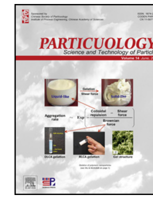
Particuology 16 (2014) 69–74

Contents lists available at ScienceDirect

Particuology

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



Experimental investigation of cluster properties in dense gas–solid fluidized beds of different diameters

Niloufar Firuzian, Rahmat Sotudeh-Gharebagh*, Navid Mostoufi

Multiphase Systems Research Laboratory, Oil and Gas Processing Centre of Excellence, School of Chemical Engineering, College of Engineering, University of Tehran, Tehran, Iran

ARTICLE INFO

Article history:
Received 13 May 2013
Received in revised form 16 September 2013
Accepted 9 October 2013

Keywords:
Cluster
Optical fiber probe
Gas–solid fluidized bed
Column diameter

ABSTRACT

The local solid flow structure of a bubbling fluidized bed of sand particles was investigated in three different columns to characterize the properties of clusters. The experiments were performed using a reflective optical fiber probe. The variations in size, velocity, and void fraction of the clusters due to changes in the superficial gas velocity, particle size, and radial positions were studied. The results indicate that the velocity of the clusters remained unchanged while their size increased as the column diameter increased. In addition, the radial profile of the clusters' velocity did not depend on the radial position. The results indicate that larger particles form larger clusters, which move slower.

1. Introduction

The hydrodynamics of fluidized bed reactors have been investigated by many researchers. For example, the mechanism of bubble formation, existence of aggregates, and changes in flow regimes has attracted much attention. Clusters are of considerable importance to the flow structure in gas–solid fluidized beds and play a major role in mass and heat transfer as well as in gas and solid radial and axial concentration/velocity profiles and their residence time. Therefore, researchers have attempted to obtain detailed information on the characteristics and parameters of clusters, such as size, velocity, solid concentration inside clusters, and time fraction of the clusters' existence, to gain a better understanding of their structure.

Various methods of measurements have been employed to provide experimental evidence for the influence of clusters on the flow structure of gas–solid fluidized beds. Sharma, Tuzla, Matsen, and Chen (2000) used capacitance probe to study the effect of particle size on cluster properties in a fast-fluidized bed with a diameter of 15 cm and determined that the characteristics of clusters are affected by gas velocity and particle size. Their results indicated that larger particles produce clusters that move slower and are longer. Cocco, Shaffer, Hays, Karri, and Knowlton (2010) used a high-speed video camera to explore clusters of Geldart A particles in a circulating fluidized bed with a diameter of 15 cm. They analyzed images of the clusters to investigate the forces exerted on clusters and concluded that hydrodynamic, inelastic particle collision, electrostatic charging, capillary and van der Waals forces play a major role in cluster formation because no mechanism is applicable to all cases. Xu and Zhu (2011) examined clusters using a high-speed video camera and optical fiber probe in a rectangular circulating fluidized bed. They observed that lighter and smaller particles tend to aggregate and form interconnected clusters. In addition, they concluded that sphericity plays a limited role in the formation of clusters. Many researchers have employed a fiber optic probe to explore clusters in various fluidization regimes (Manyele, Pärssinen, & Zhu, 2002; Qi, Zhu, & Huan, 2008; Xu & Zhu, 2010). Guenther and Breault (2007) applied wavelet analysis to fiber optic signals for counting clusters and determining their size in a circulating fluidized bed. Their results indicate that near the wall region, large clusters break up and produce smaller clusters. Afsahi, Sotudeh-Gharebagh, and Mostoufi (2009) investigated the effects of particle size, gas superficial velocity, and radial position on the characteristics of clusters using a reflective fiber optic probe. Pandey, Turton, Yue, and Shadle (2004) used a backscatter LDV system to examine the effect of superficial gas velocity on the clusters' flow pattern near the wall region in a circulating fluidized bed with a diameter of 30.5 cm. They reported that larger clusters are produced in denser conditions associated with an increase in the load ratio. Lackermeier, Rudnick, Werther, Bredebusch, and Burkhardt (2001) performed experiments to explore clusters inside the dilute zone of a 40 cm diameter circulating fluidized bed using a laser sheet technique and high-speed video camera.

* Corresponding author. Tel.: +98 216696 7797; fax: +98 216646 1024.
E-mail address: sotudeh@ut.ac.ir (R. Sotudeh-Gharebagh).

1674-2001/$ – see front matter © 2014 Published by Elsevier B.V. on behalf of Chinese Society of Particuology and Institute of Process Engineering, Chinese Academy of Sciences.
http://dx.doi.org/10.1016/j.partic.2013.10.008

Nomenclature

$\bar{d}_p$	mean particle diameter, m
D_t	column diameter, m
H_0	static height of solids inside column, m
L_e	effective distance between consecutive receiving fibers, m
l_n	needle length, m
r/R	dimensionless distance from column vertical axis, m/m
U_c	calculated transition velocity from bubbling to turbulent regimes, m/s
U_g	superficial gas velocity, m/s
U_{mf}	gas superficial velocity at minimum fluidization, m/s
V_c	cluster velocity, m/s

Greek letters

ε_{mf}	voidage at minimum fluidization, m^3/m^3
ρ_p	particle density, kg/m^3
Δt	time delay between similar peaks in two receiving fibers, s
ω	rotation speed determined by tachometer, rad/s

In addition to experimental studies, some researchers have used computer modeling to investigate cluster behavior in gas solid fluidized beds. Helland, Bournot, Occelli, and Tadrist (2007) provided a summary of the results from computational studies that investigated the effect of cluster formation on the drag coefficient. Lu et al. (2005) proposed a cluster-based approach model and estimated the flow parameters, such as pressure drop, solid concentration, and gas velocity in the risers.

