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Calculation of teeter bed height of teetered bed separator based on jet theory

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ABSTRACT

The teeter bed zone is the critical component of the teetered bed separator (TBS), and the calculation of its height plays an important role in optimizing structure of TBS and improving separation performance of coarse slime. This paper simulates the velocity profile in TBS using jet theory and discusses the relationships between velocity profile and axial height as well as fractional open area. The separation of 2–0.3 mm coals using TBS with different bed lengths was also performed. The simulation results show that flowing behavior in the teeter bed zone through the distributor could be simplified as single round hole jet in con-current ambient; the fractional open area and axial height of TBS are two important influencing factors, and the even velocity distribution could be easily achieved with greater axial length and larger fractional open area. The height of the teeter bed zone could be calculated using $H_{tb} = \exp(\frac{1.0164-\varphi}{0.2089}) \times d_0$, showing that the teeter bed height increases with an increase in hole diameter and a decrease in fractional open area. The experimental results show that good performance with Ep value of 0.117 is achieved using the TBS with bed length of 1000 mm, due to the even velocity distribution with minimum flow disturbance resulted from the use of larger bed length.

1. Introduction

Fluidization is one of the major techniques for fine particle processing and it is employed in a wide range of industrial applications, including the environmental, chemical and pharmaceutical industries in addition to mineral processing and power generation industries [1–3]. In terms of fluidized bed technology, the teetered bed separator (TBS) was developed from hydrosizer concept and evolved into equipment that made the separation possible primarily on a basis of density. It is thus utilized in coarse slime separation due to its significant advantages [4–6]. In addition, it has also been used in dealing with other metallic and non-metallic materials [7].

The TBS permits separation by particle density for particles with narrow size range [8–9]. The coal slurry is fed from the top of cylindrical vessel and met by evenly distributed upward water, thus generating an autogeneous medium with certain density. The lower density particles will go to the overflow stream while the higher density particles will report to the underflow stream. The suspension density could be controlled through underflow valve. Honaker and Mondal [10], Li [11], and Chen [12] hold different views about zones classification in the TBS; accordingly, the teetered bed separator is proposed to be divided into five main zones as shown in Fig. 1, namely, overflow collection zone (A), feed zone (B), separation zone (C), teeter bed zone (D) and underflow collection zone (E). The teeter bed zone is characterized by fluidization, where an autogeneous heavy medium bed forms with low pressure, high concentration of particles, and high suspension density, thus achieving separation of the feed based on particle density. The teeter bed zone is a key component of the TBS and its fluidization characteristics, such as stability and uniformity, have a significant effect on separation performance. Therefore, the calculation of the teeter bed height plays an important role in optimizing the design of the TBS and improving the separation performance.

As a major part of the TBS, the distributor greatly influences the fluidization quality in the teeter bed zone, and the parameters of the distributor determining the formation of high quality fluidization bed will affect the teeter bed height [13–18], such as pressure drop, aperture size, aperture distribution pattern, and opening rate, i.e., fractional open area. Shi and Fan [14] investigated the effect of distributor pressure drop on fluidization state. Luo et al. [17] analyzed the effect of gas distributor on separation performance of dense phase high density fluidized bed. Maharaj et al. [18] simulated the flow behavior using the Multiple Eulerian and Mixture Model in Fluent 6.1 on a basis of seven kinds of distributor plates with different apertures and geometric arrangements in teetered bed separator. Chen et al. [12] simulated the flow field in the TBS and studied the flow velocity distribution and pressure distribution using a computational fluid dynamics (CFD) method. Huang et al. [19–20] measured and analyzed the flow field of an upward-flow hydraulic separator using Particle Image Velocimetry technique (PIV) and revealed the state of flow field, velocity distribution in various zones and the size of vorticity field.

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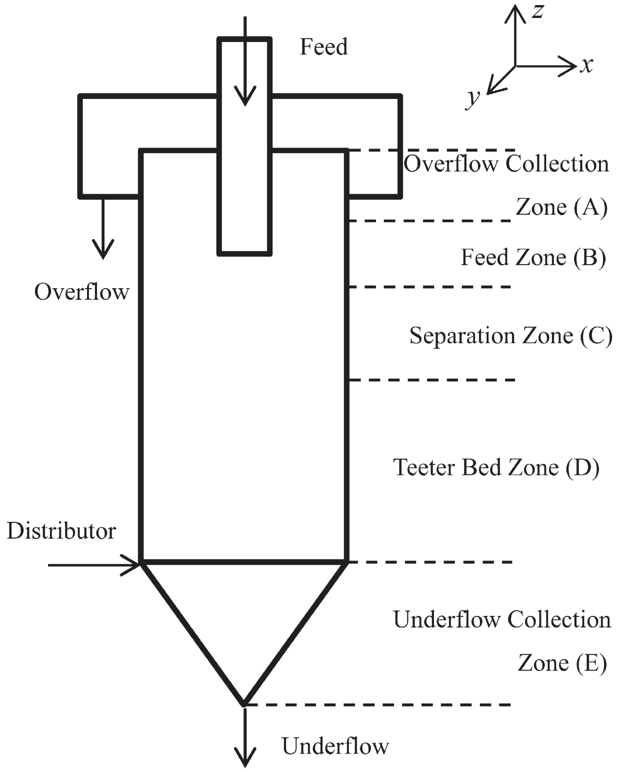

Fig. 1. Schematic diagram of the teetered bed separator.

