Powder Technology 267 (2014) 322–332

Contents lists available at ScienceDirect

Powder Technology

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

Numerical simulation on distribution characteristics of flexible filamentous particles in a fluidized bed dryer

Fan Geng [a], Gang Luo [a], Yimin Li [a,*], Longji Yuan [a], Zhulin Yuan [b], Xuan Wu [c]

[a] School of Electric Power Engineering, China University of Mining and Technology, Xuzhou 221116, China
[b] College of Energy Sources & Environment Engineering, Southeast University, Nanjing 210096, China
[c] School of Energy And Environment, Inner Mongolia University of Science and Technology, Baotou 014010, China

ARTICLE INFO

Article history:
Received 27 November 2013
Received in revised form 28 June 2014
Accepted 5 July 2014
Available online 12 July 2014

Keywords:
Distribution characteristics
Flexible filamentous particles
Fluidized bed dryers
Cluster
Chain model

ABSTRACT

Distribution characteristics of flexible filamentous particles are investigated in a fluidized bed dryer. The gas–solid two-phase flow in the riser was simulated by Euler–Lagrange method to capture fluidization behavior. Namely, the air flow was defined as continuous phase and the individual flexible filamentous particle was simulated with the chain model. Then the dynamic characteristics of particle distribution in the riser were investigated numerically and experimentally, and the influences of fluidization parameters on particle distribution characteristics were discussed in detail. The research results show that the distribution of flexible filamentous particles in the riser is not uniform, and the formation and development of local regions with higher particle concentration or particle clusters could be found. Furthermore, the gas flow rate and the material flow rate have profound influence on the fluidization behavior and the distribution characteristics of particles. The simulation results are consistent with the experimental findings. Therefore, the simulation model is valid to predict the dynamic behavior of flexible filamentous particles.

1. Introduction

Fluidized bed processing has been widely used at a commercial scale, such as drying, cooling, agglomeration, chemical reaction, combustion and coating of particulate materials. Fluidized bed dryer is one of the most effective means for drying material, mainly due to its good mixing, high heat and mass transfer rate, and easy handling of materials. It could also be used for drying many types of solid particles, including powders, granules, agglomerates and other powder materials [1,2]. Moreover, there are many industrial applications dealing with flexible filamentous particles, such as pulp fibers, pastures, cut-tobacco particles, microfibers in textiles, polymers in medicine, tobacco mosaic virus and DNA molecules in biology [3]. When handled by a fluidized bed dryer, these flexible filamentous particles usually heterogeneously distribute across the dryer, and the distribution and concentration of particles are dynamically changed due to the drying process. Furthermore, these flexible filamentous particles could form clusters easily during the process, especially in high concentration regions. Cluster occurrence is one of the most characteristic features of dense gas–solid flow in the riser of a circulating fluidized bed (CFB) [3–6].

The existence of heterogeneous distribution and cluster has profound influence on the performance of a fluidized bed riser. Especially, particle clusters make the flow field more accessible and the flow changes unstably in time and space, which directly influence the heat and mass transfer, and finally lead to the product quality. Therefore, the studies on particle distribution and clusters have gained much attention from both experimental studies and numerical works during the last decades. And the previous results all suggest that particle clusters could affect CFB performance on both hydrodynamics and chemical reactions. Although clusters in the dense riser flow are well accepted, a clear definition of clusters is still lacking so far. It is therefore of great importance to gain more insight into particle distribution and cluster phenomenon [3,7–9].

Though there are many researches on particle distribution and particle clusters, few reports have considered the impact of material type on cluster characteristics as we know. Sharma et al. investigated particle size on cluster characteristics in a fast fluidized bed [10]. Das et al. studied clustering behavior of the fast fluidized bed and investigated Geldart Group B particles like coal and iron ore in a circulating fluidized bed (CFB) [11]. Chew et al. performed experiments in a circulating fluidized bed riser with Geldart Group B particles, which have been carried out with an emphasis on cluster characterization [12]. However, relative study on cluster characteristics is scarce with the consideration of special type of particles. When it comes to flexible filamentous particles, they are a special kind of particles and have many industrial applications. These type of particles are easy to hold together due to their non-uniformity of shape and moisture content [3]. Then they could easily associate into higher-order structures with slow quantitative change (such as growth of the number of particles), and finally form

* Corresponding author. Tel.: +86 516 83591800.
E-mail address: lymcumt@163.com (Y. Li).

http://dx.doi.org/10.1016/j.powtec.2014.07.001
0032-5910/

the so-called clusters [13–16]. Once a cluster forms in the process, it is impossible for it to disappear easily, and how it evolves has a close relation with its motion state [3].

According to the analysis above, the consequential configurations of flexible filamentous particles play a significant role in cluster formation while dynamical simulation on long flexible particles is still a difficulty. Thus numerical investigation on the bulk movement of flexible filamentous particles is also very limited, especially in concentrated systems which are the common cases in industries. Moreover, cluster formation in the risers and their particle scale behavior is still difficult to investigate experimentally, especially for flexible filamentous particles since the multi-scale flow behavior in gas–solid two-phase flow systems is complex, and relative measurement techniques are limited.

