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Powder Technology 161 (2006) 227 – 234

POWDER TECHNOLOGY

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Fluidization of fine particles in a sound field and identification of group C/A particles using acoustic waves

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Received 28 July 2004; received in revised form 3 November 2005; accepted 10 November 2005
Available online 27 December 2005

Abstract

Effects of sound field on the fluidization of fine particles have been comprehensively examined by using fine powders (4.8–65 μm average in size) including Al_2O_3, TiO_2, glass beads and FCC catalyst. It is found that the fluidization quality of fine particles can be enhanced with the assistance of a sound field, resulting in higher pressure drops and a lower u_{mf}. The effect of sound on the fluidization of fine particles is strongly dependent on the particle properties (Geldart type and particle size) as well as the parameters of the sound field such as sound pressure level (or intensity) and frequency. Given a fixed sound frequency, the effect becomes more significant at a higher sound pressure level. For the present sound-aided fluidized bed system, there is a resonant frequency at about 100–110 Hz, at which the effectiveness of the sound wave in improving fluidization of fine particles is most remarkable. In addition, based on the different attenuation features of sonic waves in the gas–solid suspension of group C and A particles, a novel acoustic method is explored to distinguish group C from group A particles.

Keywords: Fluidization; Fine particles; Sound field; Acoustic waves; Group C particles; Group A particles; Identification

1. Introduction

Fluidization is an advantageous technique for handling fine particles and is extensively used in the chemical, advanced materials, pharmaceuticals and food industries. However, fine particles, 30 μm in size or smaller, classified as group C (cohesive) particles by Geldart [1], are generally believed to be unsuitable for fluidization since they tend to form agglomerates as a consequence of strong interparticle forces. As early as in 1955, however, Morse [2] found that the fluidization quality of cohesive particles could be enhanced by the application of acoustic fields. It was concluded that the fluidization of cohesive, fine-grained powders was improved markedly by applying low-frequency and high-intensity sonic energy. Recently, Nowak and Hasatani [3] used a speaker powered by an audio amplifier as the source of external energy and observed an improved fluidization quality for cohesive particles when low-frequency (<120 Hz) acoustic energy of sufficient intensity (>100 dB) was introduced. With the addition of acoustic energy, the minimum fluidization velocity can also be decreased and the heat transfer ameliorated. The maximum effect was obtained at a resonant frequency. Chirone et al. [4,5] and Russo et al. [6] reported a series of studies concerning the influence of acoustic waves on fluidization of cohesive particles. Their observation showed that homogeneous fluidization of zeolitic catalyst (11 μm), ash (8 μm) and talc (5 μm) particles could be achieved when operated in an acoustic field with appropriate combinations of bed weight and sound intensity and frequency. The elutriation rates of fine particles from beds could also be reduced by a high-intensity sound. Similar positive influences of acoustic wave on fluidization of eight different cohesive powders were also reported by Leu and Huang [7], though their results demonstrated that to achieve the entire fluidization of each powder was difficult, even when applying a strong acoustic wave. Experimental results by Chirone et al. [5] further showed that severe channelling was observed throughout the tested range of

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doi:10.1016/j.powtec.2005.11.005

Table 1
Criteria for quantitatively distinguishing C/A particles

Author	Index	Criterion for group C	Boundary of A/C
Barerns, 1966	FI=$u_{\mathrm{mf,cal}}/u_{\mathrm{mf,obs}}$	FI$<10^{-3}$	$3\times10^{-3}<$FI<5
[1]	d_p	$d_p<25–40$ μm	–
[10]	$K_1=D_{1,\max}/F_{\mathrm{van}}$	$K_1<0.01$	$K_1=0.01$
Geldart, 1984	$R_H=\rho_{tp}/\rho_{bp}$	$R_H>1.4$	$1.25<R_H<1.4$
Zhao, 1991	AOR	AOR$>40°$	$35°<$AOR$<40°$
Wang, 1995	$\hat{S}_e=\frac{1}{(\rho_p-\rho_g)d_p}$	$\hat{S}_e>25$	$\hat{S}_e=25$

gas velocities for pigments of very small size (<1 μm) in a sound field. This suggests that for these solids, the application of an acoustic field cannot bring the beds to a state of uniform fluidization. Despite the above-mentioned previous work, a thorough investigation of the sound-aided fluidization of fine particles, e.g., its influencing factors such as the frequency/intensity of acoustic waves and the properties of primary particles has not been carried out thus far. Therefore, a comprehensive study on the fluidization of fine particles in a sound field is necessary.

