Journal of the Taiwan Institute of Chemical Engineers 000 (2016) 1–11

Contents lists available at ScienceDirect

Journal of the Taiwan Institute of Chemical Engineers

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

Fluidization characteristics and density-based separation of dense-medium gas–solid fluidized bed: An experimental and simulation study

Jingfeng He[a,b,*], Mingbing Tan[a], Yuemin Zhao[a,b], Chenlong Duan[a,b], Yaqun He[b], Zhenfu Luo[b]

[a] School of Chemical Engineering and Technology, China University of Mining and Technology, Daxue Street, Xuzhou, Jiangsu 221116, China
[b] Key Laboratory of Coal Processing and Efficient Utilization of Ministry of Education, China University of Mining and Technology, Daxue Street, Xuzhou, Jiangsu 221116, China

ARTICLE INFO

Article history:
Received 8 September 2015
Revised 23 November 2015
Accepted 16 December 2015
Available online xxx

Keywords:
Coal cleaning
Dense-medium fluidized bed
Fluidization characteristics
Stability-region
Numerical simulation
Separation flowsheet

ABSTRACT

Experimental and simulation approaches were combined to investigate the fluidization characteristics of a dense-medium gas–solid fluidized bed (DMGFB) for coal cleaning. Results indicated that the static bed height should be adjusted by maintaining a stable height of 150–300 mm to avoid its harmful effect on fluidization stability. Bed pressure drops presented favorable stability with slight fluctuations at a superficial gas velocity of 11.68 cm/s (1.6 U_{mf}). The uniform density distributions with slight variations throughout the whole bed were verified by comparing the experimental, simulated and calculated results. A fluidization index, U_{mb}/U_{mf}, was used to conduct stability-region analysis for DMGFB. On the basis of fluidization stability, a successive beneficiation flowsheet via a DMGFB separator was used to perform density-based separation of 6–50 mm sized run-of-mine coal. Results demonstrated that the low-ash clean coal with a yield of 61.36% was efficiently obtained with the ash content reduced from 39.64% to 10.18% and sulfur content rejected from 1.36% to 0.85%. Probable error E values were 0.06 and 0.075 g/cm^3 in high- and low-density separation stages, indicating efficient separation performance. The dry coal beneficiation technique has great potential for utilization in arid and water-deficient areas and countries.

1. Introduction

Given the decreasing amount of coal resources around the world, particularly in China, the efficient beneficiation and cleaning utilization of coal have become significantly important in the energy consumption. Water-based coal separation technology, such as water-based dense-medium cyclone separation, hydraulic jigging separation, and flotation, is currently the dominant approach in coal beneficiation industry [1–5]. However, a considerable number of available coal resources are mainly distributed in some arid and water-deficient countries and regions, including India, South Africa and the west regions of China. Therefore, water-based coal separation technology is difficult to popularize in these areas that face serious water-shortage problems. Furthermore, reserves of high-quality coal are decreasing rapidly and the quality of available coal is gradually worsening. In particular, lignite is a significant raw energy material that shows abundant global reserves as a low-rank coal. However, lignite has two unfavorable properties, namely, high moisture content and low metamorphic grade, which make it susceptible to water degradation. Therefore, the use of wet separation technology on lignite is unfavorable. In summary, dry coal beneficiation technologies in coal cleaning and utilization must be developed.

Conventional technologies for dry coal separation (*e.g.* air jigging, air shaking table and FGX separator, *etc.*) show the disadvantages of limited treating capacity and low separation efficiency, which have large limitations in industry [6]. Separation technology based on a dense-medium gas–solid fluidized bed (DMGFB) has become a focused subject in the past few years. This technology utilizes a fluidizing gas and fluidized medium with a specified size range to form a dense-phase gas–solid fluidized bed. According to Archimedes' theorem, a feedstock is stratified by bed density: light particles (clean coal) float and dense particles (tailings) sink. Researchers from different countries (*e.g.* India, Canada, Australia, South Africa and Japan) have conducted a series of theoretical and

* Corresponding author at: School of Chemical Engineering and Technology, China University of Mining and Technology, Daxue Street, Xuzhou, Jiangsu 221116, China. Tel.: +86 516 83591102.
E-mail address: jfhe@cumt.edu.cn (J. He).

http://dx.doi.org/10.1016/j.jtice.2015.12.016
1876-1070/

Nomenclature

Symbol term and units

D_c	column diameter of fluidized bed: m
E	probable error value: g/cm^3
g	acceleration due to gravity: m/s^2
h	depth between two vertical positions of the bed: m
H_f	bed height: m
H_s	static height of fluidized bed: m
p_n	pressure in position n of the bed: Pa
P	pressure: Pa
ΔP	bed pressure drop between two vertical positions of the bed: Pa
r	distance from left side wall of fluidized bed: m
U	superficial gas velocity: m/s
U_{mb}	minimum bubbling velocity: m/s
U_{mf}	minimum fluidization velocity: m/s

Greek letters

ρ	mean density of certain bed height: kg/m^3
ρ_{25}	separating density with the partition coefficient of 0.25: kg/m^3
ρ_{50}	optimum separating density: kg/m^3
ρ_{75}	separating density with the partition coefficient of 0.75: kg/m^3

experimental studies from various viewpoints and obtained many satisfying results [7–13]. Researchers at China University of Mining and Technology (CUMT) have contributed to DMGFB technology since 1980s, and have acquired many fundamental theoretical and practical achievements [14–17]. They proposed the reliable separation theories for DMGFB on the stability of air distribution [18], uniformity of density distribution [19], kinetic behavior of dense media and coal particles [20,21], and three-level separation mechanism of various-sized coal particles in DMGFB separator [22]. They also successfully clarified the density-dependent separation principle of coals with various densities [22]. In practice, a modularized separation system based on the DMGFB separator was designed and established with a capacity of 40–60 tons/h [23]. Thereafter, the effective separation and cleaning of 6–50 mm sized run-of-mine (ROM) coal was successfully realized by utilizing a semi-industrial-scale DMGFB separation system [24].

