Powder Technology 283 (2015) 570–578

Contents lists available at ScienceDirect

Powder Technology

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

Numerical study on the effect of fine coal accumulation in a coal beneficiation fluidized bed

Qinggong Wang [a,b,*], Weidi Yin [a], Hairui Yang [a], Junfu Lu [a,*], Bin Zhao [c]

[a] Key Laboratory for Thermal Science and Power Engineering of Ministry of Education, Department of Thermal Engineering, Tsinghua University, Beijing 100084, China
[b] Qianxuesen Laboratory of Space Technology, China Academy of Space Technology, Beijing 100094, China
[c] College of Metallurgy and Energy, North China University of Science and Technology, Tangshan 063009, China

ARTICLE INFO

Article history:
Received 8 February 2015
Received in revised form 25 April 2015
Accepted 1 June 2015
Available online 9 June 2015

Keywords:
Coal beneficiation
Fine coal accumulation
TFM–DEM hybrid model
Modeling

ABSTRACT

One important phenomenon in coal beneficiation fluidized bed (CBFB) is the accumulation of fine coal particles in beneficiation due to poor screening efficiency and attrition of coal samples. The effect of fine coal accumulation is numerically studied in this work using a TFM–DEM hybrid model. The gas phase and medium solid phase are modeled by a two-fluid model (TFM), while the fine coal particles are modeled by the discrete element method (DEM). Particles with a diameter of 0.9 mm are used as the fine coal sample in the simulation. The gas–solid flow pattern and particle dynamics are investigated with different concentrations of fine coal particles accumulated in the bed. For model validation purpose, the mean bed density distributions are compared with the experimental reports from He et al. (2013). The results show that a critical particle concentration exists in the fine coal accumulation process in CBFB. When the fine coal particles are less than 11 wt% in the bed, the flow pattern of medium phase is little affected and the coal particles are well mixed in the bed. However, when the particle concentration exceeds this threshold, the uniformity of bed density distribution is destroyed and particle stratification occurs along the bed height according to their density difference. Flow dynamics of the dense bed and main forces acting on the fine coal particles are analyzed to explain the underlying mechanism. With a large number of particles accumulated in the bed, the mixing effect of medium flow is suppressed. Motion of the fine coal particles is less dependent on the bed disturbance, instead, the particle gravity plays a decisive role in the particle distribution and results in the particle segregation in the fine coal accumulation process.

1. Introduction

The coal beneficiation fluidized bed (CBFB) technology is a dry method developed in recent decades for coal beneficiation. In CBFB, the medium solids are fluidized by supplied gas to generate a pseudo-fluid state. Light and heavy species of raw coal will stratify in such a state according to their density differences. The separation efficiency is dependent on fluidization regime, operating conditions, and feed characteristics [1–3]. Generally, coal beneficiation in CBFB is density based, thus uniformity and stability of the dense fluidized bed is prerequisite for coal separation [4,5]. The bed property and beneficiation quality are largely affected by parameters such as fluidized air velocity, bubble configuration, and medium property. These factors have been widely studied in laboratory and their influences have been well reported [6–11]. However, the realistic situation is much more complex in the industrial process. One important phenomenon is the accumulation of fine coal particles in the continuous beneficiation process due to poor screening efficiency and attrition of coal sample [12–14]. The fine coal particles accumulated in the bed have small size difference to the medium particles, thus they show close flow pattern to the medium and cannot be separated in the beneficiation process. As a result, the amount of fine coal particles will gradually increase as the beneficiation proceeds. Accumulation of fine coal particles in the medium can have a strong influence on the bed property and then affect the separation performance of the equipment. Due to this reason, systematic studies are necessary in order to better understand the accumulation process and its effect on CBFB operation.

