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Characteristics of pressure fluctuations and fine coal preparation in gas-vibro fluidized bed

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ABSTRACT

To improve the separation efficiency of air dense medium fluidized beds for dry coal preparation, a gas-vibro fluidized bed has been proposed in which magnetic powder is used as the heavy medium. Pressure fluctuations in the gas-vibro fluidized bed were investigated using time- and frequency-domain analysis methods. The relationship between pressure fluctuations, bubble behavior, and separation efficiency was established. The low amplitude of the standard deviation, the power spectral density (PSD), the incoherent-output PSD, and the high amplitude of the coherent-output PSD, which corresponds to the bubble behavior in the bed, were improved for coal preparation. The coal ash content was reduced from 42.55% to 16.54% by using the gas-vibro fluidized bed.

Introduction

Coal, oil, and natural gas are the most important primary energy sources, and they accounted for 29.9%, 33.1%, and 23.9%, respectively, of the global primary energy consumption in 2012 (BP, 2013). In many countries, such as China, India, and South Africa, coal accounts for over half of the total primary energy supply. However, significant environmental pollution results from coal firing without coal preparation prior to use. Wet beneficiation technologies, which produce large amounts of wastewater, are popular in coal preparation plants. However, these technologies are inefficient in arid and cold regions. Furthermore, low-rank coal, which easily forms slimes with water cannot be separated by wet beneficiation technologies. An air dense medium fluidized bed (ADMFB) without water has been proposed for dry coal preparation (Zhao et al., 2011; Azimi, Karimipour, Rahman, Szymanski, & Gupta, 2013; He, Zhao, Luo, He, & Duan, 2013; Mohanta, Rao, Daram, Chakraborty, & Meikap, 2013). Vibrational energy is applied to the fluidized bed to achieve fine coal separation (Wang, He, He, Ge, & Liu, 2013; Yang, Zhao, Luo, Song, & Chen, 2013; Yang et al., 2013b).

The gas-vibro fluidized bed, in which the fluidization velocity pulses regularly with time, can improve the fluidization quality by removing slugs and gas channeling, reducing the bubble size, and enhancing gas–solid contact compared with traditional fluidized beds in which the fluidization velocity is constant (Wang & Rhodes, 2005; Gui & Fan, 2009; Hadi, van Ommen, & Coppens, 2012; Reyes, Mahn, Guzmán, & Antoniz, 2012). It uses magnetic powder as the dense medium and may improve the separation efficiency of the ADMFB (Dong et al., 2013).

Pressure fluctuations can provide information on the fluidization quality and dynamic behavior, including gas turbulence, the rise and eruption of bubbles, particle behavior, and pressure wave propagation in a gas–solid fluidized bed (Sobrino, Sánchez-Delgado, García-Hernando, & de Vega, 2008). The time series of the pressure signals can be analyzed using time-domain, frequency-domain, and state-space methods (Johnsson, Zijerveld, Schouten, van den Bleek, & Leckner, 2000; van Ommen et al., 2011). The minimum fluidization velocity (Punčochář, Drahoš, Čermák, & Selucký, 1985; Sobrino, Almendros-Ibañez, Santana, & de Vega, 2008; Mohanta, Daram, Chakraborty, & Meikap, 2012), pressure wave propagation (Bi, 2007), particle dispersion (Kang, Woo, Ko, & Kim, 1997), complex dynamics of a fluidized bed (Tahmasebpour, Zarghami, Sotudeh-Gharebagh, & Mostoufi, 2013), and bubble flow (Sasic, Leckner, & Johnsson, 2006; Croxford & Gilbertson, 2011)

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Nomenclature

$C_{xy}(\omega)$	coherence function
$COP_{xy}(\omega)$	coherent-output power spectral density for two time series recorded at position *x* and *y*
f	gas pulsation frequency
$IOP_{xy}(\omega)$	incoherent-output power spectral density for two time series recorded at position *x* and *y*
M	number of segments
N	total number of pressure data points
N_{FFT}	data point number of the FFT
p	pressure time series
$p_x(t)$, $p_y(t)$	pressure time series measured at position *x* or *y*
$S_{xx}(\omega)$, $S_{yy}(\omega)$	power spectral density of the pressure time series measured at position *x* or *y*
$S_{xy}(\omega)$	cross power spectral density for two time series recorded at position *x* and *y*
t	time
v	instantaneous gas velocity
v_0	continuous gas velocity
v_p	amplitude of pulsed gas velocity
$X_i(\omega)$	one-sided Fourier transform of $p_x(t)$ at the *i*th segment by a fast Fourier transform
$X_i^*(\omega)$	complex conjugate of $X_i(\omega)$
$Y_i(\omega)$	one-sided Fourier transform of $p_y(t)$ at the *i*th segment by a fast Fourier transform
$Y_i^*(\omega)$	complex conjugate of $Y_i(\omega)$
σ_p	standard deviation of a pressure time series
$\sigma_{xy,c}$	standard deviation of the coherent-output power spectral density
$\sigma_{xy,i}$	standard deviation of the incoherent-output power spectral density

