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Holdup and velocity profiles of monosized spherical solids in a three-phase bubble column

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HIGHLIGHTS

- Acrylic beads with a nominal diameter of 3 mm were used as the solid phase.
- Phase Doppler Anemometry was used to quantify the flow characteristic.
- The detailed turbulent characteristics of bubbles and solid phase were revealed.
- The mean solid phase concentration was exponential decay with the height z.
- The axial dispersion sedimentation model was available.

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ABSTRACT

Non-invasive laser detective techniques, Phase Doppler Anemometry (PDA), were used to measure solids holdup and velocity profiles in a three-phase gas–liquid–solid bubble column. The cylindrical bubble column was driven by a point air source made of a 30-mm diameter perforated air stone centrally mounted at the bottom. It had an inner diameter of 152 mm and was filled with liquid up to 1 m above the point source. Monosized acrylic beads with a nominal diameter of 3 mm were used as the solid phase. With added salt, the liquid density was adjusted to 1.0485 kg/m^3 for matching the density of the solid phase which was 1.05 kg/m^3. The bubble diameters generated were within the range of 600–2400 μm. The turbulent characteristics of the bubbles and the solid phase were measured at five different air rates, namely 0.4, 0.6, 0.8, 1.0 and 1.2 L/min (corresponding to the superficial gas velocities of 0.375, 0.549, 0.752, 0.919 and 1.128 mm/s, respectively). The time averaged velocity measurements indicated t Prod. Type: FTPhat a large circulation flow pattern exist in the column. Driven by the bubbles, the solid motion was upward in the center region and downward near the walls in the bubble column. The solid holdup values decrease slightly along the radial position in the lower part of the bubble column, and it became uniform in the upper part. The mean solid phase concentration is exponential decay with the height *z*. The solids velocity and holdup distribution presented here can improve the understanding of the flow behavior in a three-phase bubble column.

1. Introduction

Gas–liquid–solid bubble columns are widely used in chemical industry, food technology, biochemical processing and water treatment (e.g. Ge et al., 2007; Yang et al., 2007). A variety of operations, such as crystallization, adsorption as well as oxygenation, can be conducted in a bubble column. Bubble column reactors have a number of advantages as a chemical reactor due to the simplicity of operation, absence of moving parts and low operating costs, and the solid particles can be easily added in or withdrawn from the column. From an engineering application point of view, the successful scale up, design and operation of the three-phase bubble column mainly depend on the accurate prediction of the behavior and features of all the three phases, such as phase volume fraction and their distributions, liquid flow patterns, and mixing of the bubbles and solid particles. At present, the understanding of the three-phase bubble column is far from complete due to the complex interactions among the three phases.

In the design of the three-phase bubble column, the solids holdup and velocity distribution in the flow field are important variables, which are strongly affected by the flow of bubbles. Bubbles buoy up at much higher velocities than the liquid velocity, and it is an important factor in the upward transport of both liquid and solid particles in the flow field. This has been observed by both flow visualization (Tsuchiya et al., 1992) and radioactive particle tracking (Larachi et al., 1997). They reported that the

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particles are transported at high velocities, by following the trajectories of bubbles. Jena et al. (2009) developed correlations for minimum liquid fluidization velocity with solid phase holdup and gas holdup in a gas–liquid–solid fluidized bed. They reported that the solid phase holdup is found to increase with the increase of both liquid and gas velocities, and the gas holdup increases with gas Froude number, but decreases with liquid Reynolds number. Razzak et al. (2010) studied axial distribution of phase holdups in a riser of a gas–liquid–solid circulating fluidized bed. They investigated the effects of gas and liquid superficial velocities as well as solids circulation rate on radial distribution of phase holdups at different axial locations. Gas holdup was higher at the central region of the riser and increased axially due to coalescence of small bubbles (the larger bubbles are inclined to the central region) and decrease of hydrostatic pressure at higher levels in the riser. They found that the solids circulation rate had a negligible effect on the liquid holdup at lower axial locations compared to the top of their riser. Mota et al. (2011) studied an air–water–solid bubble column by using spent grains as the solid phase, and they suggested that the non-uniform distribution of solid phase can increase the coalescence of bubbles.

