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Experimental study of cluster properties in a two-dimensional fluidized bed of Geldart B particles

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ABSTRACT

The paper presents an analysis of measurement results on cluster properties in a two-dimensional lab-scale cold fluidized bed operating in turbulent and circulating fluidized bed modes. Experiments were carried out with Geldart B particles of (Sauter mean) diameters varying from 0.256 mm to 0.440 mm. Different particle size distributions and bed mass were used along with different superficial gas velocities in the range of 2.75 m/s to 4.00 m/s. High-speed images of the bed were taken in a controlled lighting environment. Analysis of the experimental images was conducted to determine the horizontal length scale distribution of the solid clusters along the 3 m high CFB. Additionally, the solid hold-up inside the clusters was evaluated. The effects of particle size, bed mass and superficial gas velocity on the measured cluster properties were determined. The solid hold-up of the clusters was correlated to the horizontal length scales of the clusters to estimate the importance of each cluster size in terms of the mass fraction of solids residing in clusters of a specific width range. In the bottom region up to 0.2 m from the air distributor, about 5% of the solid mass in clusters was found to reside in structures with horizontal length scales less than 1 cm while at 1.2 m height the corresponding share was about 10%. This information is relevant for determination of the mesh resolution required to describe all the significant cluster sizes in CFD simulations. The findings of the study on the width distributions of the clusters and the solid concentrations inside the clusters may also be used as a point of comparison with corresponding measures observed in simulations, by which a quantitative validation of CFD results could be made.

1. Introduction

Circulating fluidized bed (CFB) technology has become an efficient alternative for combustion of solid fuels. Fuel flexibility is the key to the success of this technology. Combustion of the fuel is fairly uniformly distributed inside CFB boiler furnaces which leads to low hydrocarbon and CO emissions. The performance of a CFB furnace strongly depends on the mixing of gas and solid particles [1] which, in turn, is affected by the physical properties of the clusters that are formed inside the CFB riser. Clusters of particles are structures with higher solid content than in the surrounding suspension and typically with larger height than width and they have a significant existence in the time scale [2]. Due to their chaotic appearance it is complicated to measure and characterize the flow patterns and the clusters of particles in a CFB [3]. In a commercial CFB boiler, the conditions at the furnace bottom resemble the conditions in a turbulent fluidized bed (TFB) due to a larger average particle size in the bottom section. Clustering of solid particles takes place also under TFB conditions although cluster structures are somewhat different. Since the majority of the solid particles reside in clusters, cluster properties are an important issue.

In a previous study, Mondal et al. [4] estimated the horizontal and vertical length scale distributions of clusters in a pseudo 2-dimensional lab-scale cold CFB. The study involved Geldart B particles with a Sauter mean diameter of 0.256 mm. The study by Cocco et al. [5] reported that cluster characterization for Geldart A particles is easier than for those formed by Geldart B particles because for the former particles the clusters are small and more tightly packed and their shape can be generalized. By contrast, Geldart B particles form clusters of many different shapes and the magnitude of their length scales varies with almost all the operating bed parameters, such as elevation along the riser, bed mass (inventory), fluidization velocity [4] and, last but not least, the particle sizes in the bed.

Many attempts have been made to define cluster structures, sizes and other properties [6–9]. Chew et al. [10,11] showed that for Geldart B particles the position in the riser has a very dominant influence on cluster characteristics. Guenther and Breault [12] demonstrated that cluster size increases drastically in the dilute region in the upper part of the CFB. These cluster dimension variations depend very much on particle size and solid circulation rates. Bai et al. [13] reported that a higher suspension density affects the cluster appearance by making it

