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Brief Communication

X-ray measurements on the influence of optical probes on gas–solid fluidized beds

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Introduction

Absorption X-ray tomography is a powerful tool to gain insights in processes without optical accessibility. With the high speed X-ray tomographic apparatus located at Delft University of Technology, time-resolved images of a bubbling fluidized bed can be obtained (Mudde, 2011).

In this work, absorption X-ray tomography is applied to investigate the influence of a horizontally mounted two point optical probe on hydrodynamic properties of single bubbles, such as the bubble size, rise velocity and shape, as well as on the frequency of bubble splitting. Measurements are conducted with the X-ray apparatus above and below the optical probe position with and without the optical probe. The column is set to minimum fluidization conditions for single bubble injection.

Similar studies have been conducted in the past, to investigate the influence of intrusive optical probes on the measured solid-volume fraction and particle velocity (Cocco et al., 2009) as well as the influence of the of the probe size on the results from a fast Fourier or Wavelet transform (Ellis et al., 2004). However, most published results in open literature, aim at a comparison of the results between the different measurement techniques e.g. between optical probes and X-ray measurements (van Ommen and Mudde, 2008; Dubrawski et al., 2013). The objective of this work is to certify the usage of optical probes in complex environments such as industrial-scale catalytic bubbling fluidized bed reactors for permanent monitoring the hydrodynamic behavior and fluidization state.

Experimental

The hydraulic experiments are conducted in a lab-scale bubbling fluidized bed reactor located in the center of an ultra-fast X-ray apparatus (Mudde et al., 2008). The packed bed height of the bubbling fluidized bed reactor is 51 cm and it has an inner diameter of 14 cm. The complete reactor is made of acrylic glass, a description of the setup and measurement technique was already provided in Maurer et al. (2015).

The distributor plate of the reactor has a pore size of 20 μm and a thickness of 5 mm (THOMAPOR® Sinterplatte, 12150, Reichelt Chemietechnik GmbH). The Sauter mean diameter of the γ-alumina oxide particles (Puralox NWa155, Sasol Germany GmbH) was determined by a sieve analysis and laser diffraction

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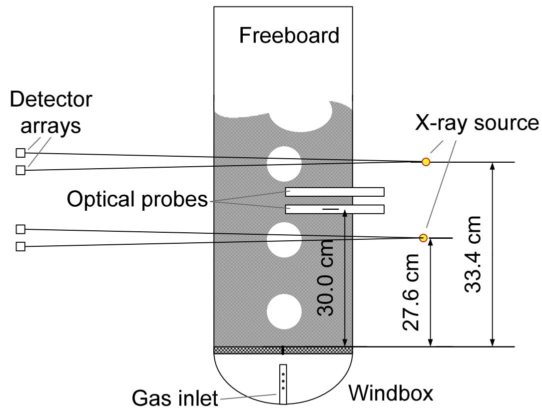

Fig. 1. Schema of the column with the corresponding measurement positions.

measurements to be 289 μm. The particles are in the intermediate range between Geldart A and B (Geldart (1972, 1973). A detailed particle characterization has been previously reported (Rüdisüli, 2012). Compressed air is used for the fluidization.

For all experiments the air flow rate was set to 0.03 m/s (minimum fluidization). Every 12 s, single helium bubbles were centrally injected via a nozzle with 4 mm inner diameter, which was pushed though the distributor plate. The injection pressure was between 1.4 and 0.9 barg at the beginning and end of the injection. The bed height change was roughly 10 mm, which corresponds to a spherical bubble with 6.6 cm diameter and 150 ml volume. In total between 49 and 52 bubbles were injected for each measurement. The bed was at ambient pressure and temperature during the experiments.

In Fig. 1 a sketch of the measurement setup is depicted, including the X-ray measurement heights and the employed optical probes. The employed optical probe consisted of two sensors, each of which had an outer diameter of 5 mm. The two sensor tips were horizontally mounted and 1 cm vertically apart. The sensor tips were located at the center of the reactor, 30 and 31 cm above the distributor plate.

