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Intensification of the density stability in the air dense medium gas–solid fluidized bed based on a binary dense media

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ABSTRACT

Intensification of the density stability in the air dense medium gas − solid fluidized bed is significantly important to the separation efficiency of this density-based separator. A binary dense media composed of the magnetite powder and quartz sand was used to achieve the intensification of the density stability. The fluctuation characteristics of the bed pressure gradients were investigated to seek for the optimum composition of binary dense media. The weight proportion of quartz sand in the binary dense media should not exceed 30%. The stability and uniformity of the bed density along the axial and radial directions of fluidized bed were experimentally investigated. The results indicated that the weight proportion of quartz sand should be controlled within 10%–20%, and the fluidization number should be adjusted from 1.5 to 1.6. A reliable mathematical model was established to predict the bed density. The calculation and measurement results agreed well, which validated the prediction accuracy. With a 10% weight proportion of quartz sand, the ash content of −13 + 6 mm sized coal was decreased from 33.35% to 11.55% with a clean coal yield of 69.48% at a fluidization number of 1.6. A satisfactory probable error value of 0.095 g/cm^3 indicated notable separation performance.

1. Introduction

Two important factors are considered significantly influence the fluidization characteristics and separation performance of the air dense medium separation system, which is named as an air dense medium gas − solid fluidized bed (ADMGFB) [1]. Because of the main composition of the fine solid powders for dense media, one factor is determined by the self-properties of dense media (type, particle size distribution, density distribution and shape) [2]. The other is affected by the external factors, such as the structure of the fluidized bed container, and the design of air distributor for the bed (bed aspect ratio and hole opening ratio of the air distributor) [3,4]. The stability of ADMGFB is determined by the fluidization quality of the fluidized bed, which is normally evaluated through the fluctuation of bed pressure drop, the distribution uniformity of bed density, and the stability of bubbling condition [5–7]. The dense media is the most important operational factor that can achieve the stability intensification of the bed density and improve the separation efficiency of ADMGFB [8]. Thus, the appropriate selection and gradation of dense media has become the studying focus in the field of mineral processing for various minerals [9–15].

From the viewpoint of the intensification of separation stability in the ADMGFB, a narrow size distribution and uniform density distribution of the dense media facilitates the controlling and adjustment of bed density for the minerals separation, which can avoid the stratification and segregation of media powders and intensify the stability and uniformity within the bed [2]. Therefore, the in-depth researches on the segregation and mixing behavior of binary particle mixtures in the bubbling fluidized bed have been conducted using various types of methods. A simple model for the initial segregating behavior of components in a gas-fluidized mixture of solids was theoretically proposed, and was proved to be qualitatively in agreement with the expected trends in terms of dependence of the segregation behavior in the experiments [16]. The hydrodynamics of the binary coal-sand mixture in a pseudo-2D rectangular bubbling fluidized bed, and the hydrodynamics of binary particle mixtures differing in size and density in low gas velocity bubbling fluidized beds were simulated using the multi-fluid Eulerian model incorporating the kinetic theory of granular flow, respectively [17,18]. The discrete particle simulation was used to investigate the mixing/segregation behavior of particle mixtures (spherical particles with diameters 2 mm and 1 mm and density 2500 kg m^{-3}) in a gas fluidized bed [19]. Furthermore, the computational fluid dynamics and discrete element method (CFD–DEM) approach was employed to investigate the size segregation of binary

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Nomenclature

Symbol

E_P	Probable error: g/cm^3
g	Gravitational acceleration: m/s^2
H_0	Static bed height: m
ΔH_0	Expanded height of the bed after fluidization: m
ΔH	Height difference between two measurement points: m
m_g	Mass of the gas phase; kg
m_s	Mass of the solid phase; kg
m_s'	Mass of the binary dense media; kg
n	The number of measurement points
N	Fluidization number
P	Bed pressure drop; Pa
ΔP	Pressure difference between two measurement points of bed pressure drop: Pa
V	Volume of the materials within the bed: m^3
V_1	Volume of the magnetite powder before mixing: m^3
V_2	Volume of the quartz sand before mixing: m^3
V_b'	Volume of the binary dense media after mixing: m^3
ΔV	Expanded volume of the bed after fluidization; m^3