Luo and Chen [12] investigated the fine coal accumulation in a CBFB by experimental approach in the last decade. They observed that a proper addition of fine coal particles (in size of 0.45–0.9 mm) in the medium can reduce the bed density effectively. A mixture of magnetic powder and fine coal particles can be used as beneficiation medium with no stratification occurring in the bed. Based on these results, fine coal particles smaller than 1 mm are usually added in CBFB to regulate the separating density [15]. However, with continuous accumulation of fine coal particles, the bed density dropped obviously [12]. The medium solids had to be refreshed in order to restore the separating bed density. He et al. [16] made a further investigation on the fine coal accumulation in CBFB using the same particle size. The results showed that density stratification did not appear below a concentration of 12% for the fine

* Corresponding authors.
E-mail addresses: wqg11@mails.tsinghua.edu.cn (Q. Wang), lvjf@mail.tsinghua.edu.cn (J. Lu).

http://dx.doi.org/10.1016/j.powtec.2015.06.007
0032-5910/

coal particles. But when the concentration was above 18%, fine coal particles with different densities stratified significantly in the bed. The density stratification resulted in fluctuation of the bed density and deteriorated the bed stability. Furthermore, Tang et al. [17] studied the fine coal particles of 1.0–3.0 mm and found that the threshold of particle concentration dropped to about 4.5%. Both the bed stability and fluidization quality cannot be maintained once the weight proportion of fine coal particles exceeded this value.

To date, studies on the accumulation of fine coal particles in CBFB are limited to the above findings. No further efforts were made to demonstrate the particle accumulation behavior in detail and to explain the underlying mechanism. Generally, the traditional experimental methods are confined to macroscopic observations, from which further insights on the flow dynamics and the underlying mechanism are hard to be obtained. Alternatively, the computational fluid dynamics (CFD) becomes a powerful method in CBFB studies. Recently, a TFM–DEM hybrid model has been introduced to model the coal beneficiation process [18]. In the TFM–DEM hybrid model, the carrier phases, including the gas phase and the medium solid phase, are modeled by the TFM, while the beneficiated particles are modeled by the DEM. Such a model combines the advantages of both TFM and DEM. The TFM can give a reliable description of the dense gas–solid flow for the continuous carrier phases [19]. The DEM can readily designate the size and density distributions of the beneficiated particles. Their trajectories and segregation behaviors can be investigated in the Lagrangian framework. Reliability of the TFM–DEM hybrid model for CBFB modeling has been demonstrated in the previous work [18] by comparing the simulated results with experiments conducted on a similar geometric model.

In this work, the TFM–DEM hybrid model is utilized to study the fine coal accumulation effects in CBFB. Similarly, The TFM is used to describe the gas phase and the medium phase, while the DEM is used to model the fine coal particles. An increasing amount of fine coal particles are considered in different cases to simulate the accumulation process. By analyzing the gas–solid flow pattern, particles flow behavior and segregation possibility, the influence of fine coal accumulation is systematically studied. Validity of the hybrid model is further confirmed in this work by comparing the simulated results with the experimental report from He et al. [16]. To explain the mechanisms of particle mixing/segregation during the accumulation process, hydrodynamics of the solids flow and main forces exerted on the fine coal particles are analyzed. Following the results in this work, better understanding of the fine coal accumulation in CBFB can be achieved.

2. Model description and simulation conditions

2.1. TFM–DEM hybrid model

The hybrid model combines the traditional TFM and DEM as illustrated in Fig. 1. In TFM, the two phases, i.e. gas phase and medium solid phase, are treated as fully interpenetrating continuums and the generalized Navier–Stokes equations are applied to both phases. The kinetic theory of granular flow (KTGF) is used to close the equations for the solid phase [20–23]. In DEM, particles are treated as discrete entities with different size/density distributions. Their motion is solved by Newton's second law of motion [24]. Particle collisions are described by the linear spring dashpot model proposed by Cundall and Strack [25]. The basic equations for TFM and DEM are shown in Eqs (1) ~ (7) in Table 1 with explanation of the symbols given in the nomenclature. The submodels in these two models are well documented in the literature [19,26–30], and thus they are not included here. Coupling between the TFM and the DEM is realized through interphase momentum transfer terms as shown in Eqs (8) ~ (15). The Gidaspow drag model [20] is used to describe the interactions between the gas phase and the medium solid phase in the TFM. In calculation of the drag force and momentum transfer between the gas phase and the discrete particles, an interpolation algorithm is used to map the properties of Lagrangian