Presently, some notable researches have been carried out to characterize the stability of the fluidized bed by different expressions and empirical mathematical correlations were developed to quantify the stability criteria by experimental approach [10,25]. Furthermore, several conspicuous efforts have been also made to study the separation performance of the DMGFB separator from various aspects with acquirement of some significantly valuable achievements [9,26,27]. Nevertheless, the DMGFB consisted of a complex multiphase fluid-particle system. Complicated exchanges of energy, mass, and momentum occurred among gas–particle phases, particle–particle phases, and particle–phase and bed walls during the fluidization and separation; these exchanges significantly affected the fluidization stability and separation performance in the DMGFB separator. However, it is difficult to directly measure or monitor the instantaneous variations of the fluidized parameters by adopting the experimental method merely, which are of considerable importance to evaluate the fluidization quality. Present results cannot provide sufficient foundations for the optimization of fluidization stability in the DMGFB. Furthermore, few investigations paid attention to the successive separation of coal for obtaining three different-quality products of low-ash clean coal, middlings, and gangue. Thus a deep understanding is required for the separation performance of the successive flowsheet for coal separation, which has more practical application prospect in industry.

In the present study, the experimental, simulation, and calculation approaches were combined to investigate the fluidization characteristics of DMGFB (hydrodynamic stability, fluctuation of bed pressure drop, uniformity of bed density, and stability-region analysis), which aimed to provide more reliable basis for optimization of fluidization stability in the DMGFB. Based on the optimal operation conditions for favorable fluidization quality in the fluidized bed, a two-stage successive separation flowsheet via a DMGFB separator was utilized to evaluate the density-based separation performance of 6–50 mm sized ROM coal for obtaining various-quality products. An attempt has been made to achieve the collaborative optimization between the product quality and separation efficiency.

2. Materials and methods

2.1. Experimental system and fluidized medium

The experimental system used for this study is illustrated in Fig. 1 and mainly consisted of an air supply system, a fluidized bed container, a gas distributor, a high-speed digital camera, a data receiving and transmission system, and a dust-removal system. A Plexiglas fluidized bed with a width of 280 mm, a height of 800 mm, and a length of 30 mm was designed and made as the basic experimental apparatus. The length of the fluidized bed is obviously much smaller than the width and height of the bed. Therefore, the fluidized bed used for experiment can be considered as a quasi two-dimensional bed (quasi 2D bed). Geldart B magnetite powder with a size range of 100–300 μm was utilized as a basic fluidized medium. The magnetite powder had a true density of 4.5 g/cm^3, a bulk density of 2.51 g/cm^3, a magnetite material content of 99.75%, and a magnetization of 78.42 Am^2/kg. These parameters showed that this magnetite powder had favorable physical properties as a fluidized medium for coal separation.

At the beginning of experiment, magnetite powders were fully fluidized for deagglomeration, and then freely settled down deaeration by suddenly shutting down air input. Afterward, the compressed air was transported from the blower into the fluidized bed container, and the airflow rate was controlled by an air valve. A rotameter was used to maintain a stable fluidization by adjusting gas velocity within a certain range. Based on the uniform air distribution theory of gas–solid fluidized bed, a double-layer, stable-pressure gas distributor was designed using a concept of low fluidization number, large pressure drop and compound air distribution [22], which was installed to locate at the bed bottom. One layer used an air dispersion device with a hood circulation structure to play a role of pre-air distribution. The other layer was composed of a micro-perforated plate with double-layer glass filtration fabric covered on both sides. The specific structures of gas distributor were favorable to maintain the stability of fluidized bed throughout the experiment. The pressure drops of various bed heights could be received and obtained dynamically and timely with a group of pressure sensors. The real-time bed expansion heights were measured by a fixed scale until the uniform bubbling condition was achieved. The average voidage of the fluidized bed was calculated according to the bed expansion degree. The bed densities of various locations were measured with several groups of gradiomanometers. The dust-removal system was used to collect the escaped fine particles from the top of fluidized bed container. A high-speed digital camera was set in front of the fluidized bed to shoot and collect the images of fluidization. The subsequent analysis system was adopted to treat the collected data. After achieving stable fluidization state in bed, the fluidization characteristics of the DMGFB system were studied by an experimental approach.

Please cite this article as: J. He et al., Fluidization characteristics and density-based separation of dense-medium gas–solid fluidized bed: An experimental and simulation study, Journal of the Taiwan Institute of Chemical Engineers (2016), http://dx.doi.org/10.1016/j.jtice.2015.12.016