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Study on particle dynamics in different cross sectional shapes of air dense medium fluidized bed separator

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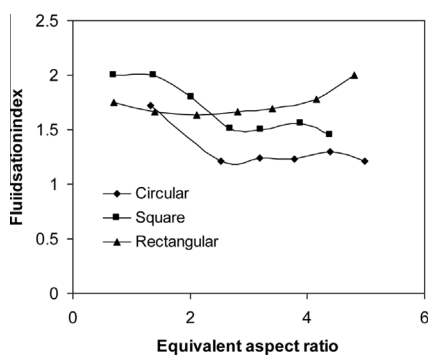
HIGHLIGHTS

- Experiments were done using square and rectangular cross sectional shape columns.
- Fine magnetite particles (−45 μm) were used for the study.
- Stability region increases with increase of equivalent aspect ratio.
- Rectangular shape column will provide better stability to fluidized bed.

GRAPHICAL ABSTRACT

Comparison of fluidization index in circular, square and rectangular cross sectional shape fluidized bed column.



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ABSTRACT

Dry coal washing is gaining popularity on account of its ability to produce clean coal without the use of water which is becoming to be a costly resource for beneficiation. Air dense medium fluidized bed separation (ADMFBS) is one of the dry beneficiation techniques which is used for cleaning of coal. Fine magnetite particles are used as medium to make pseudo-fluid by fluidization method. The effectiveness of ADMFBS depends on stability of the fluidized bed. In the present work, an attempt has been made to study the stability characteristics of different cross-sectional shapes of fluidized bed having same cross-sectional area. Different indicators like fluidization index, particulate expansion function, pressure drop of bed and distributor, minimum fluidization and bubbling velocities were used to characterize the stability of fluidized bed. The effect of different operating and design parameters on the homogeneity and stability of the fluidized bed was studied. It was observed that cross sectional shape of the fluidized bed column has a significant effect on the stability of the bed. Moreover, rectangular cross-sectional shape provides better stability properties compared to square or circular shape.

1. Introduction

Coal beneficiation is performed traditionally using heavy media separators, jigging, spiral separator, flotation, etc. which are mostly wet processes [1–4]. Commercialization of the dry coal beneficiation was threatened by wet coal beneficiation in the past primarily on account of the better separation efficiency provided by the latter. However, the advantages of dry coal beneficiations like higher thermal efficiencies and no need of water cannot be entirely ignored. Because of which dry coal beneficiation is gaining popularity. Air dense medium fluidized bed separator is one of the dry beneficiation techniques that uses magnetite powder and air as

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fluidizing mediums. It utilizes the pseudo fluid characteristics of air–magnetite fluidized bed to form a uniform and stable suspension of certain density, and separation is achieved by sink and float of coal particles as per their density, size and shape [5–14]. Feed and media characteristics, operating and design parameters of the fluidizing system regulate the uniformity of density and stability of fluidized bed, and ultimately affects the particle separation [15–16]. Thus stability is one of the parameter which controls the separation efficiency of the air dense medium fluidized bed separator.

Many investigators have described conditions of stability of fluidizing bed system in various ways [17–22]. The gas–solid fluidization is considered to be stable if operating velocity falls between minimum fluidization and minimum bubbling velocity. According to Wilhem and Kwauk [18] a non-bubbling fluidization condition exists if Froude Number at the minimum fluidization is less than 0.13. Romero and Johanson [19] also proposed that if the product of four dimensionless groups $(Fr_{mf})\,(\mathrm{Re}_{mf})\left(\frac{\rho_s-\rho_f}{\rho_f}\right)\left(\frac{H_{mf}}{D_c}\right)$ is less than 100, then the fluidization is smooth and non bubbling. Where Fr_{mf} is Froude number at minimum fluidization, Re_{mf} is Reynolds number at minimum fluidization, $\frac{\rho_s-\rho_f}{\rho_f}$ is density ratio, $\frac{H_{mf}}{D_c}$ is aspect ratio at minimum fluidization, ρ_s and ρ_f are density of solid particle and fluid respectively, H_{mf} is bed height at minimum fluidization velocity, D_c is diameter of column. Judgment of stability based on the above criterion requires accurate determination of the minimum fluidization velocity. Recently Mohanta et al. [23] also developed a correlation to calculate minimum fluidization velocity of magnetite powder of different sizes accurately using pressure drop method which is based on the basic particle properties rather than force balance and dimensional analysis method and may be used for the ADMFBS. Value of fluidization index which is defined as ratio of minimum bubbling velocity and minimum fluidization velocity (U_{mb}/U_{mf}), is also another parameter that indicates the stability conditions of fluidized bed as per Singh and Roy [20]. Higher the fluidization index larger is the stability region. According to Abrahamsen and Geldart [21], fluidization bed is said to be stable if plot between expansion function and superficial velocity of air, is a straight line.

