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Effect of acoustic field on minimum fluidization velocity and drying characteristics of lignite in a fluidized bed

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ABSTRACT

The fluidization and drying characteristics of Shengli lignite in a sound-assisted fluidized bed are investigated. The effects caused by sound frequency and sound pressure level on the minimum fluidization velocity and drying rate are studied. Experiments indicated that acoustic field can improve the fluidization quality and drying rate of Shengli lignite. The minimum fluidization velocity decreased with an increase in sound pressure level and has a minimum value at a sound frequency of 1.5 kHz. The drying rate of Shengli lignite was especially increased during the initial period of the drying process, while the effect was minor toward the end of process. Based on the determination of TG, FTIR, and BET, the structure changes of Shengli lignite were measured to assess the changes in the quality of dried lignite with the assistance of acoustic field. The weight loss rate of dried lignite decreased with the introduction of acoustic waves. Total pore volume, average pore diameter, and specific surface area were significantly reduced with introducing acoustic waves. Carbonyl decreased progressively with the assistance of acoustic field while carboxyl and hydroxyl increased and decreased thereafter. In addition, the energy consumption of fluidized bed drying system after inducing acoustic field is investigated.

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1. Introduction

Lignite is a kind of low rank coal with high moisture content, ranging typically from 50 to 70% by weight on a wet coal basis, which reduces 20–25% of the energy efficiency of combustion in removing this associated water. Therefore, lignite drying is the first and essential step for their transportation, storage, and utilization as energy resources. Owing to many excellent transport properties like solid mixing and the heat and mass transfers between gas and solid phases, fluidized bed dryer has successfully been used for drying of low rank coals such as Illinois coal [1], Turkish lignite [2], Chinese Shenhua lignite [3], Loy Yang brown coal [4] and Victorian brown coal [5].

However, lignite belongs to viscous particles. The agglomerative phenomenon of lignite is a serious problem using fluidized bed dryer. To enhance the fluidization quality of lignite, additional field assisted fluidized bed was investigated such as magnetic field, vibration, agitation, and acoustic field. It is well known that the application of an acoustic field can improve the fluidization quality of Geldart C particles [6,7] and Geldart A particles [8,9]. The results of David RE et al. [10,11] showed that high frequency (sound) vibrations could decrease the minimum fluidization velocity and provide a more uniform fluidization. Wankhede US et al. [12] found that acoustic energy of sufficient intensity and sound pressure level significantly improved the quality of fluidization of fine powders and heat transfer rates. In addition, Guo QJ et al. [13] reported the influence of sound waves on fluidization of quartz sand and SiO_2 particles in high temperature fluidized bed. Raganati F et al. [14,15] reported the influence of sound waves on fluidization of CO_2 adsorbents materials. Their observations showed that the adsorption process of CO_2 can be enhanced by reason of the fluidization quality improvement of CO_2 adsorbents materials.

In fact, high-intensity acoustic energy is capable of increasing heat and mass transfer efficiency in drying of apple, red bell pepper [16], and clipfish [17]. Power ultrasound introduces pressure variations at solid/gas interfaces, and therefore increases the surface moisture drying rate [18]. Therefore, external and internal resistance may be seriously affected during drying by acoustic energy, thus increasing drying rate [19]. In the present study, the effects caused by sound frequency and sound pressure level on the minimum fluidization velocity (u_{mf}) and drying rate in a sound-assisted fluidized bed dryer were investigated. The aim of the present study was to investigate the acoustic field which enhanced the fluidization quality and drying rate of lignite. Based on the determination of TG, FTIR, and BET, the structure changes of lignite were measured which has great significance to store and utilize of lignite. The sound-assisted fluidized bed drying system has a better performance in energy saving due to better mass and heat exchange inside the dryer.

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2. Experiment

The schematic diagram of the sound-assisted fluidization system was showed in Fig. 1. Experiments were carried out in a quartz column with a height of 800 mm and an inner diameter of 60 mm. The distributor was a porous glass plate with a thickness of 2 mm and pore size of 2 mm. An ultrafine mesh filter was located at the distributor. Nitrogen was used as the fluidization gas and drying medium. The fluidized gas was heated in an electric furnace. Sheng Li lignite used in this study has a mean diameter of 2.5 mm and a particle density of 900 $kg \cdot m^{-3}$. Before the experiments, the particles were sieved using Taylor sieve. The mass of Sheng Li lignite was 0.185 kg in this work. Table 1 listed the typical properties of Sheng Li lignite.

Table 2 listed the experimental parameters and their values. The gas flow rate was measured and adjusted by a rotor flowmeter. A manometer was installed to record the pressure signals above the distributor. Acoustic field system measurements were performed with signal generator, sound amplifier and loudspeaker. The electric signal was then amplified with a sound amplifier and sent to a loudspeaker installed on the top of the fluidized bed. A precision sound pressure level meter was used to measure the sound pressure level in the fluidized bed, with a 160 dB maximum sound pressure level to be measured. The sound frequency was controlled by a signal generator.

