Powder Technology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Powder Technology

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

Analyzing the fluidization of a gas-sand-biomass mixture using CFD techniques

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ARTICLE INFO

Article history:
Received 28 April 2016
Received in revised form 31 October 2016
Accepted 5 December 2016
Available online xxxx

Keywords:
CFD
Bubbling fluidization
Segregation
Gasifier
Biomass
Sand

ABSTRACT

Fluidization taking into account the presence of the material to be gasified is a differential addressed in this study. Accordingly the solid phase was composed of a binary mixture of sand and biomass. This work deals with the numerical simulation using CFD of a gasifier bubbling fluidized bed for the system composed of gas - biomass – sand. In order to determine the best fluidization conditions, a factorial design 2^3 was carried out varying the biomass particle density and diameter and the biomass percentage in the solid phase. To perform the simulations, ANSYS CFX 15.0 was used, adopting an Eulerian approach coupled to the Kinetic Theory of Granular Flow. The k-ε turbulence model was adopted. Seventeen simulations were performed setting the gas superficial velocity to 0.38 m s^{-1}. Based on the results of the factorial design, it was possible to qualitatively identify the tests to which the system reached a bubbling fluidization. Segregation of the particulate medium occurred for assays where the ratio between the mass of each biomass particle and the mass of each sand particle was >1.0 coupled to a ratio between biomass and sand volume fractions in the bed ≤ 0.5. The variable with the highest significance in the model equation was the diameter of the biomass particle. Volumetric fraction profiles of gas, sand and biomass were obtained to the 17 factorial design conditions as well as a model that predicts the bed expansion. The assay that reached greater bed height (0.50 m), staying on bubbling regime, was the one with 15% biomass volume fraction with 375 μm diameter and 45% sand, indicating those are good conditions for fluidization.

1. Introduction

Fluidized bed reactors are used for combustion or gasification of charcoal and biomass for energy generation [1]. According to Tagliaferri et al. [2], bed dynamics is the main characteristic of fluidized bed reactors, since bubbles induce an excellent gas-solid contact and high rates of heat and mass transfer. The dynamic behavior of the fluidized bed determines whether particles will mix or segregate. Segregation is important to develop classifiers, for which particle separation is necessary [3], while a mixture is useful for processes requiring intimate gas-solid contact.

Predicting if segregation or mixing will occur in fluidized beds is not an easy task. They will occur as a function of the magnitude of the particle weight and forces resulting of the particle/fluid and particle/particle interactions acting on the jetsam and flotsam particles.

Gas-solid systems may occur in different operation regimes depending on parameters such as gas surface speed, particle properties and bed geometry [4]. According to Taghipour et al. [5], two approaches may be used to model gas-solid multiphase flow: a) Lagrangean approach (discrete method based on molecular dynamics); b) Eulerian-Eulerian approach (method based on continuum mechanics treating both phases as inter-penetrating).

This study used the Eulerian-Eulerian approach, applying the Navier-Stokes equation to the continuous and particulate phases, the coupling between phases being represented by pressure and the interphase exchange coefficient. In this approach, particles have a dynamic behavior similar to that of the fluid phase. The great advantage of using the Eulerian approach is the lower computational cost for flows with high particle concentration. One of the properties imposed to particles, which must be determined to solve the Eulerian-Eulerian

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http://dx.doi.org/10.1016/j.powtec.2016.12.023
0032-5910/

formulation, is viscosity, which may be obtained using the Kinetic Theory of Granular Flow (KTGF).

KTGF is the most widespread transcription for modeling and simulation of gas-solid flow [6–11]. It was developed by Gidaspow [11], becoming standard for the representation of fluidized beds. KTGF is also an important tool for modeling the hydrodynamics of the particulate phase, in which case the temperature of the particulate phase represents the basic concept of the theory [12].

During random particle oscillation, inelastic collisions occur, consequently dissipating energy. Granular temperature measures such random particle oscillations. The complete mathematical description of KTGF was done by Gidaspow [11].

The hydrodynamics of fluidized bed reactors has attracted many researchers for decades, who have tried to understand the complex interactions happening between gas and particles [2,13–18].

The general objective of this work was to carry out a hydrodynamic study of a bubbling fluidized bed gasifier with a particulate phase consisting in a binary mixture of biomass (material to be gasified) and sand. Simulations were performed following a 2^3 factorial planning with variation of the biomass properties (particle diameter and density) and the percentages of biomass in the mixture. This allowed to analyze the influence of biomass properties on fluidization behavior and also to find best fluidization conditions, where segregation effects are minimized.

2. Methodology

Particle fluidization in a given gasifier was modeled using the Eulerian-Eulerian approach, which considers the gaseous (continuous) and solid (particulate) phases as inter-penetrating within each computational cell. The process was considered to be carried out in isothermal conditions (300*K*), without mass exchange between the phases. The principles of mass and momentum conservation were applied to the gaseous and particulate phases, as shown in Eqs. (1) & (2) and (3) & (4), respectively.

$$\frac{\partial}{\partial t}\left(\alpha_g \rho_g\right) + \nabla\left(\alpha_g \rho_g \vec{v}_g\right) = 0 \tag{1}$$

$$\frac{\partial}{\partial t}\left(\alpha_s \rho_s\right) + \nabla\left(\alpha_s \rho_s \vec{v}_s\right) = 0 \tag{2}$$

where subscript *g* and *s* are for gaseous and particulate phases, respectively; α is volumetric fraction, ρ: density; and $\vec{v}$: velocity vector.