In the present work, an attempt has been made to study the stability characteristics of air–solid fluidized bed in two different cross-sectional shapes i.e., square and rectangular shapes having same cross-sectional area and this is compared with results of circular shape cross sectional area fluidized bed done by Sahu et al. earlier [16]. Different indicators like fluidization index, particulate expansion function, pressure drop of bed and distributor, minimum fluidization and bubbling velocities are used to characterize the stability of fluidized bed [16]. The effect of different operating and design parameters on the homogeneity and stability of the fluidized bed was also studied. In addition to these, empirical mathematical correlations were developed to quantify the stability criteria. The suitable cross sectional shape for better stability was found out.

2. Materials and methods

2.1. Magnetite sample

Magnetite powder is used as solid medium in air dense medium fluidized bed separator. Magnetite powder along with air flow forms a pseudo-fluid having bulk density in between the density of light and heavy particles. Magnetite sample was sourced from M/s. Uranium Corporation of India Ltd., Jaduguda mine, Jharkhand, India. The magnetite powder with size below 45 μm gave good performance with respect to minimum fluidization and minimum bubbling velocities and bed expansion characteristics. This phenomenon was observed in circular cross sectional fluidized bed system [16]. Therefore magnetite powder of below 45 μm and having harmonic mean diameter of 7.26 μm was taken as solid medium. The magnetite powder used has particle density of 4.7 gm/cc and bulk density of 2.2 gm/cc. The chemical analysis of magnetite sample was carried out by standard wet chemical method and was found to be 65% Fe.

2.2. Experimental procedure

The details about the experimental setup used for the present study can be known from earlier work of Sahu et al. [16]. However in the present study square and rectangular cross sectional columns were used instead of circular cross sectional column used by Sahu et al. [16]. The square and rectangular cross sectional columns used have the same cross sectional area as circular cross sectional column. Dry compressed air was used for fluidizing the dried magnetite particles. Before starting the experimental runs the bed was fluidized and then de-fluidized suddenly for breaking any agglomeration that might have been formed. During each experimental run bed expansion and pressure drop were noted down at different superficial velocities. Fluidization was stopped once the bubbling started in the bed. Fluidization runs were carried out with different weights of bed materials to achieve different initial static heights of bed in both square and rectangular shape of equal cross sectional area columns. Stability study criteria were evaluated in each case and were compared with the earlier results of circular cross sectional shape of fluidization setup [16]. The details about the experimental procedure can be known from earlier work of Sahu et al. [16].

3. Results and discussion

3.1. Stability of fluidized bed

Normal fluidized bed characteristics are studied before studying the stability of the fluidized bed. Fig. 1 shows the pressure drop curves (pressure drop vs superficial velocity) for different initial static bed height of the magnetite particles. Fig. 1a shows the results for square cross section and Fig. 1b shows the results for rectangular cross section. It can be observed from the figures that with the increase of superficial velocity pressure drop increases up to the point of minimum fluidization velocity and with further increase of the superficial velocity pressure drop remain constant which satisfies the normal fluidizing criteria [17]. Further the dependency of minimum fluidization velocity and minimum bubbling velocity on equivalent aspect ratio was studied. The dependency for square cross sectional shape is shown in Fig. 2a and for rectangular cross sectional shape is shown in Fig. 2b. These figures show that the datas fall in a straight line indicating a linear dependency. Another important observation from Fig. 2 is that as the aspect ratio is increasing the difference between the minimum bubbling velocity and minimum fluidization velocity is increasing indicating the increase of stability region.

Again the characteristics of the fluidized bed were examined using expansion function given by Abrahamsen and Geldart [21] and the results are shown in Fig. 3. The plotting of $\ln(\varepsilon^3/1-\varepsilon)$ against ln (superficial velocity) gives a straight line. It indicates that the system operates in non-bubbling condition in both square and rectangular shape cross sectional area fluidized bed column.

3.2. Shape comparison

The stability characteristics of magnetite powder and fluidization characteristics for formation of a stable and non-bubbling