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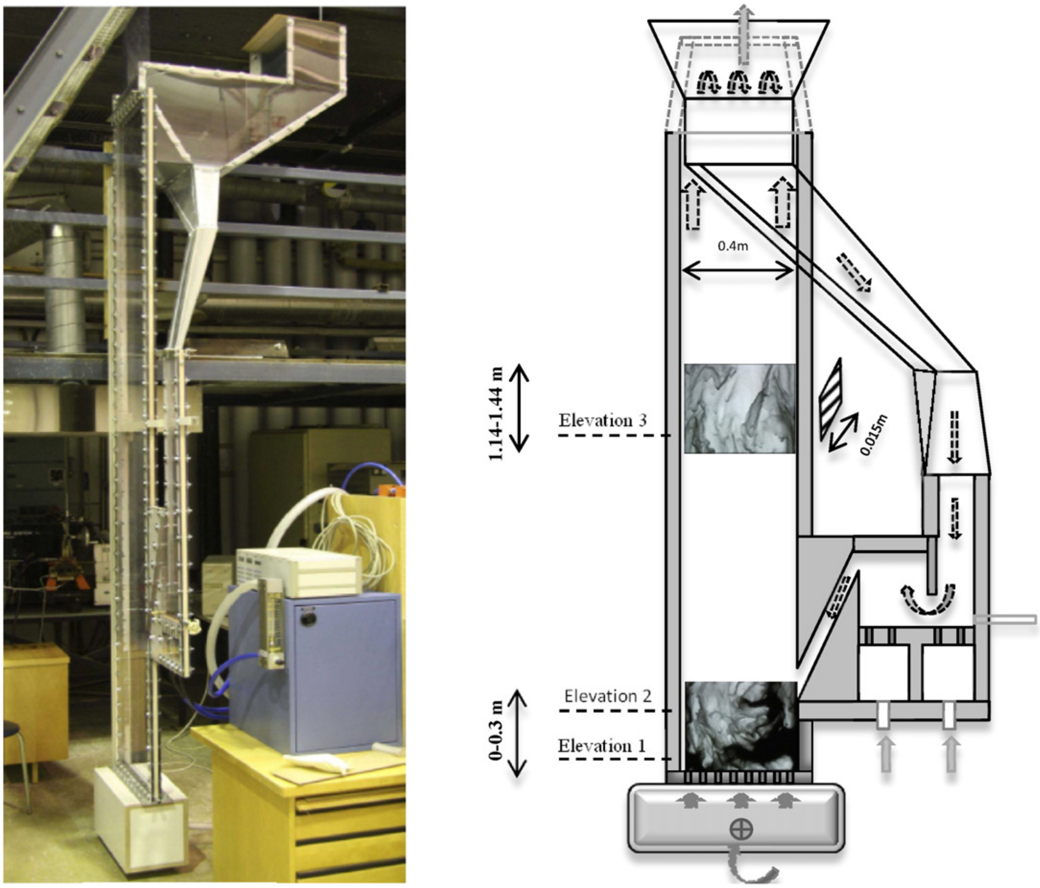

a. b.

Fig. 1. (a) Photograph of the lab-scale CFB. (b) Functional diagram of the CFB along with experimental images at heights $z = 0.00$–0.30 m and 1.14–1.44 m from the experiment with $m = 3.26$ kg bed mass containing only 0.256 mm diameter particles and at a superficial gas velocity of $u = 2.75$ m/s.

U shaped, but when the suspension density is low the particles tend to form strands at the lower elevation of the CFB and their appearances vary with the specific location in the riser [10,11]. A similar approach of image analysis was adopted by Rhodes et al. [14] and Yang and Zhu [15].

With the increasing number of contributions from many researchers it is obvious that it is interesting to study circulating fluidized bed hydrodynamics for Geldart B particles for different bed conditions across the riser [16]. As suggested by Knowlton et al. [17] the solids concentration distribution in a CFB is affected by the particle size distribution, which influences the gas-solid interactions. The present work also studies the effects of particle size distribution on cluster properties. In the paper quite extensive results are reported in order to provide a set of results that can be used for tuning or validation of CFD models.

In order to increase the efficiency in reactor design and modelling, knowledge of flow patterns and hydrodynamic behavior of the CFB is needed. Computational fluid dynamics (CFD) simulations have become an important tool for increasing the understanding and even for the development of CFB processes. To accurately describe the CFB hydrodynamics, transient simulations are necessary and they should be performed with a fine computational mesh to gain required accuracy to allow for a deeper phenomenological understanding of the system [18,19]. A rule-of-thumb that has become popular is to take a mesh resolution equal to 10 particle diameters which seemed to produce grid-independent results [20]. In the process of defining the mesh spacing for detailed transient simulations, the fine clusters must be taken into consideration since they can contain a significant share of the solid inventory in the CFB. In the present study, the importance of clusters of different length scales is determined by analyzing images taken from a small fluidized bed. Both CFB and TFB conditions are included in the study.

Table 1
Particle mixtures and the abbreviations used.

Particle mixture	Abbreviation
100% 0.256 mm	Mixture 1
10% 0.44 mm, 90% 0.256 mm	Mixture 2
35% 0.44 mm, 65% 0.256 mm	Mixture 3
100% 0.44 mm	Mixture 4

Table 2
Bed mass, superficial gas velocity and measured solids circulation rates per riser cross-sectional area for the different cases studied.

Particles	Bed mass kg	Superficial gas velocity m/s	Solid circulation rate kg/(m^2 s)
Mixture 1	1.94	2.75	23.7
Mixture 1	3.26	2.75	46.7
Mixture 4	3.26	2.75	0.0
Mixture 4	3.26	3.50	0.3
Mixture 4	3.26	4.00	4.9
Mixture 2	3.26	2.75	8.1
Mixture 3	3.26	2.75	4.5