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Effects of pressure and fines content on bubble diameter in a fluidized bed studied using fast X-ray tomography

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HIGHLIGHTS

- Using our fast X-ray tomographic scanner we measure bubble size and velocity.
- Increasing the pressure from 1 to 5 bar reduces the bubble size significantly.
- The bubble size can be accurately described by Darton's model.
- Adding 50% fines to a Geldart A powder reduces the bubble size by 20%.

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ABSTRACT

Using a fast X-ray tomography setup the bubble size and velocity has been measured in a 25 cm diameter fluidized bed of Geldart B powder and a 24 cm bed of Geldart A powder. The average bubble size has been determined for a measurement period of 60 s. The resolution of this setup is about 4.5 mm per pixel at a rate of 250 reconstructions per second. It is possible to detect bubbles as small as 2.2 cm.

The Geldart B powder consists of polystyrene particles with an average diameter of 607 μm and a bulk density of 625 kg/m^3. This bed was studied at pressures ranging from 1 to 5 bar. The superficial gas velocities varied from 12 to 32 cm/s for the atmospheric pressure measurements; for the highest pressure from 10 to 15 cm/s. The bubble size is significantly reduced at higher pressures for similar gas flows.

The Geldart A powder consist of a base of aluminum oxide particles with an average diameter of 76 μm and a bulk density of 680 kg/m^3. A varying amount of fines was added to these base particles for the different mixtures. The fines consist of aluminum oxide particles with an average diameter of 38 μm and a bulk density of 620 kg/m^3. The fines contents varied from 0%$_w$ to 50%$_w$. An increase in fines content results in a clear reduction of the average bubble size. If the fines content is increased from 0%$_w$ to 50%$_w$ the average spherical equivalent bubble diameter is reduced by 20%.

1. Introduction

Fluidization is used in many chemical engineering applications. Fluidized beds provide a large contact surface area in a relatively small volume and do not need mechanical stirring. If the gas flow is increased, the bed will generally begin to bubble. Although this ensures the bed is well mixed, the gas passing through a bubble has limited contact with the particles. Since fluidized beds are often used in gas conversion processes, these bubbles will reduce the performance of the bed. Beetstra et al. [1] discuss that a 40% reduction of the bubble size may lead to a 50% increase in conversion. In [2] different gas injection strategies were employed. Moreover, the authors used electrical fields to influence the interparticle forces. In both cases a reduction of the bubble size was observed. Addition of fines also improves the conversion [3,4]. In [1] the influence of fines on the fluidization behavior of porous alumina particles is reported. These researchers added up to 50% fines to their powder and found that the average bubbles size decreases with increasing fraction of fines. From video images taken in a pseudo 2D bed, the authors found that for higher gas velocities the bubble size distribution shifted to smaller values with a smaller standard deviation.

Apart from adding fines, an increase of the operation pressure also reduces the bubble size, see e.g. [5]. As most experiments in laboratories are done at ambient pressures, relatively little literature on measurements of the bubble size at elevated pressures can be found. In this paper, we investigate the influence on the bubble size of (1) increasing the pressure inside the bed from 1 bar to about 5 bar and (2) adding fines (particles with a $d_{50} < 45$ μm). The size of the bubbles is measured using our fast X-ray tomography setup [6,7].

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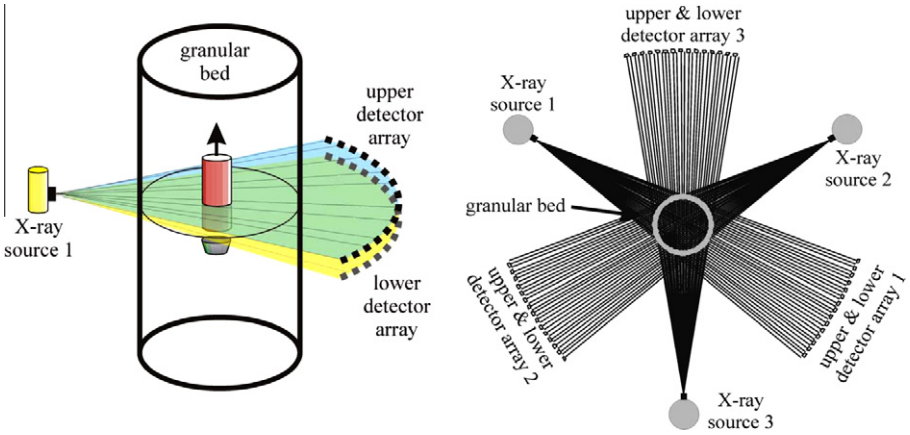

Fig. 1. Schematic of the X-ray setup. Left: side view showing only one source and its two detector arrays for clarity. Right: top view of complete setup.