Abbreviations

ADMFB	air dense medium fluidized bed
COP	coherent-output power spectral density
ESEM	environmental scanning electron microscope
EDS	energy dispersive spectrometer
FFT	fast Fourier transform
IOP	incoherent-output power spectral density
PSD	power spectral density

have been investigated in many studies using pressure fluctuations. Van Ommen et al. (van Ommen, de Korte, & van den Bleek, 2004; van Ommen et al., 2011) used the advanced analysis methods as an online tool to detect defluidization in an industrial fluidized bed. In this study, pressure fluctuations in a gas-vibro fluidized bed for coal preparation were investigated to determine the relationship among pressure fluctuations, bubble behavior, and separation efficiency.

Experimental

The experimental system is shown in Fig. 1. The fluidized bed diameter was 200 mm, and the static bed height was 100 mm, according to the separation process. A novel gas distributor with 5 μm inner diameter holes was used to enhance the gas distribution. Two pressure differential transmitters (168P2500DB1NB, Aphpa Instruments, USA) and one data logger (cDAQ-9178, National Instruments, USA) were used to record the pressure fluctuations in the bed. Pressure drops were measured with respect to the midpoint between positions *x* and *y* through three 4 mm inner diameter copper tubes with a fine mesh net on the side

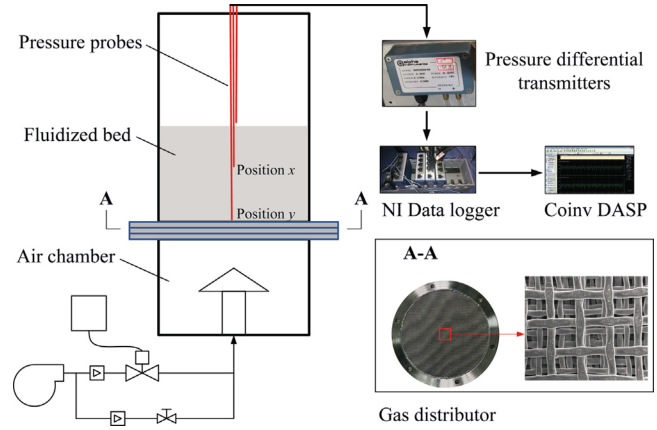

Fig. 1. Schematic of experimental system.

facing the fluidized bed. The sampling frequency was 1000 Hz, and the sampling time was 20 s. Approximately 20,000 data points were recorded for signal processing for each experimental condition. Coinv DASP software (v10, Coinv, China) was used to record the data and to conduct signal processing. A butterfly valve that was driven by an electric motor was used to generate an active pulsed gas flow, and an inverter was used to control the gas pulsation frequency from 0.87 to 6.98 Hz. A high-speed camera (*i*-Speed III, Olympus, Japan) was used to record bubbles in the bed. Approximately 1000 pictures were taken per second, and the bubble average diameter at position *x* was analyzed using an image processing method.

In the gas-vibro fluidized bed, the gas velocity pulses regularly with time, and the waveform of the gas velocity is shown in Fig. 2, where v is the instantaneous gas velocity, v_0 is the continuous gas velocity, v_p is the amplitude of pulsed gas velocity, f is the gas pulsation frequency, and t is time. In this study, the value of v_0 is 0.01 m/s, and v_p is 0.09 m/s, to ensure a suitable fluidization number (defined as the quotient when dividing fluidizing gas velocity by minimum fluidization velocity). The fluidization number of the fluidized bed for coal separation should be less than 2.0, according to previous research (Zhao et al., 2010). Different bed densities can be obtained by choosing different fluidization numbers. In this study, the fluidization number was 1.4.

Magnetic powder, which can be recovered by a magnetic separator and be recycled in the separating process, was used as the dense medium because of its suitable bulk density (2650 kg/m^3). The size distribution of the dense medium as analyzed by a laser particle size analyzer (S3500, Microtrac, USA) is given in Table 1.

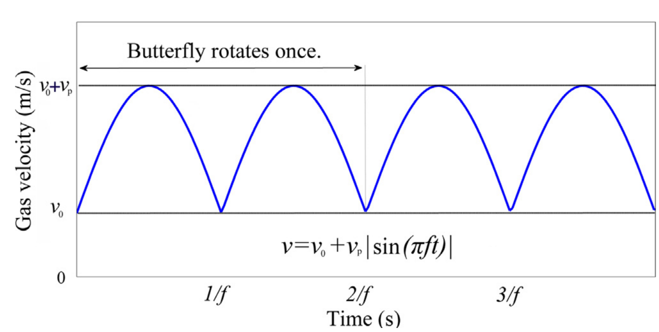

Fig. 2. Waveform of gas velocity in gas-vibro fluidized bed.