The moisture content values and the drying rate values were calculated through the following equations:

$$X = {}^{W_0 - W_{d,t}} \Big/ {}_{W_0} \quad (1)$$

$$M_R = {}^{(X_t - X_\infty)} \Big/ {}_{(X_0 - X_\infty)} = {}^{X_t} \Big/ {}_{X_0} \quad (2)$$

$$R = -M_w {}^{dM_R} \Big/ {}_{dt} \quad (3)$$

where, X is moisture content values, W_0 is initial lignite sample weight, $W_{d,t}$ is dried coal weight at any time, M_R is moisture content ratio, X_0 is initial moisture content, $X_{,t}$ is moisture content at any time, X_∞ is the equilibrium moisture content at the end of drying process, M_0 is moisture content, R is drying rate and t is drying time. The equilibrium moisture content (X_∞) was assumed to be zero at the end of drying process and therefore the moisture ratio was simplified.

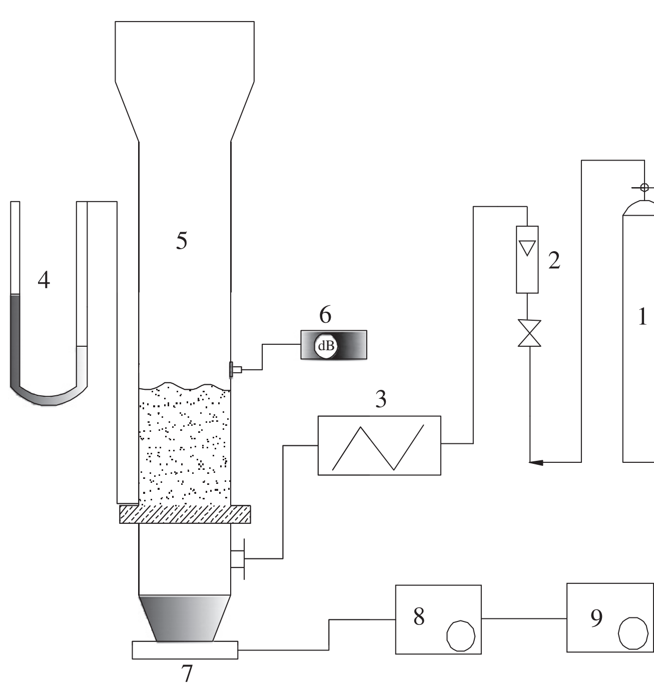

Fig. 1. Schematic diagram of experimental apparatus. 1. N_2; 2. rotameter; 3. preheater; 4. manometer; 5. fluidized bed; 6. sound pressure level meter; 7. loudspeaker; 8. sound amplifier; and 9. signal generator.

Table 1
Typical properties of Sheng Li lignite.

Proximate analysis [wt.%]					Ultimate analysis [wt.% (d.a.f. basis)]					$Q_{net,ar}$/MJ/kg
M_{ar}	M_{ad}	A_d	V_{daf}	FC_{daf}	C	H	N	S	O	
28.68	13.98	21.04	44.1	55.9	55.68	3.56	1.18	1.84	37.74	14.12

Thermogravimetric (TG) data was sampled using a STA 409 PC/4/H TGA unit (Netzsch, Germany). Sample weights with 5 mg were used in experimental runs. The TGA tests were performed over a temperature from ambient to 600 °C at a heating rate of 15 °C/min. Infrared spectra of the raw lignite, dried lignite at T = 120 °C, t = 15 min, $u_g = 1.25$ m/s with and without acoustic assistance were analyzed using a Nenus 470 FTIR spectrometer (Nicolet, USA). Infrared spectra of the lignite sample for the 4000–400 cm^{-1} region were studied by curve fitting analysis using a commercially available data-processing program. The data for the N_2 adsorption–desorption isotherm were collected using a 3H-2000PS Specific Surface Area Analyzer (Beishide Instrument, China). The surface area was estimated by the Brunauer Emmett Teller (BET) method, and the average pore size and total pore volume were determined by the Barrett Joyner Halenda (BJH) method.

3. Results and discussion

3.1. Minimum fluidization velocity of lignite

Minimum fluidization velocity (u_{mf}) is an important factor in understanding the hydrodynamic behavior of fluidized beds. The minimum fluidization velocity was obtained from the intersecting point of the defluidization curve with the constant pressure line.

3.1.1. Effect of the sound frequency

To investigate the effects of the sound frequency on the minimum fluidization velocity of lignite, experiments were carried out with the sound frequency varying from 1 kHz to 4 kHz and sound pressure level fixed at 140 dB. Fig. 2 showed that the plot of pressure drops versus gas velocity for the lignite particles. According to Fig. 2, the minimum fluidization velocity was determined at different values of sound frequency. The results are given in Fig. 3. The minimum value of minimum fluidization velocity was obtained at optimum sound frequency of 1.5 kHz. It can be seen from Fig. 3 that the minimum fluidization velocity of lignite decreased with increasing sound frequency, and further increased.

For the high moisture content lignite particles, the cohesive force between two particles is predominantly the liquid bridge force and hydrogen bond force. The cohesive force decreases, reaches a minimum, and then increases with the increase of sound frequencies [13]. With sound excitation, the disruption of lignite particle agglomerates depends on the sound prompting energy. However, low frequency sound waves cannot affect the fluidized quality of lignite continuously. In addition, a low sound frequency leads to a relative low sound energy due to the

Table 2
Experimental conditions.

Parameters	Values
N_2 temperature (°C), T	120
N_2 flow rate (m/s), u	0–1.8
Particle size (mm), D_p	2.5
Particle density (kg/m^3), ρ_p	900
Sound frequency (kHz), *f*	1–4
Sound pressure level (dB), SPL	90–150

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