International Journal of Mining Science and Technology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Segregation modes, characteristics, and mechanisms of multi-component lignite in a vibrated gas-fluidized bed

Su Ding [a,b], Luo Zhenfu [a,*], Lei Lingyan [c], Zhao Yuemin [a]

[a] School of Chemical Engineering & Technology, China University of Mining & Technology, Xuzhou 221116, China
[b] Xuzhou Coal Mining Group, Xuzhou 221006, China
[c] School of Environmental Science and Spatial Informatics, China University of Mining & Technology, Xuzhou 221116, China

ARTICLE INFO

Article history:
Received 10 September 2017
Received in revised form 10 October 2017
Accepted 28 November 2017
Available online xxxx

Keywords:
Dry-beneficiation
Multi-component lignite
Segregation mode
Degree of homogeneity

ABSTRACT

The segregation modes and characteristics of 1–6 mm multi-component lignite were studied in a microporous, vibrated, gas-fluidized bed of Φ110 mm × 400 mm. The effects of particle density and size, vibration frequency and amplitude, and gas velocity on these characteristics were considered. The average size, average density, size deviation coefficient, and density deviation coefficient were used to identify lignite size and density. The separation efficiency was adopted to evaluate the segregation performance, and the segregation mechanisms were explored. The results show that $\varepsilon_{size,max}$ of heterogeneous multi-size-component lignite with $K_{size} = 65\%$ reaches 80% at $f = 20$ Hz, $A = 5$ mm, and $N = (1,3)$. $\varepsilon_{density,max}$ of heterogeneous multi-density-component lignite with $K_{density} = 25\%$ reaches 50% at $f = 15$ Hz, $A = 5$ mm, and $N = (1,1.5)$. The density segregations of 1–3 and 3–6 mm multi-component mixtures are remarkable, $\varepsilon_{density,max} = 42\%$ and 31% at $f = 14$ and 16 Hz, and $A = 3$ and 5 mm, respectively. The size segregation of 1–6 mm multi-component mixture is prominent and $\varepsilon_{size,max} = 55\%$ at $f = 15$ Hz, $A = 5$ mm. The medium-sized mixture with a narrow size distribution at low frequency is favorable for density segregation, and a mixture with a wider size distribution at high frequency is most favorable for size segregation. Precise control of gas flow and vibration as well as optimal design of the fluidized bed can improve the performance of segregation in the vibrated gas-fluidized bed.

1. Introduction

With the expansion of coal mining and mining mechanization, the production of fine lignite with high ash has been increasing. Deposited primarily in northeastern and northwestern China, in addition to the country's other cold or arid regions, lignite has a low metamorphic grade and easily becomes muddy when exposed to water. Therefore, it cannot be processed by conventional wet separation technology, and research on dry lignite beneficiation technology has become a major area of interest for the sustainable development of China's coal industry. It is important to meet the rapid growth of energy demand while achieving energy savings and emission reductions.

Dry separation in a dense medium gas-fluidized bed has resulted in the successful dry beneficiation of coarse coal of 6–50 mm with high efficiency [1–3]. However, the bubbles formed by fluidization can cause macro mixing of the dense medium, which tends to short-circuit fine particles and increases the product mismatch. Therefore <6 mm fine coal cannot be separated effectively. Some scholars have introduced external forces to inhibit bubble formation. A vibrated gas-fluidized bed with a dense medium proved to be an effective, low-energy-consuming method of dry beneficiation [4–7]. The medium preparation, however, is difficult, because the yield is low and the processing cost is high. Therefore, the vibrated gas-fluidized bed with no medium has been favored by researchers because of its simple process and low cost [8].

Scholars have concentrated on the separation of binary simulated particles. Jin et al. plotted the separation equilibrium phase diagram of Geldart 's A, B, and D particles, composed of mung beans, glass beads, millet, silica gel, sand, and iron powder, with equal and unequal density [9]. This study introduced Williams' separation coefficient, and established the separation criterion and operation range.

Dong et al. studied the effect of internal horizontal tubes on the separation characteristics of $d_p = 1.42$ mm millet and $d_p = 0.045$–0.2 mm titanium concentrates [10]. Liu et al. determined the relationship between separation efficiency and vibration strength, as well as the transition point of mixing and separation of $d_p = 0.6$,

---

* Corresponding author.
E-mail address: zfluo@cumt.edu.cn (Z. Luo).

https://doi.org/10.1016/j.ijmst.2017.12.009
2095-2686/

Please cite this article in press as: Su D et al. Segregation modes, characteristics, and mechanisms of multi-component lignite in a vibrated gas-fluidized bed. Int J Min Sci Technol (2017), https://doi.org/10.1016/j.ijmst.2017.12.009

