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Fluidized Bed Medium Separation (FBMS) using the particles with different hydrophilic and hydrophobic properties ☆

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ABSTRACT

Three kinds of particles with different hydrophilic and hydrophobic properties were used as fluidized particles of Fluidized Bed Medium Separation (FBMS). A minimum fluidization velocity, an apparent specific gravity of fluidized bed and floating-sinking behaviors of dry and wet coals were measured in the range of relative humidity from 50% to 80%. In a hydrophilic particle, the fluidization became unstable with increasing relative humidity because particle aggregation took place at a high humidity, and hence floating-sinking behaviors depend on changes in a relative humidity. On the other hand, in a highly hydrophobic particle, the fluidization was stable and floating-sinking behaviors based on the specific gravity difference were obtained even for wet coals and at a high relative humidity. Therefore, the FBMS using a highly hydrophobic particle is applicable at a high relative humidity without a control device of relative humidity.

1. Introduction

It is well known that a gas–solid fluidized bed has an apparent specific gravity and viscosity which are properties similar to those of a liquid [1–4]. When an object is inserted in the bed, an object having smaller specific gravity then it floats in the bed, and an object having larger gravity it sinks. Because of this, it becomes possible to separate objects based on their specific gravity difference even though this technique is a dry method. Compared to a wet type specific gravity separation method using a liquid instead of the particle bed, this dry method has some advantages. For example, (1) it is not necessary to have waste liquid treatment process, (2) there is no necessity to check leaking of liquid from the apparatus, (3) it is relatively of low cost, (4) it is possible to use this dry method in a cold region. Because of these advantages, this dry method is being employed for various kinds of separations. Fraser and Yancey [5] and Luo and Chen [6] used this method as a coal preparation technology. Joy et al. [7] separated fluorspar, pallasite and galena as a mineral processing technology. Zaltzman et al. [8–10] used this as an agricultural products separation between potatoes and mud or pebbles. The authors also have used this method so far for (a) coal preparation [11,12], (b) mineral processing for separating silicastone and pyrophyllite [13,14], (c) material separation in automobile shredder residues [15–17] was succeeded. However, these separations were conducted under a low relative humidity (*RH*) condition, $RH \leqslant 60\%$. This dry method could be affected by *RH* because adhesive force between particles changes largely depending on *RH*. Especially, at a high *RH*, particles are aggregated strongly and a stable fluidization is not obtained because of a large adhesive force, and hence it is not easy to float or sink objects based on the difference in their specific gravities. Because of this, for using this dry method in a region where the *RH* changes largely during a year, an *RH* control device should be installed in order to keep an accurate separation. However, from the cost point of view, it is not required to install the device. Hence, an alternative method to solve the problems should be necessary.

In order to achieve the requirement, it should be possible to obtain the conditions which do not change adhesive force and fluidization stability in the wide range of *RH*. Then, in this study, three kinds of particles with different wettability (hydrophilic and hydrophobic) properties were used as fluidized particles, and a minimum fluidization velocity, an apparent specific gravity of fluidized bed, floating-sinking behaviors of dry coals were obtained under various *RH* conditions. From the results, we investigated the effects of *RH* on fluidization stability and floating-sinking behaviors in the fluidized bed with different wettability particles.

In this dry method, separation target objects are usually dry ones because it is not necessary to employ drying process after separation. However, it is also required that the dry method is applied to wet objects because there are many advantages described above and it can be possible to skip dry process before separation.

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Nomenclature

D	equivalent volume diameter (cm)	h_{sp}	normalized height of sphere (–)
D_{fb}	diameter of fluidized bed column (m)	m_P	mass of fluidized particles (kg)
g_c	specific gravity of coal (–)	R_n	number ratio of coal (%/0.05)
g_{fb}	apparent specific gravity of fluidized bed calculated by method-1 (–)	RH	relative humidity (%)
g'_{fb}	apparent specific gravity of fluidized bed calculated by method-2 (–)	u_0	superficial air velocity (cm/s)
g_{sp}	specific gravity of sphere (–)	u_{mf}	minimum fluidization velocity (cm/s)
h	height of sphere or coal in a fluidized bed (m)	$u_{mf(50\%)}$	minimum fluidization velocity at RH = 50% (cm/s)
h_{ave}	average surface height of fluidized bed (m)	ΔP_b	pressure drop of bed (Pa)
$h_{ave(50\%)}$	average surface height of fluidized bed at RH = 50% (m)	ΔP_d	pressure drop of air distributor (Pa)
h_c	normalized height of coal (–)	θ	contact angle (°)
		ρ_w	density of water (kg/m^3)

Actually, when coals having relatively high water content are inserted in the bed, there is a problem that it is difficult to float or sink those coals based on their specific gravity. Then, in this study, floating-sinking behaviors of wet coals were also investigated. Based on the comparison with dry and wet coals results, we investigated the effect of wet objects on floating-sinking behaviors in the bed using different wet particles.