Greek letters

ε	Bed expansion rate
ρ	Bed density: kg/m^3
$\bar{\rho}$	Mean bed density: kg/m^3
ρ_i	Instantaneous value of the bed density at each point: kg/m^3
ρ_b	Bulk density prior to the fluidization with a single dense medium: kg/m^3
ρ_{b1}	Bulk density of the magnetite powder: kg/m^3
ρ_{b2}	Bulk density of the quartz sand: kg/m^3
ρ_b'	Bulk density of binary dense media; kg/m^3
ρ_f	Fluidized density of the bed; kg/m^3
ρ_{25}	Density for clean coal with a mass fraction of 25%; kg/m^3
ρ_{75}	Density for clean coal with a mass fraction of 75%; kg/m^3
$\Delta\rho$	Standard deviation of the bed density: kg/m^3
ω	Weight proportions of quartz sand in the binary dense media; %

mixtures in the presence of fine particle in bubbling gas–solid fluidized beds. The results indicated that adding fines increased segregation of small and large particles by lowering inter-particle interactions [20]. A Digital Image Analysis procedure was applied to the case of binary mixtures of corundum and glass particles in the bubbling fluidized beds, in order to obtain the bubble fundamental characteristics [21]. The mixing–segregation performance in a gas fluidized bed of binary density system was conducted by analysis of the residence time distribution and mixing degree. The results indicated that the solid movement by fluidization gas was more important than solid axial dispersion [22]. Normally, two types of solid media powders with different true densities are mixed to form a binary dense media in order to easily intensify and adjust the separation density within the ADMGFB. The researchers at China University of Mining and Technology proposed that the vanadium titanium magnetite powder and a small amount of coal fines can be mixed to form the binary dense media for coal separation [2,23].

Despite some new findings in the binary dense media for the separation of mineral particles, the deep investigation on the density stability intensification and adjustment of the ADMGFB through the experimental approach is significantly necessary for the selection and preparation of the appropriate binary dense media in industry. In addition, a reliable mathematical model is urgently needed for the prediction and adjustment of bed density in the separation. In the investigation, the magnetite powder and quartz sand with specific size fractions and densities were uniformly mixed to form the binary dense media. Under suitable operational conditions, the stable fluidization could be formed within the ADMGFB with a uniform density-adjusting range using the binary dense media. The fluctuation characteristics of bed pressure gradient and the stability and uniformity of bed density were experimentally investigated in the ADMGFB based on the binary dense media. Effects of the operational parameters, including the static bed height H_0, fluidization number N (defined as $N = U/U_{mf}$, U and U_{mf} refer to the operational gas velocity and the minimum fluidized gas velocity, respectively), and the weight proportion of quartz sand in the binary dense media ω, on the fluidization stability and density uniformity intensification of the ADMGFB were studied in detail to explore the optimum operational conditions for coal separation. A mathematical model based on the binary dense media was established to predict and adjust the bed density, and the dependability of this model was validated.

2. Materials and methods

2.1. Materials

The dense media utilized in this work were magnetite powder and quartz sand with specific size fractions and densities. The particle size distributions of the magnetite powder and quartz sand are shown in Fig. 1. The dominant size fractions of these two types of dense media

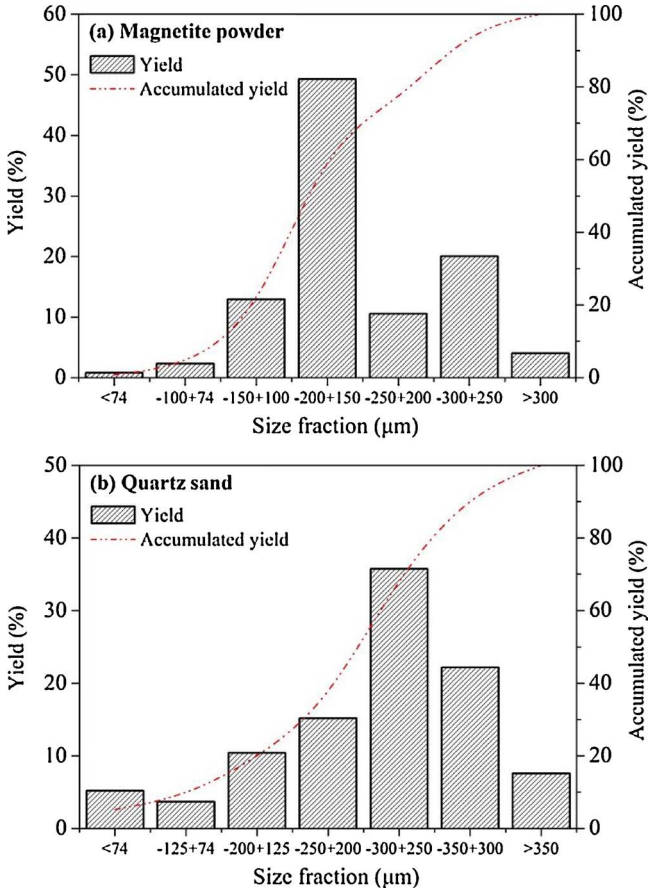

Fig. 1. The particle size distributions of the magnetite powder and quartz sand.