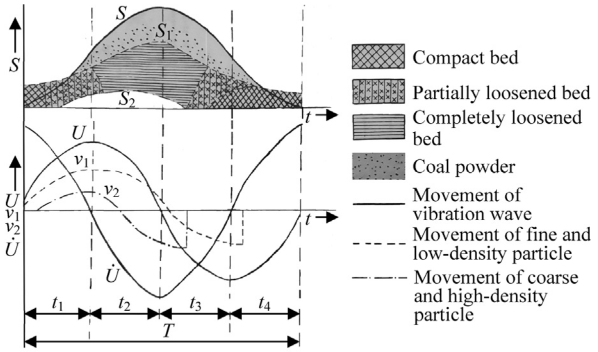
2, and 4 mm molecular sieve particles and $d_p = 6$ mm soybean at a low gas flow rate [11]. Fan et al. determined the bed pressure drop of Geldart D particle mixtures of $d_p = 2.6$ mm corn and $d_p = 4$ mm plastic beads and established the mathematical model of critical fluidization velocity based on the force analysis and the Ergun formula [12]. Roger, Valeri, Daleffe et al. investigated the dynamics and segregation patterns of binary, flat, Gaussian, and reference particles with the mean Sauter diameter equal to 2.18 mm in fluidized, vibrated, and vibrofluidized beds [13]. Matthew et al. investigated binary, ternary, and poly-disperse mixtures of nuts and round glass beads of different sizes and conducted comparative numerical analyses [14]. The results showed that a slight increase of intermediate species in the ternary mixtures reduced segregation and enhanced mixing. Yang et al. studied density segregations of binary mixtures composed of $d_p = 1$–1.8 glass beads, $d_p = 1$–2.2 millet, and $d_p = 3.8$–5 mm rice with similar sizes and different densities or with different sizes and different densities [15–17]. They introduced an ash mixing coefficient to quantitatively determine the degree of segregation, revealed the mechanism of density separation based on energy transfer and dissipation analysis, and found the density segregation conditions: a surge disturbance zone with suitable size. Moreover, they carried out the semi-industrial lignite separation experiments from 1–3 and 3–6 mm.

The segregation process of lignite with wide density and size distributions is complex and difficult to control, and usually presents various segregation patterns. The research in this field is lacking. This study primarily considers segregation modes, characteristics, and mechanisms for the success of density segregation in a vibrated gas-fluidized bed.

2. Segregation mechanisms

The alternative vertical motion of vibration and gas flow provides energy for segregation. Ideal energy propagation behavior in a vibrated gas-fluidized bed is shown in Fig. 1 [18]. Fig. 1 shows that pressure at any point in the bed has a sinusoidal periodic variation with time, based on the sinusoidal loading excitation, and developed a phase difference. Bubbles created a low-frequency disturbance to a fluctuating pressure signal.

In response to periodic motion, the particle layer makes a synchronized periodic movement, which is illustrated in Fig. 2. Note that in the previous $\pi/2$ cycle, the bed is compact initially, and then turns loose, gradually departing from the gas distributor. In the $\pi/2$–π cycle, the bed continues to rise until the bed looseness finally reaches the maximum. In the π–$3\pi/2$ cycle, the bed height begins to decrease, and it tends to become denser with time, and, during the later stages, returns to the gas distributor. In the $3\pi/2$–2π cycle, the bed gradually becomes more compact.



S, S_1, S_2 -Displacement of vibration, fine and low-density particle, coarse and high-density particle

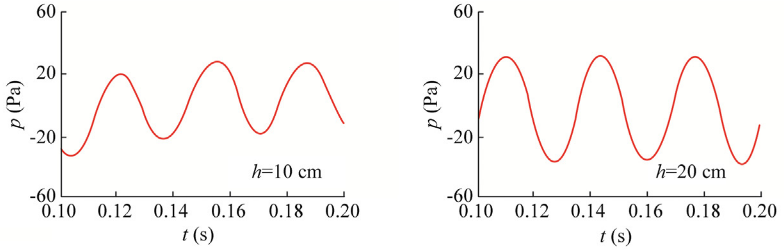
U, v_1, v_2 -Velocity of vibration, fine and low-density particle, coarse and high-density particle

$\dot{U}$ -Acceleration of vibration

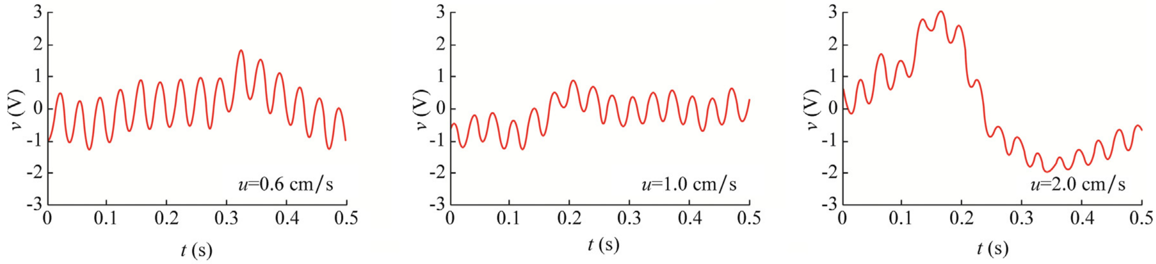
Fig. 2. Process of bed loosening and particle stratification at four stages of sinusoidal period.

Bed loosening provides conditions for particle movement. Initially, fine particles with low density ascend early, while coarse or heavy density particles lag behind and move slowly. In the $\pi/2$–π cycle, fine particles with low density continue rising because of inertia, but their velocity slows down; coarse or heavy density particles move slowly, and a small portion of the coarse particles with heavy density even shift to descend. In the π–$3\pi/2$ cycle, fine particles with low density veer downward, and coarse or heavy density particles fall on the gas distributor gradually and become immobile. In the $3\pi/2$–2π cycle, fine particles penetrate the bed clearance and arrive at their destination.

Particles in free space are influenced by gravity, gas buoyancy, and medium resistance, which can be expressed as



(a) At different heights of bed



(b) Under different gas velocities at h=10 cm

Fig. 1. Tracing of pressure wave.

Please cite this article in press as: Su D et al. Segregation modes, characteristics, and mechanisms of multi-component lignite in a vibrated gas-fluidized bed. Int J Min Sci Technol (2017), https://doi.org/10.1016/j.ijmst.2017.12.009