2. Experiment

2.1. Particle and coal

Table 1 shows physical properties of different wet particles employed.

Particle-1: Glass beads.
Particle-2: Silicon coating treatment for Particle-1.
Particle-3: Silane coupling treatment for sands.

In order to examine the wettability of these particles, contact angles were measured by the contact angle measurement instrument (DSA20, Krüss) using the following procedure. First, fluidized particles were put into an acrylic container, 6.5 cm × 3.5 cm × height 0.9 cm. After that, 100 μL of ultrapure water was dropped on the top of the particle bed. Next, contact angle was calculated by using the picture taken from the side of the bed every 30 min after dropping. Fig. 1 shows contact angles with respect to the elapsed time for each fluidized particle. Firstly, in the result of Particle-1, water goes inside the particle bed immediately. In Particle-2, water remains on the top for around 1 h. In Particle-3, for 3.5 h, water remains on the surface, and contact angle keeps more than around 106°. From these results, wettability was gradually changed from a hydrophilic to a highly hydrophobic with increasing number of particle (Particle-1 to Particle-3).

Coal (Ikeshima-coal) was used as a floating-sinking object. Fig. 2 shows specific gravity number-based distribution and equivalent volume diameter for 73 coals. The reason for black key in the figure is described later. Coals with specific gravity less than 1.4 occupy around 50%. The number ratio decreases with increasing specific

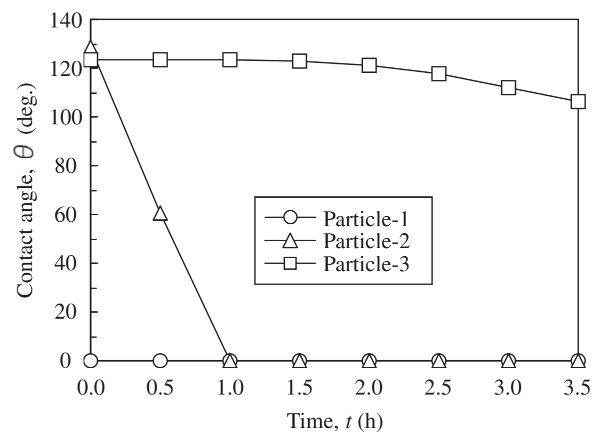

Fig. 1. Time dependences of contact angle for each fluidized particle employed.

gravity, coals having specific gravity larger than 1.65 are only around 7%. Equivalent volume diameter is within the range 2.0–4.5 cm, average and standard deviation of the diameter was 3.26 ± 0.44 cm. In general, it is said that specific gravity of high-grade coal is 1.4–1.6 [18]. Then, eight coals with specific gravity less than 1.6, shown by the black key in Fig. 2, were used as floating-sinking objects.

Table 1
Characteristics of fluidized particles employed.

	Particle size D_p (μm)	True specific gravity g_p (–)	Bulk specific gravity g_b (–)
Particle-1	250–300	2.49	1.53
Particle-2	250–300	2.49	1.53
Particle-3	210–420	2.61	1.59

2.2. Experimental apparatus

Fig. 3 shows schematic view of experimental apparatus. A fluidized bed column was made from an acrylic cylindrical pipe with thickness 0.6 cm, the inner diameter 15 cm and height 42 cm. An air distributor was placed at the bottom of the bed. The structure of the distributor is that a sail cloth was sandwiched by two stainless plates having hole of diameter 0.2 cm, pitch 0.3 cm and open ratio 40.3%. A superficial air velocity u_0 was controlled by the motor valve equipped between the blower and the fluidized bed column. Control of RH was done by changing flow ratio of high and low humidity flow lines which were obtained by passing air flow through the bottles with filled by water and silica gel particles, respectively. The experiment was conducted under RH = 50%, 60%, 70%, 80%. A particle bed pressure drop ΔP_b and a minimum fluidization velocity u_{mf} were measured by the following method. First, the dependence of u_0 on the air distributor pressure drop ΔP_d was measured without putting particles into the bed column. After that the particles were put into the column so that the height is 10 cm, and the particle bed was completely fluidized at $u_0 \approx 20$ cm/s. Then, the sum of pressure drop of the bed and air