The applied X-ray tomographic scanner consists of three point sources, tube 1, 2 and 3 and six detector arrays (two on top of each other), see Fig. 2(a). The detector arrays are 40 mm vertically apart, though this means the measurement planes through the column are (on average) 10.7 mm apart (8.4 mm when they enter the column, 13.1 mm at the other side). Each detector array is equipped with 32 detectors, measuring the attenuation of the X-rays with 2500 Hz. The spatial resolution of the measurement system is 4.4 mm. With the help of a seven point calibration, the attenuation is converted into a path-length of existing cavities (i.e. bubbles). Beam hardening effects are automatically taken into account by the seven point calibration (Alles and Mudde, 2007).

The simultaneous algebraic reconstruction technique (SART) is used for the 2D image reconstruction. This technique is well described in Mudde (2011). For the measurement shown in Fig. 2(b), two empty, thin walled acrylic glass tubes with 22 mm and 52 mm in diameter were inserted into the setup as dummy bubbles to evaluate the accuracy and the threshold between the dense and bubble phase. In Fig. 2(b), the intensity data is converted into pathlength of air for each detector by the seven point calibration. It can be seen, that the diameters in Fig. 2(b) are approximately equal to the diameters of the thin walled acrylic glass tubes. However, a diameter of about 20 mm is the minimum size which can be reliably reconstructed, even if the spatial resolution of the measurement setup is higher.

Results and discussion

Bubble hold-up

To investigate, whether the single bubble injection was working properly, the bubble hold-up (percentage of bubbles over time in the fluidized bed) with and without employed optical probe, for the lower and higher detector is plotted in a three-dimensional graph in Fig. 3. For this measurement the lower X-ray plane is about 2 cm above the higher optical probe tip. It should be noted that this hold-up depends on the frequency of bubble injection and should only be used for comparison between the measurements with and without optical probe conducted in this study.

As expected, the maximum in bubble hold-up is observed in the center, and rotationally symmetric. Even for the measurement with employed optical probe we do not see a significant cleft, which would be an indicator for bubble splitting due to the stationary aligned optical probe, or further indication for an increased bubble splitting frequency. Also the measured maximum bubble hold-up is about 0.9% in all cases, slightly higher at the lower detector, but independent whether or not an optical probe is used. The influence of a 5 mm optical probe is negligible for the bubble hold-up distribution of single bubbles.

Bubble size

Some reconstructed three-dimensional bubble images with and without employed optical probe are provided in the Supplementary information. Out of these qualitative results, a systematic analysis of the mean bubble size, the standard deviation as well as the standard deviation of the mean was conducted. For the

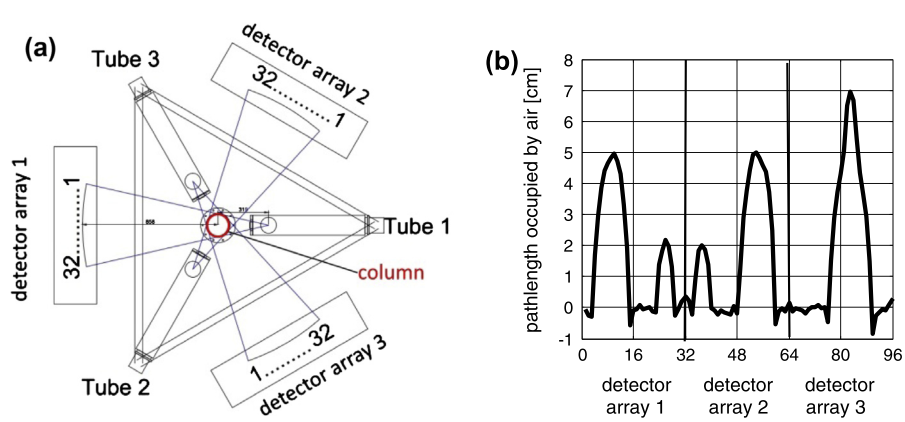

Fig. 2. (a) Top-view of the X-ray tomographic scanner; (b) Generic raw data converted into path length cavities.