The purpose of this paper is to dynamically simulate flexible filamentous particles, investigate the distribution characteristics of the particles in a CFB riser. In particular, the influences of particle properties, gas velocity and material feed rate on fluidization behavior and distribution characteristics of particles in the riser are investigated. Moreover, the development of local regions with higher particle concentration, i.e. "particle clusters" is emphasized. And the realistic process of cluster formation in the riser as well as its influence was discussed. Furthermore, the computational results are compared with relative experimental findings, which could be used to validate the mathematical model and the computational method.

2. Computational models

2.1. Physical model

Fig. 1(a) shows the cold sample of the fluidized bed dryer of the present work, which consists of a fan, a riser, a material inlet and a separator as well as closed loop piping [14]. Instead of simulating the entire dryer system, only the main section of the dryer, the riser (Fig. 1(b)), is simulated without the inlet and exit configurations. Normal air is used as operation gas, which comes into the riser from the bottom inlet. It is a continuous through flow for particles in the riser, which has to be accounted for in the simulation. And flexible filamentous particles are chosen as operating particle, which are fed into the riser at the bottom inlet, and removed from the riser at the upper outlet under the main action of air flow.

2.2. Mathematical method

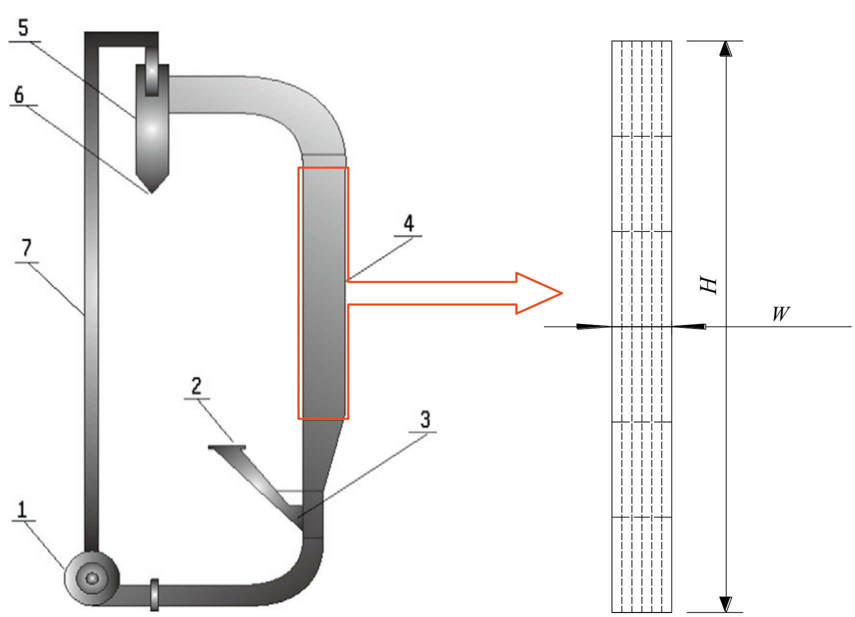
2.2.1. Particles

In order to study the dynamic characteristics of filamentous particles in the flow field, Euler–Lagrange model is employed to evaluate the two-phase flows in two dimensions. Meanwhile, air is defined as the continuous phase and individual particle is traced. Particularly, the solid phase is made up of the flexible filamentous particles, and the particle behavior is modeled by the chain model based on discrete element method [17–19], which has been provided by the current authors [9]. The method has been well established in our previous studies [9,13] and successfully used in the dense particle system such as the rotary dryer.

As shown in Fig. 2 [13], each particle is treated as chains of three rigid bodies connected through ball and socket joints, and the force analysis of each part is carried out respectively. Since the chain model is more complex than sphere particles, which includes realistic features, such as contact forces between particles, joint constraint and friction action, additional constraints are imposed on the behavior of contacting particles, and Lagrange's equations for the chain model are introduced. Thus the behavior of a multi-rigid-body system could be described as [9]:

$$\begin{cases} \frac{\mathrm{d}}{\mathrm{d}t}\left[\frac{\partial \mathrm{T}}{\partial \dot{\boldsymbol{q}}}\right]-\frac{\partial \mathrm{T}}{\partial \dot{\boldsymbol{q}}}=\mathbf{Q}+\boldsymbol{\Phi}_q^{\mathrm{T}}\boldsymbol{\lambda}+\boldsymbol{\Phi}_q^{(R)\mathrm{T}}\boldsymbol{F}^{(R)} \\ \boldsymbol{\Phi}(\dot{\boldsymbol{q}},t)=0 \\ \boldsymbol{\Phi}^{(R)}(\dot{\boldsymbol{q}},t)=0 \end{cases} \tag{1}$$

where $\boldsymbol{q}$ is a set of independent coordinates, and T is the kinetic energy of the system. $\dot{\boldsymbol{q}}=\boldsymbol{d}\dot{\boldsymbol{q}}/\boldsymbol{d}t$, $\boldsymbol{\Phi}_{\mathrm{q}}=\partial\boldsymbol{\Phi}/\partial\boldsymbol{q}$, and $\boldsymbol{\Phi}(\boldsymbol{q},t)\in R^m$ are the relative distance vectors at contact points of the bilateral constraints with the consideration of the friction. And $\boldsymbol{\lambda}$ corresponds to the normal reaction



1.fan 2. feeder 3.material inlet 4.riser
5.separator 6. material outlet 7. wind pipe
(a) The structure of the bed (b) the riser

Fig. 1. Schematic diagram of the fluidized bed dryer.