The other purpose of this study, as indicated in the title of this article, is to develop an acoustic method to distinguish cohesive (group C) particles from non-cohesive (group A) particles. According to the available literature, a few valuable criteria have been developed for quantitatively distinguishing groups C/A particles, as summarized in Table 1. Baerns [8] came up with the fluidizability index (FI), which was defined as the ratio of the minimum fluidization velocity ($u_{\mathrm{mf,cal}}$) calculated by a traditional relationship to the actual minimum fluidization velocity ($u_{\mathrm{mf,obs}}$) determined by pressure drop and heat transfer measurements. The difficulty in using the *FI* lies in that the $u_{\mathrm{mf,obs}}$ for each powder has to be determined experimentally and very often arbitrary for Group C particles. Later classification of fine particles based on the observation of particle fluidization behaviour was developed by Geldart [1,9]. According to Geldart's scheme, particles with a diameter smaller than 25–40 μm, depending on their densities, may be classified to the cohesive powder category (group C). This criterion, though very qualitative, is accepted worldwide by researchers in the field of particle technology. Molerus [10] proposed another criterion taking into consideration the interparticle forces (the van der Waals force) and suggested that K_1, the ratio of the maximum fluid drag force ($D_{1,\max}$) to the van der Waals forces (F_{van}), should be 0.01 for the A/C boundary. Geldart et al. [11] used an empirical criterion, called Hausner ratio, R_H (the ratio of tapped to aerated bulk density of the particles), as an easily available index for characterizing the fluidizability of particles. Also, an experimental method has been proposed by Bai et al. [12] for distinguishing group C particles from other groups based on the dynamic pressure signals from the bed collapse tests. It was found that the pressure signals for group C particles obviously had a higher dominant frequency, smaller fluctuation and less chaotic nature than those obtained from groups A and B particles. Zhao et al. [13] identified group C powders through the angle of repose (AOR). It was assumed that particles with AOR>40° could be classified as group C powders. More recently, Wang and Li [14] put forward another criterion by introducing an intrinsic factor, i.e., the equivalent specific surface area per unit mass of particles, defined as $1/[(\rho_p-\rho_g)d_p]$. In the present work, an

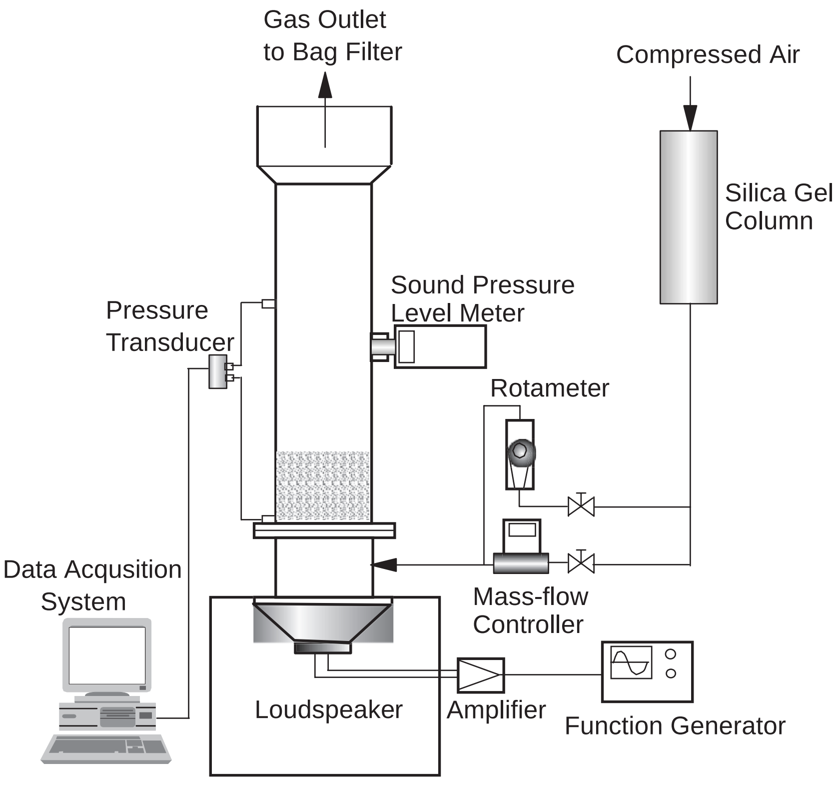

Fig. 1. Schematic diagram of experimental apparatus.