The previous studies on the TBS mostly focused on the effects of distributor configuration on the flow field, velocity distribution, and pressure distribution. Few investigations could be found on the calculation of the teeter bed height and the quantitative correlations between the teeter bed height and the distributor structure parameters. Along with the progressive understanding of fluidization characteristics in the teeter bed zone, the calculation of the teeter bed height and its influencing factors should be paid more attention. According to the flow behavior of a jet, the flowing of upward current through the distributor in the TBS could be regarded as submerged turbulence jet with round hole. Therefore, in this paper, an attempt was made to characterize the teeter bed zone using jet theory and to analyze the velocity profile of single round hole jet in co-current ambient and to discuss the relationships between structure parameters of the TBS and velocity profile in the teeter bed zone. In this respect, the calculation of the teeter bed height was explored; meanwhile, the separation of 2–0.3 mm coal samples was carried out to validate the calculation technique of the teeter bed height, thus paving a way of designing teetered bed separator and achieving high-efficiency separation of coarse slime separation.

2. Simulation of velocity profile in the TBS

2.1. Introduction of jet theory

Using submerged turbulence jet with round hole in the free and static ambient as an example, Fig. 2 briefly illustrates the formation of jet which includes the start zone and the main zone [21–22]. Different velocities along the jet/ambient interface exist when the jet goes into static ambient, causing velocity gradient and momentum transfer to occur. As the jet expands rapidly, the jet radius increases while the jet velocity and velocity gradient decrease until the jet disappears in the ambient. Due to its irregularities, the flow along the jet/ambient interface is complicated and non-continuous, but it is assumed that the interface is expanding linearly for ease in analysis.

When the ambient is flowing with a certain velocity, $u_a \neq 0$, Hua [23] determined the characteristics of velocity fields in the ambient with different flowing directions using the techniques of Acoustic Doppler Velocimeter (ADV) and Planar Laser Induced Fluorescence (PLIF), and also attained the calculations of the characteristic half width and the axial velocity. Table 1 summarizes the calculation equations of the axial velocity and the characteristic half width in the ambient varying flowing patterns.

2.2. Velocity profile in TBS

The flowing of upward water through the distributor in the TBS behaves the same as that of water jet going into the con-current ambient. Fig. 3 depicts a typical distributor with uniform holes and certain specific fractional open area, presenting that the simulation of velocity profile in the TBS can be simplified to that of single hole in a hypothetical distributor with the same fractional open area. Therefore, the flowing behavior in the teeter bed zone through the distributor can be simplified as single round hole jet in con-current ambient. It is demonstrated from theoretical analysis and experimental work that tangential velocity and radial velocity are both much smaller than axial velocity in any cross-section and could be neglected [12].

Fig. 4 gives the flowing of single round hole jet in con-current ambient.

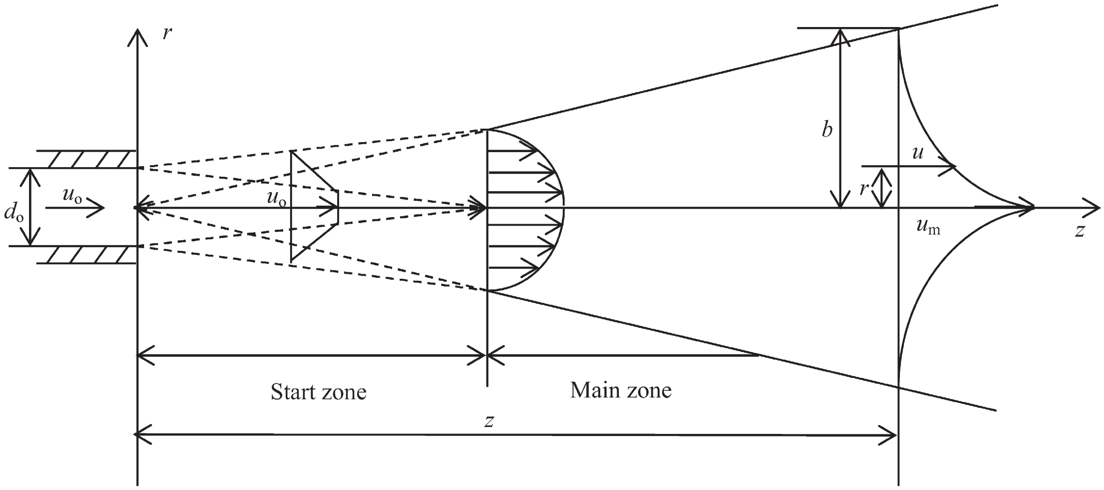

Fig. 2. Illustration of formation of a typical submerged jet.