In spite of the extensive experimental and computational studies performed to characterize clusters, there is no general rule for cluster behavior in gas solid fluidized beds. Some conclusions have been reported in the literature, but they are not applicable under other operating conditions and fluidization regimes. Therefore, additional investigation is required to obtain further insight into the impact of various operating conditions on cluster features. In addition, to apply the results from experimental data on the industrial scale, it is essential to investigate the influence of column diameter on cluster characteristics. Therefore, the aim of this work was to study the dependence of cluster properties on different variables including the bed diameter in the dense section of bubbling fluidized beds. To achieve this goal, a set of experiments was performed with three sizes of bubbling fluidized beds. To obtain detailed information on the clusters, the changes in the cluster size, velocity, and void fraction were investigated using a reflective type fiber optic probe at various radial positions with the aid of a computer program.

2. Experimental

Three separate columns with inner diameters of 150, 90, and 50 mm were used in the current experiments. A schematic of the experimental setup is shown in Fig. 1. The probe was inserted into each column through small holes provided at intervals of 5 cm. Air at ambient temperature and atmospheric pressure entered the bed after passing through a perforated plate distributor, and its flow rate was regulated by a mass flow controller. A cyclone was placed at the gas exit to return fine solids back to the bed. To minimize electrostatic effects, the whole system was electrically grounded.

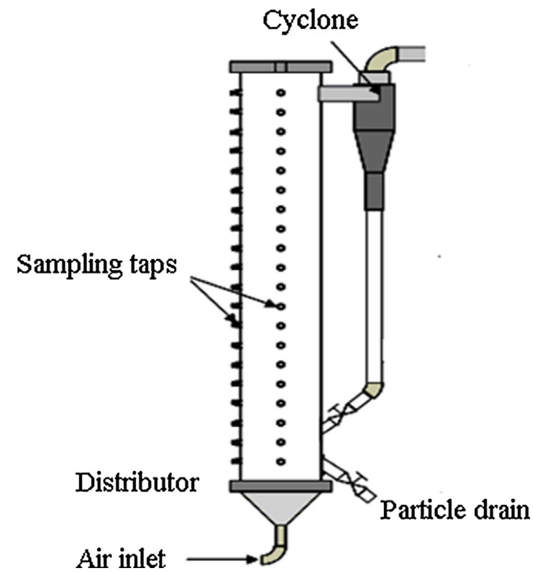


Fig. 1. Schematic diagram of the experimental set up.

Table 1
Characteristics of solid particles.

U_c (m/s)	U_{mf} (m/s)	ρ_P (kg/m^3)	$\bar{d}_p$ (µm)	Particle
0.85	0.03958	2640	150	Sand 150
1.0	0.0563	2640	300	Sand 300

The experiments were performed at various operating conditions and different radial locations. The solids used in the experiments were 150 and 300 µm sand particles. The properties of these solids are provided in Table 1. The values of U_{mf} and U_c in this table were estimated using empirical correlations (Yang, 2003). The ratio of the static bed height to the column diameter (H_0/D_t) in all of the experiments was set to 1.5. The superficial air velocity varied between 0.3 and 1.1 m/s. The data were obtained at a frequency of 60 kHz in each position over 15 s. Therefore, 900,000 data points were recorded at each sampling position. The data were collected at distances of 5, 5, and 10 cm above the distributor in the 50, 90, and 150 mm columns, respectively. To ensure reproducibility of the results, the experiments were repeated at least 3 times in each spatial position.

A fiber optic probe was employed to collect the local data. In this probe, four emitting and three 60 µm receiving optical fibers were aligned in an alternative array. The diameter of each fiber with the cladding was 125 µm. A thin glass attached to the probe tip prevented particles from occupying the blind zone. A light beam was projected through the emitting fibers into the bed. The particles passing the probe tip reflect the light, which was received by the three receiving fibers, multiplied by the photo-multiplier and converted into a voltage signal. The closer the particles, the clearer the generated peaks were in receiving signals. Then, after amplifying the voltage signal, it was stored on a PC. The calculation of clusters velocity was based on the time delay of the reflected light from moving clusters that was identified by the receiving fibers. The clusters moving vertically produced similar signals in the three receiving fibers with a specific time delay, Δt, associated with the cluster velocity. The calculation of the cluster velocity was performed based on the effective distance between consecutive receiving fibers. To determine the effective distance between the fibers, calibration of the fiber optic probe is essential. This calibration was performed with the aid of a variable speed motor that rotated a thin needle. The rotating speed of the motor was