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Effect of bubbles addition on teetered bed separation

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ABSTRACT

To improve the separation efficiency of a conventional Teetered Bed Separator (TBS) in beneficiation of fine coal with a wide size range, an Aeration TBS (A-TBS) was proposed in this investigation. The bubbles were introduced to A-TBS by a self-priming micro-bubble generator. This study theoretically analyzed the effect of bubbles on the difference in hindered settling terminal velocity between different density particles, investigated the impact of superficial water velocity (V_{SW}) and superficial gas velocity (V_{SG}) on bed fluidization, and compared the performance of the TBS and A-TBS in treating 1–0.25 mm size fraction particles. The results show that the expansion degree of fluidized bed which was formed by different size particles or has different initial height, is increased by the introduction of bubbles. Compared with the TBS, at the same level of clean coal ash content, the A-TBS shows an increase in the combustible recovery of clean coal, ash content of tailings, and practical separation density by 5.26%, 6.56%, and 0.088 g/cm^3 respectively, while it shows a decrease in the probable error (E_p) and V_{SW} by 0.031 and 3.51 mm/s, respectively. The addition of bubbles at a proper amount not only improves the separation performance of TBS, but also reduces the upward water velocity.

1. Introduction

The application of Teetered Bed Separators (TBS) in coarse coal slime separation has been extensively studied [1–6]. In a TBS separation, the particles are separated or classified based on their hindered settling velocity, which is determined by the particle size and density jointly [7–9]. However, the mismatch of high density fine particles and low density coarse particles usually appears during the conventional TBS separation process, especially when the coarse coal slime has a wide size range. In this case, the clean coal is usually contaminated by high density fine coal slime, while low density coarse particles are lost into the tailings [9,10].

A number of methods have been adopted to improve the separation efficiency of the conventional TBS. For instance, the tangential feeding method was introduced in the TBS to reduce the disturbance of inlet flow on bed stability, showing an positive effect in reducing the probable error (E_p) value at the same superficial water velocity (V_{SW}) and bed height [11,12]. Inclined plates were introduced in the TBS to even the upward water current, thereby improved the separation bed stability [13–15]. Derived from the Shallow Layer Theory, the inclined plates improve the processing capacity of the TBS by more than 3 times, and its separation density changes little with particle size. An internal component, consisting of the multiple truncated reverse taper perforated plates, was proposed by Tang et al. to enhance the particulate fluidization characteristic of fine coals in the TBS [16]. According to the laboratory experiments and numerical simulation results, the internal component is effective in improving the separation performance of the normal hindered fluidized bed. In conventional TBS separation, V_{SW} is the only adjustable parameter in terms of bed density control. Therefore, a high V_{SW} is necessary for forming a high separation density fluidized bed. However, a high V_{SW} may strengthen the influence of particle size on the TBS separation. Hence, some fine or ultrafine gangue particles are transported toward the outer overflow launder. In order to solve this problem, some researchers adopted jigging action or heavy medium in TBS separation processes, both of which showed the positive effects on the separation performance [17,7]. A research shows that the separation efficiency of TBS could be improved significantly by the combination of dumping blocks and jigging water [18]. Because a better distributed upward water flow and an eddy are provided by the dumping blocks and jigging water, both of which promote the expansion of bed. In addition, a hydro-float separator introduces bubbles in fluidized separation and exhibits a good separation performance [19–21]. In the hydro-float separator, the separation time of particles is prolonged, and the difference in density between hydrophobic and hydrophilic particles is

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widened by the selective adsorption behavior of bubbles. Up to now, the gas–solid fluidized bed that is used for coal separation has also been studied [22–24].

In this investigation, the effect of bubbles addition on separation efficiency of TBS was analyzed from the perspective of the difference in hindered settling terminal velocity. An experimental system of Aeration TBS (A-TBS) where bubbles are introduced by a self-priming micro-bubble generator was established. This bubble generator shows obvious advantages in generating micro-bubbles, which is adopted from the cyclonic micro-bubble flotation column [25]. Therefore, the bubble generation method in this system is different from the hydro-float. This research was conducted in three steps. First, the effect of bubbles on the enhancement of difference in particle hindered settling terminal velocity was analyzed theoretically. Then, the impact of V_{SW} and superficial gas velocity (V_{SG}) on the difference of fluidization behavior in particle size and bed height was investigated. Last, the separation tests of 1–0.25 mm size fraction coal particles were conducted by the TBS and A-TBS. We want to explore the feasibility of adding bubbles into a TBS.

2. Theory

In TBS separation, particles are mainly separated and classified according to their hindered settling velocity. Therefore, the separation performance of the TBS can be optimized if there is a sizeable difference in hindered settling velocity between heavy and light particles.

The hindered settling terminal velocity of a particle in the separation medium is described by Eq. (1):

$$V_g = V_0\theta^n = \sqrt{\frac{\pi d(\delta-\rho)g}{6\psi\rho}}\theta^n \tag{1}$$

where V_g is the hindered settling terminal velocity of particles, m/s; V_0 the free settling terminal velocity of particles, m/s; θ the loose degree of separation bed, and its physical meaning is the proportion of liquid in the liquid–solid suspension, %; n the experimental index mostly between 2.33 and 4.60 relating to the property of particles; d the size of particles, m; δ the density of particles, kg/m^3; ρ the density of separation medium, kg/m^3; ψ the resistance coefficient; and g the acceleration due to gravity, m/s^2.

