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Influence of operating parameters and flow regime on solid dispersion behavior in a gas–solid spout-fluid bed

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HIGHLIGHTS

- Solid dispersion behavior in a 3-D spout-fluid bed was investigated via CFD–DEM.
- Detailed trends of both local and overall solid dispersion behavior.
- Impact of various operating parameters on lateral and vertical solid dispersion.
- Solid dispersion is the most effective in the Jet-in-fluidization regime.
- Total gas flow rate plays dominated role on the overall solid dispersion.

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ABSTRACT

The dispersion behavior of the solid phase in a three-dimensional spout-fluid bed was numerically investigated via the approach of coupled computational fluid dynamics and discrete element method (CFD–DEM), in which the fluid and solid phases were solved using the Eulerian and Lagrangian framework, respectively. Detailed trends of both the local and overall dispersion behaviors of the solid phase in the system were quantitatively studied, and the impact of various operating parameters (namely, spouting gas velocity (U_{sp}), background velocity (U_{bg}), particle diameter (d_p), the bed depth (L) and bed height) and flow regime on lateral and vertical solid dispersion was investigated. The results show that varying U_{sp}, U_{bg} and d_p affects the local solid dispersion in the spout and fountain regions more than the annulus. To enhance the overall solid dispersion, either U_{sp} or U_{bg} or L can be increased, or d_p and bed height can be decreased. Meanwhile, the total gas flow rate plays the dominated role for overall dispersion of solid phase. Finally, solid dispersion is the most effective in the Jet-in-fluidization regime, followed by the Spouting-with-aeration then the Intermediate/spout-fluidization regimes.

1. Introduction

In recent years, interests in the hydrodynamics of the spout-fluid bed have flourished due to the combined advantages of the bubbling fluidized bed (Chew et al., 2015) and the conical spouted bed (Aguado et al., 2003). Moreover, the wider range of flow rates possible in the spout-fluid bed compared to that for fluidized bed or conical spouted bed leads to a lower tendency for slugging, which in turn allows for a wider operational range for particles with varying sizes and densities (Sutkar et al., 2013a). These distinguishing characteristics make the spout-fluid bed increasingly popular in many gas–solid operations, such as particle mixing (Zhang et al., 2012a; 2013), thermoplastic composites (Zong et al., 2011), drying of solid material (Zielinska and Markowski, 2007), coating and granulation of solids (Kfuri and Freitas, 2005; Seiler et al., 2008), coal gasification and combustion (Lim et al., 1988; Thamavithya et al., 2012). An in-depth investigation of the gas–solid hydrodynamics in the system plays an important role in improving

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Abbreviations: 3-D, Three-dimensional; CFD, Computational fluid dynamics; DEM, Discrete element method; DP, Dispersion coefficient; DPx, Dispersion coefficient in the X direction; DPy, Dispersion coefficient in the Y direction; DPz, Dispersion coefficient in the Z direction; TFM, Two-fluid model

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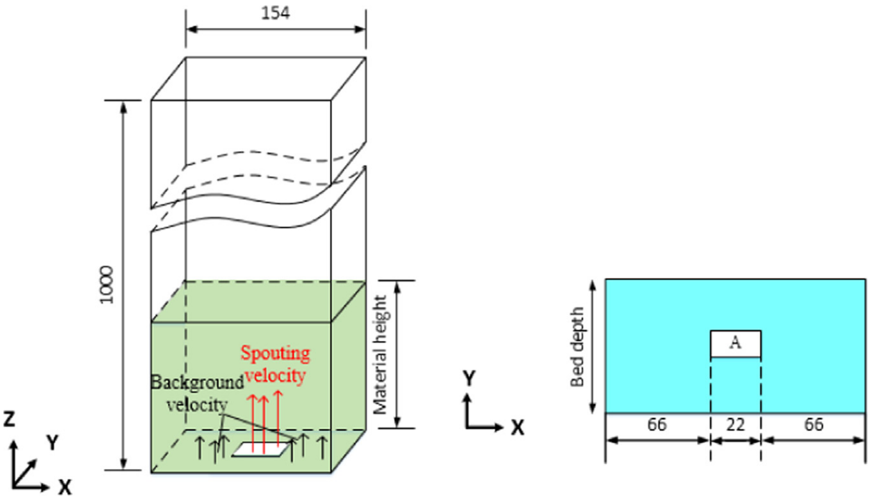

Fig. 1. The schematic of the 3-D spout-fluid bed simulated, which is similar to the experimental setup with a cross section of 154 mm (width) by 84 mm (depth) and a height of 1000 mm (Link et al., 2008).