But in published literature, there is still no sufficient information about phase holdups, solids velocities and circulation in the three-phase bubble column (Mena et al., 2011). The results from the computational fluid dynamics simulating can provide valuable insight in the complex field of three-phase fluidization systems, but the numerical models must first be fully verified with experimental and/or field data. The detailed turbulence characteristics of the entire flow field in a model three-phase bubble column are desirable. The non-invasive measurement techniques such as Laser Doppler Anemometry (LDA) and Phase Doppler Anemometry (PDA) have been proven to be effective for measurement of the detailed characteristics of liquid and bubbles (Brenn et al., 2002; Gan et al., 2011). PDA is an extension of LDA based upon phase Doppler principles. It is an optical technique that can determine the size and velocity of spherical particles simultaneously and does not influence the flow field of the bubble column. The measurements are targeted toward the distinct phase, thus allowing detailed analysis of particulate flows. The distribution of statistical size and velocity moments in a flow field can be quantified, as well as the particle concentration and local size-velocity correlation. Movement of the measurement point in the flow allows mapping of entire flow fields. However, there is no reported information for the PDA measurements of three-phase bubble columns so far in the literature due to experimental difficulties (a critical one is that the laser light will be blocked by the dispersed phases in bubbly flows of high gas fraction). By overcoming many of these difficulties, the experiments were conducted with the maximum air fraction restricted to be 2.58% in this study. The purpose of this study is to demonstrate the use of PDA for a gas–liquid–solid bubble column and to provide detailed information for the solids circulation velocities and holdup profiles. This information

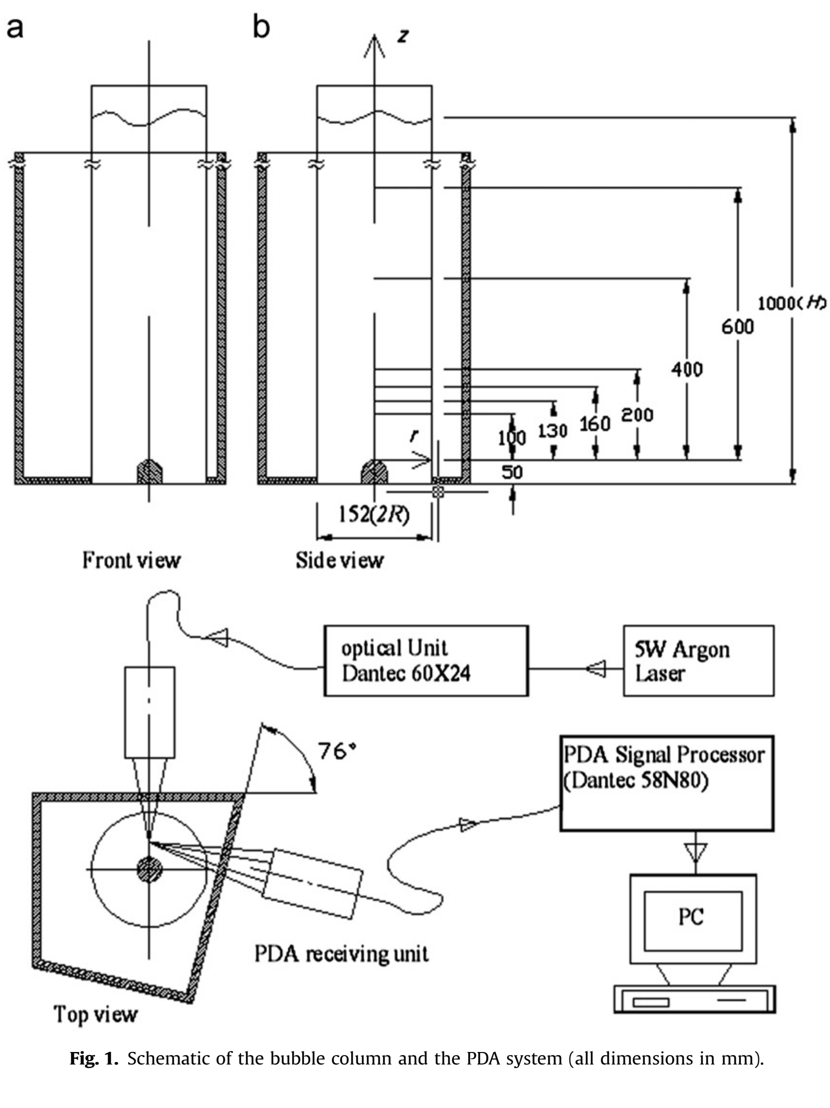

Fig. 1. Schematic of the bubble column and the PDA system (all dimensions in mm).