherr, 2001; Nitin, & Chhabra, 2005; Rajitha, Chhabra, Sabili, & Comiti, 2006) evaluated the drag force for non-spherical particle motion in different systems. Wadell sphericity is another popular correcting concept, which is defined as,

$$\phi = \frac{\Delta S_s}{\Delta S_r}, \tag{1}$$

where ΔS_s is the surface area of a spherical particle with the same volume as the real particle and ΔS_r is the surface of the real particle. The Zingg factor, or dynamic shape factor, describes particle morphology geometrically as follows,

$$F_z = \frac{N}{M} = \frac{LH}{B^2} \tag{2}$$

where aspect ratio $N = L/B$, $M = B/H$ and L, B and H are the length, breadth and height of the real particle(linear dimensions in three perpendicular directions). The particle is a cylindrical rod when $F_z > 1$, and plate-like or chip-shaped when $F_z < 1$. Being geometrical, the Zingg factor can be measured directly. Figs. 1 and 2 show, respectively, how sphericity changes with the thickness of platy particles and with the length of rod particles (equivalent size defined as 1, diameter = 1 for cylinder or circular particle and side length = 1 for square rod or plate).

* Corresponding author.
E-mail address: liubq2007@sohu.com (B. Liu).

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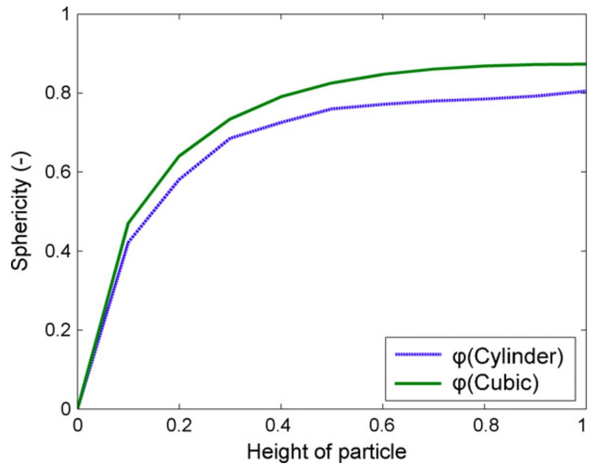

Fig. 1. Sphericity of platy particle vs. its height.

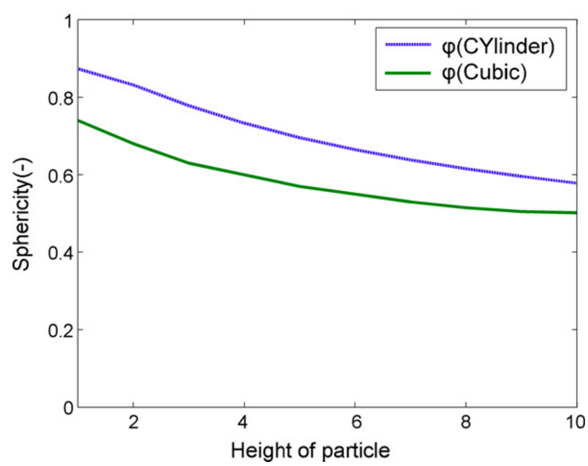

Fig. 2. Sphericity of rod particle vs. its height.

2. Effect of particle morphology on fluidization

2.1. Experiment

A test fluidized-bed was constructed as shown in Fig. 3 with an inner diameter of 40 mm and a height of 1.5 m. Plasticine (density $\rho = 1476\,\mathrm{kg/m^3}$) was selected as the bed material and it was shaped into eight types of morphology as shown in Table 1.

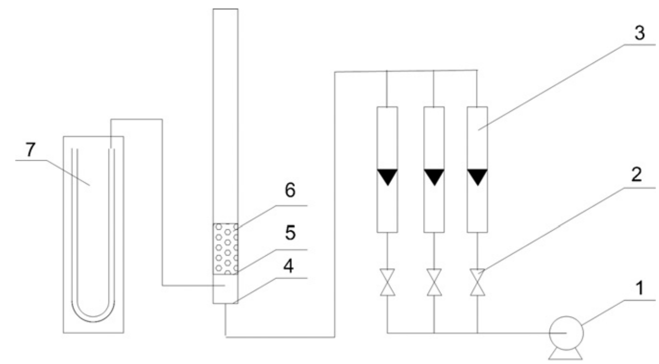

Fig. 3. Cold fluidized model system.

The experimental procedure was to increase the air supply and then decrease it, while the bed pressure drop, bed height, porosity, etc., were recorded to seek some relationship between them and the particle morphology.

2.2. Pressure drop variation

Fig. 4 shows the pressure drop variation with sphericity for both increasing and decreasing air flux, suggesting a tendency for non-spherical particles to accumulate in the fluidized-bed, such as is experienced with Jingxi anthracite (Liu, 2005a,b).

2.3. Minimum fluidizing velocity U_{mf} and fluidization quality

Table 2 shows the minimum fluidizing superficial gas velocity U_{mf} as could be found from a log–log plot of pressure drop versus velocity, and the bed porosity which could be obtained from bed-height measurements.

Particles with different morphologies have different values of U_{mf}. For cylindrical particles of low sphericity, U_{mf} is low while for plate-like particles with an aspect ratio N of 2, U_{mf} has the highest value. Circular plate-like particles have higher U_{mf} than square cylindrical particles with the same sphericity.

Bed-surface disappear gas velocity due to pressure drop fluctuation is defined as U_{sb} which is further expressed in terms of

Table 1
Experimental particle parameters

Item	Particle	Size (mm)	Shape factor			Static porosity	Bed height (mm)
			Φ	N	F_z		
1	Sphere	7(d)	1	1	1	0.35	58
2	Circular plate-like	7.4 × 4.4 ($d \times h$)	0.85	1	0.595	0.312	90
3		8.1 × 3.5 ($d \times h$)	0.8	1	0.432	0.369	65
4		9.6 × 2.5 ($d \times h$)	0.7	1	0.26	0.377	95
5	Cylinder	4.4 × 11.5 ($d \times h$)	0.8	2.61	2.61	0.457	65
6	Square cylinder	9.5 × 9.5 × 2.0 ($l \times b \times h$)	0.6	1	0.21	0.406	64
7		13.2 × 6.6 × 2.1 ($l \times b \times h$)	0.6	2	0.64	0.442	88
8		15.7 × 5.2 × 2.2 ($l \times b \times h$)	0.6	3	1.14	0.512	75