Table 1
Parameters settings of all the simulated cases conducted in the current work.

Spouting velocity, U_{sp} (m/s)	Background velocity, U_{bg} (m/s)	Bed depth, L (m)	Particle diameter, d_p (mm)	Particle number (dimensionless)	Number of grids (dimensionless)	Bed height (m)
61, 63, 65, 67, 69	3.5	0.084	4.04	44800	18360	0.195
65	3.1, 3.3, 3.5, 3.7, 3.9	0.084	4.04	44800	18360	0.195
65	3.5	0.084, 0.1008, 0.1176, 0.1344, 0.154	4.04	44800, 55054, 64215, 73180, 90133	21420, 18360 22950, 24480, 26010	0.195
65	3.5	0.084	3.6, 3.8, 4.04, 4.2, 4.4	65484, 55678, 44800, 41449, 35756	18360	0.195
65	3.5	0.084	4.04	44800, 53760 62720	18360	0.195, 0.234, 0.273

the efficiency of gas–solid interactions and thereby the system performance.

Past experimental studies have provided valuable information on the hydrodynamics in the spout-fluid bed, such as spout characteristics (Zhong et al., 2008), gas and particle mixing behaviors (Zhang et al., 2011), impact of draft plate/tube inserts (Sutkar et al., 2013b), influence of rolling friction (Goniva et al., 2012), and flow regimes under different operating conditions (Link et al., 2005; van Buijtenen et al., 2011a) and multiple chambers (van Buijtenen et al., 2011b). Numerical approaches have served as useful complements to the experimental studies. Two main approaches are available to model dense gas–solid flows, namely the Eulerian (i.e., based on a continuum assumption of phases) (Li et al., 2011, 2009) and the Lagrangian (i.e., track individual particles) (Gui and Fan, 2009). Compared to the two-fluid model (TFM), the coupled computational fluid dynamics–discrete element method (CFD–DEM) offers advantages in terms of providing dynamic information, such as positions, velocities and forces of the particles, which are extremely useful for an in-depth understanding of the solid behavior. Alongside the experimental efforts, numerical investigations have been carried out to study the hydrodynamics in the spout-fluid bed, such as granulation (Link et al., 2007), flow regimes (Link et al., 2005, 2008), gas–solid behavior (Zhong et al., 2006), particle mixing (Zhang et al., 2010), and spout evolution (van Buijtenen et al., 2012).

The performance of the spout-fluid bed especially in terms of heat and mass transfer is strongly influenced by the local mixing behavior of the solid phase. As an example, in catalytic processes, solid mixing is critical to avoid dead zones which lead to catalyst deactivation or overheating of catalysts, which in turn results in poor process efficiency and product selectivity (Wei and Zhu, 1996). As another example, in the thermal conversion of low-rank solid fuels such as biomass and coal, the local mixing of the solid fuel strongly influences the distribution of reacting particles and gas across the cross-section, which not only affects the heat distribution but also the resulting emissions (Olsson et al., 2012). The local solid mixing behavior, which can be quantitatively evaluated from its dispersion characteristics (Liu and Chen, 2011, 2012; Olsson et al., 2012; Pallarès and Johnsson, 2006), is known to be a critical parameter in the operation of gas–solid processes. Accordingly, numerous experimental and numerical efforts focusing on the solid dispersion behavior have been reported in the bubbling fluidized bed (Oke et al., 2014; Olsson et al., 2012), circulating fluidized bed (Jiradilok et al., 2008; Samruamphianskun et al., 2012), and spouted bed (Berghel et al., 2008). For the spout-fluid bed of interest in the current effort, Zhang et al. (2012b) has experimentally studied the overall dispersion behavior using particle trajectory, but neither the local solid dispersion nor the influence of the dominant operating parameters (namely, spouting velocity (U_{sp}), background velocity (U_{bg}), and particle