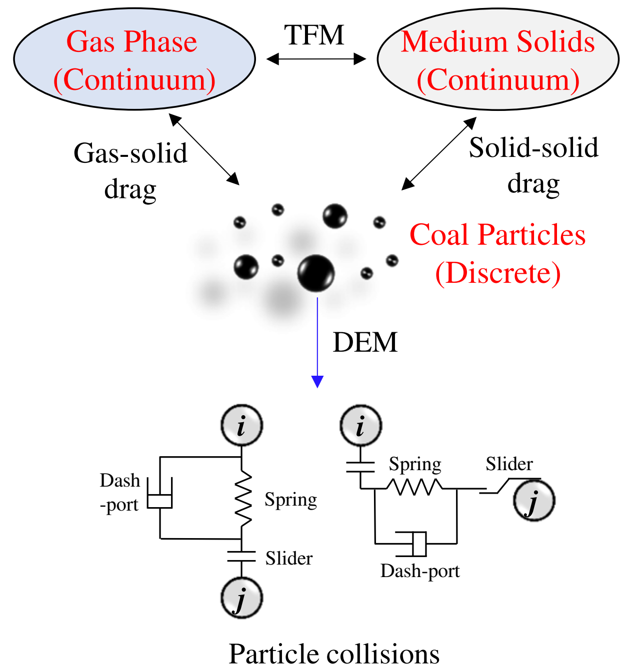

Fig. 1. Schematic illustration of the TFM–DEM hybrid model.

particles to and from the Eulerian gas field. The Gidaspow drag model [20] is also used to describe their interactions. To simplify the code, the cell averaged algorithm is used to calculate the drag force or momentum transfer term between the continuum solid phase and the discrete particle phase [18]. The solid–solid drag correlation developed by Syamlal [31,32] is used to couple the interactions between the medium phase and the discrete particles. The TFM–DEM hybrid model is incorporated in the open-source code MFIX [33,34]. A more detailed description of the TFM–DEM hybrid model and its validation on CBFB modeling can be seen in the former publication [18].

2.2. Simulation conditions

The geometrical CBFB model used in the simulation is schematically shown in Fig. 2. It has a width of 0.25 m and a total height of 0.4 m. A two-dimensional (2D) bed was used for the TFM to save computational cost in modeling of the dense medium flow. For the DEM, the bed thickness was set to one diameter of the discrete particles. The physical parameters used in the simulation are listed in Table 2. A fine mesh of 2.5 mm was applied in the simulation. One kind of Geldart B type magnetite powder with a true density of 3.25 g/cm^3 and a mean diameter of 0.2 mm was used as the medium solids. A fine coal sample of 0.9 mm was considered as the accumulated particles with four separate density distributions, i.e. 1.3 g/cm^3, 1.5 g/cm^3, 1.7 g/cm^3, and 1.9 g/cm^3. Such a density distribution covers the general density range of raw coal sample [12]. The fluidized air was evenly introduced to the bed bottom with a velocity of 0.085 m/s. In the initial state, the medium solids were packed in the bottom region of the bed and the fine coal particles were aligned above the medium solids. A random order was used for particles from different density fractions in arrangement. The Johnson–Jackson boundary condition [35] was used for the continuum solid phase. A real time step of about 1×10^{-7} was used for the DEM particles while a self-adapting time step between 1×10^{-4} and 1×10^{-7} was applied for the TFM calculation. Other details of the setting parameters used in the TFM–DEM hybrid model can be found in the former publication [18].

To simulate the coal accumulation process and obtain the steady flow state at different particle concentrations. six cases were used in the simulation considering different mass proportions of the fine coal