2. Experimental setup

Using X-ray tomography it is possible to study the size and velocity of bubbles inside a bubbling fluidized bed. For this purpose a setup has been developed at TU Delft [8]. A fluidized bed with a diameter of 25 cm is positioned in the middle of the setup. It is placed on a height adjustable table, so the bed can be studied at different heights. With the setup measurements in two parallel planes can be taken. The cross-sections of both planes are reconstructed using the Simultaneous Algebraic Reconstruction Technique (SART). In this way bubbles can be detected in the lower and upper plane. Corresponding bubble images can be matched, and in that way the speeds and true volume of the bubbles can be determined. With the current setup it is possible to reconstruct 250 images per second and detect bubbles with a diameter as small as 2.2 cm.

In this work, we use X-ray Computed Tomography to study the size of gas bubbles in fluidized beds. The technique relies on the absorption and scattering of X-ray photons by the solids in the fluidized bed. The measurement setup consists of three X-ray sources and three detector banks. These X-ray sources are mounted at 120° around the fluidized bed. Each source generates a fan beam which is detected by the corresponding detector bank on the opposite side of that source. A single detector bank has two detector arrays, one above the other. A schematic overview can be seen in Fig. 1. The two detector arrays create two measurements planes. The average distance between the planes is 1.86 cm. Each detector array consists of 32 sensors, so there are 192 sensors in total.

The three X-ray sources used in the setup are YXLON Y.TU 160-D06 tubes. These tubes have a maximum voltage of 160 kV and a maximum current of 12 mA. Depending on the type of particles and column used, an appropriate voltage and current is selected. For the experiments with a perspex column filled with aluminum oxide particles the settings for the X-ray tubes were: tube 1: $V = 150$ kV, $I = 0.4$ mA; tube 2: $V = 150$ kV, $I = 0.4$ mA; tube 3: $V = 150$ kV, $I = 0.7$ mA. For the experiments with a stainless steel column with polystyrene particles the settings were: tube 1: $V = 150$ kV, $I = 2.0$ mA; tube 2: $V = 150$ kV, $I = 2.3$ mA; tube 3: $V = 150$ kV, $I = 2.8$ mA. In front of the tubes a lead collimator is placed to create a flat measurement plane. These collimators also reduce the amount of scattered radiation. The detector banks consist of two arrays of each 32 Hamamatsu S1337 – 1010BR detectors. These are $CdWO_4$ scintillation crystals, which are optically coupled to the PIN photodiode. Their crystal size is 10 mm × 10 mm × 10 mm. These detectors are installed on small printed circuit boards and mounted in a curved plastic arc. The curvature of this arc is such that all detectors are aimed directly at the X-ray source on the opposite side of the setup. The data from the detectors is recorded at 2.5 kHz and stored using a National Instruments CompactRIO embedded control and acquisition system. This system is controlled using a host-pc running LabView. One minute of measuring results in about 100 MB of binary data. This data is later used to reconstruct the solids distribution in each of the two parallel bed cross-sections.

2.1. Fluidized bed

The bottom of the column, that is used to contain the fluidized bed, consists of a wind box. This wind box has a 1 in. tube connection, which directs the gas flow downward inside the box. This ensures a uniform distribution of gas through the bronze sintered distribution plate at the top of the wind box. This plate has pore sizes ranging from 30 to 70 μm and a thickness of 7 mm. On top of this wind box the actual column, that contains the fluidized bed, is mounted. Compressed air, controlled by a flow controller, is used to fluidize the bed.

The pressurized measurements were done using a stainless steel column with an inner diameter of 25 cm. The column wall has a thickness of 2 mm. The main part of the column is 70 cm high and another 50 cm part can be put on top. To seal the vessel, a stainless steel lid with tube connections is mounted on top. The outlet of the vessel is connected to a valve, which controls the pressure inside the vessel.

The fines experiments were done using a perspex column with an inner diameter of 24 cm and a wall thickness of 5 mm. This column also consists of two parts, a 70 cm high main section and a 50 cm extension. There is another 50 cm extension, which can be placed on top, for extra room inside the vessel. The vessel can be sealed using a perspex lid with filters and tube connections.

The fine particles, used in the fines measurement series, produce a significant amount of dust, when the bed is fluidized. To prevent this dust from leaving the column, filters were placed in the lid of the column. Since the smaller particles become airborne easiest, these particles get stuck on the filters. This will change the particle size distribution in the bed slightly. This may affect the measurement results. The filters can also become clogged, which will raise the pressure inside the vessel and affect the measurements as well. To prevent this an extension of 50 cm has been mounted on top of the vessel. This decreased the amount of particles, which collected on the filters significantly.

To study the effect of pressure, polystyrene particles were used with a d_{50} diameter of 607 μm and a bulk density of 625 kg/m^3. These particles are type B particles according to the classification by Geldart [10]. The static bed height is approximately 55 cm.