The equation of motion to the continuous and particulate phases results in Eqs. (3) and (4), respectively.

$$\frac{\partial}{\partial t}\left(\alpha_g \rho_g \vec{v}_g\right) + \nabla\left(\alpha_g \rho_g \vec{v}_g^{\,2}\right) = -\alpha_g \nabla p + \nabla \bar{\bar{\tau}}_g + \alpha_g \rho_g \vec{g} + K_{gs}\left(\vec{v}_g - \vec{v}_s\right) \tag{3}$$

$$\frac{\partial}{\partial t}\left(\alpha_s \rho_s \vec{v}_s\right) + \nabla\left(\alpha_s \rho_s \vec{v}_s^{\,2}\right) = -\alpha_s \nabla p - \nabla p_s + \nabla \bar{\bar{\tau}}_s + \alpha_s \rho_s \vec{g} + K_{gs}\left(\vec{v}_g - \vec{v}_s\right) \tag{4}$$

where *p* is static pressure; p_s pressure in the solid phase; $\bar{\bar{\tau}}_g$ and $\bar{\bar{\tau}}_s$: viscous stress tensors of the continuous and particulate phases, respectively; $\vec{g}$: gravitational acceleration; ρ_g and ρ_s: densities of the continuous and particulate phases, respectively; and K_{gs}: coefficient of interaction between phases.

For the formulation of the models represented by Eqs. 3 and 4 to be complete, values must be obtained for the terms p_s, $\bar{\bar{\tau}}_g$ and $\bar{\bar{\tau}}_s$. These terms may be obtained through the KTGF, as described by Taghipuor et al. [5] and Armstrong et al. [12].

The geometry of the bubbling fluidized bed gasifier was built in 2D, in order to minimize computational effort. This sort simplification was also done by various other authors [1,5,12,19]. The built geometry (2.0 m high, 0.58 m diameter, and 0.40 fixed bed high) was based in the actual dimensions of a gasifier available at the Laboratory for Advanced Process Control and Optimization, at Federal University of Pernambuco (Fig. 1). A mesh independence test described in [20] was carried out in order to select the best mesh. The selected computational model was validated against the experimental data of Taghipuor et al. [5]. This validation procedure is described in detail in [21].

Simulations were performed using the software ANSYS FLUENT 15.0, by means of a partnership established with the Computational Fluid Dynamics Laboratory (Lab CFD) of the Federal University of Rio de Janeiro. The system of equations obtained using the mechanistic modeling (Eqs. (1–4)) was solved in a segregated form, using the methods named in Table 1 and the k-ε turbulence model. Particle viscosity was calculated by KTGF; the models employed are listed in Table 2. According to

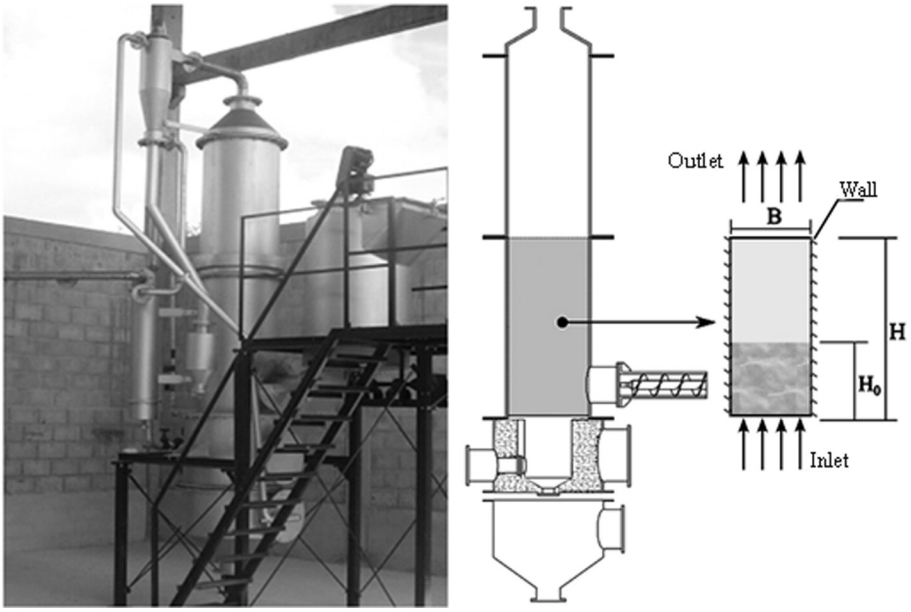

Fig. 1. Schematic drawing of the 2-D Geometry (H = 2.0 m, H_o = 0.40, B = 0.58 m).

Please cite this article as: M.C.S. Sant'Anna, et al., Analyzing the fluidization of a gas-sand-biomass mixture using CFD techniques, Powder Technol. (2016), http://dx.doi.org/10.1016/j.powtec.2016.12.023