The influence of particle size and shape on the hindered settling terminal velocity is neglected since the separation test is usually conducted with particles of a narrow size range. Therefore, the particle size (d), resistance coefficient (ψ), and experimental index (n) are considered to be constants in this research.

A constant K_1 is defined as Eq. (2):

$$K_1 = \sqrt{\frac{\pi dg}{6\psi}} \tag{2}$$

In the liquid–solid condition, the difference in hindered settling terminal velocity between particles of different density is as follows:

$$\Delta V_a = V_{g1} - V_{g2} = K_1\left(\sqrt{\frac{\delta_1-\rho_a}{\rho_a}} - \sqrt{\frac{\delta_2-\rho_a}{\rho_a}}\right)\theta_a^n \tag{3}$$

where ρ_a and θ_a are the density of the separation medium and the bed loose degree in the liquid–solid condition respectively; δ_1 and δ_2 the density of high density particles and low density particles, respectively.

In the gas–liquid–solid condition, the difference value is following:

$$\Delta V_b = V_{g1} - V_{g2} = K_1\left(\sqrt{\frac{\delta_1-\rho_b}{\rho_b}} - \sqrt{\frac{\delta_2-\rho_b}{\rho_b}}\right)\theta_b^n \tag{4}$$

where ρ_b and θ_b are the corresponding index in the gas–liquid–solid condition.

Eq. (5) is derived from Eqs. (3) and (4).

$$\frac{\Delta V_a}{\Delta V_b} = \frac{\sqrt{\frac{\delta_1-\rho_a}{\rho_a}} - \sqrt{\frac{\delta_2-\rho_a}{\rho_a}}}{\sqrt{\frac{\delta_1-\rho_b}{\rho_b}} - \sqrt{\frac{\delta_2-\rho_b}{\rho_b}}} \times \left(\frac{\theta_a}{\theta_b}\right)^n \tag{5}$$

In Eq. (5), ρ_a can be regarded as 1 g/cm^3 approximately for the separation medium is usually water. ρ_b is lower than 1 g/cm^3 ($0 < \rho_b < 1$), because the gas phase is considered as a part of the separation medium. In coal preparation, the low density particles are coal particles, while the high density particles are gangue particles. Therefore, δ_2 can be considered as 1–1.5 g/cm^3, and the difference value (Δ) in density between heavy and light particles is 0.1–1.2 g/cm^3 [24,26]. Eq. (5) can be simplified as Eq. (6).

$$\frac{\Delta V_a}{\Delta V_b} = \frac{\sqrt{\delta_2+\Delta-1} - \sqrt{\delta_2-1}}{\sqrt{\delta_2+\Delta-\rho_b} - \sqrt{\delta_2-\rho_b}} \times \sqrt{\rho_b} \times \left(\frac{\theta_a}{\theta_b}\right)^n \tag{6}$$

A constant K_2 is defined as Eq. (7):

$$K_2 = \frac{\sqrt{\delta_2+\Delta-1} - \sqrt{\delta_2-1}}{\sqrt{\delta_2+\Delta-\rho_b} - \sqrt{\delta_2-\rho_b}} \times \sqrt{\rho_b} \tag{7}$$

The value of K_2 is calculated by using the Matlab Software on the basis of the value ranges of δ_2, Δ, and ρ_b. To simplify the graphical representation, we give the value of any unknowns in Eq. (7), and the change of K_2 value with all other unknowns are obtained. For instance, assuming the Δ is 1 g/cm^3, the K_2 value with the change of both δ_2 and ρ_b are shown in Fig. 1. In this case, the maximum value of K_2 ($K_{2,\max}$) is 1.4137, while the δ_2 is 1 g/cm^3 and ρ_b is 0.65 g/cm^3. In the same way, a corresponding $K_{2,\max}$ can be obtained by selecting the different Δ values. The dependence relation between the $K_{2,\max}$ and Δ is presented in Fig. 2. The calculation result indicates the value of K_2 is greater than 0, and the $K_{2,\max}$ does exist as a constant once the ranges of δ_2, Δ, and ρ_b are given.

Eq. (8) is derived from Eqs. (6) and (7).

$$\frac{\Delta V_a}{\Delta V_b} = K_2 \times \left(\frac{\theta_a}{\theta_b}\right)^n \leqslant K_{2,\max} \times \left(\frac{\theta_a}{\theta_b}\right)^n \tag{8}$$

Eq. (8) demonstrates that the difference in hindered settling terminal velocity between different density particles can be enlarged by introducing bubbles in the TBS separation process, if the loose degree of fluidized bed is more than $\sqrt[n]{K_{2,\max}}$ times of that without aeration. Both the n and $K_{2,\max}$ are constants. Therefore, form

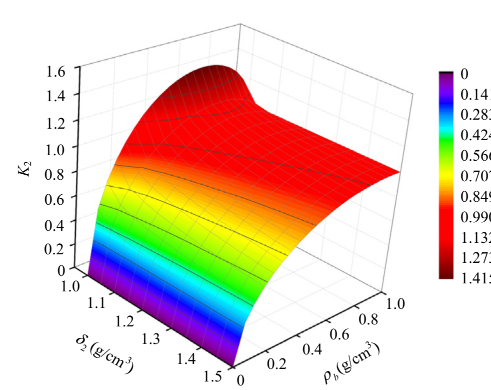

Fig. 1. Computed results of K_2 (Δ = 1 g/cm^3).