EXPERIMENTAL INVESTIGATIONS OF RISE BEHAVIOUR OF MONO-DISPERSED/ POLY-DISPERSED BUBBLY FLOW IN QUIESCENT LIQUIDS

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Summary

The experimental investigations of rise behavior of mono-dispersed/ poly-dispersed bubbles are important to improve closure model of drag force for large scale CFD models to simulate macroscopic dispersed gas-liquid flows. In this work, experimental investigations on mono-dispersed/ poly-dispersed bubbly flow with equivalent bubble diameters of 0.6, 2.85, 4.85, 7.5 mm are presented. The fluctuations in the bubble rise velocities of the individual bubbles were found to increase with increase in number of bubbles. Further, the drag coefficient for the swarm of bubbles was calculated as a function of bubble diameter, gas volume fraction, and liquid viscosity.

Keywords

Bubble, rise velocity, mono-dispersed, poly-dispersed, drag coefficient

Introduction

Many engineering applications involve gas-liquid flows e.g. in chemical processing, oil and gas, biochemical operations etc. From last two decades, several efforts have been made to develop CFD models based on continuum and discrete particle methods for detailed simulations of large-scale gas-liquid flows. In order to improve the predictive capabilities of CFD models to simulate dispersed gas-liquid flows, it is necessary to develop accurate closure models that can account for the effect of bubble shape/ size on different interfacial forces acting on a bubble (drag, lift and virtual mass) and more importantly the influence of neighboring bubbles (or gas hold-up) on the magnitude of the above-mentioned forces. Many researchers investigated, both experimentally and numerically, the rise behavior of single bubble under quiescent liquid condition and developed correlations to estimate the drag force acting on a bubble which can account for size/shape of the bubbles and volume fraction. As compared to the investigations of rise behavior of single bubbles the rise behavior of mono-dispersed bubbles/ poly-dispersed bubbles in quiescent liquids is not well understood.

In most of the experimental investigations on mono-dispersed bubbly flow (Zénith et al. [1], Mercado et al. [2], Lain et al. [3]), the rise behavior of a mono-dispersed bubbles (d_B =1.5 - 2.5 mm) for small gas volume fraction ($\alpha_G \leq 0.1$) using different experimental techniques was studied to quantify liquid velocity fluctuations created by the bubbles and to measure the velocity of the bubbles. In all the previous literature on the multiple bubbles, small size bubbles ($d_B < 3$ mm) were considered. But in practical situations, there exists a wide bubble size distribution where bubble-bubble interactions and wakes behind individual bubbles influence the bubble rise behavior. It is therefore necessary to investigate the rise behavior of multiple bubbles with a wide bubble size distribution to develop the closure models that can account for the influence of bubble-bubble interactions on the magnitude drag forces. In the present work, experimental investigations of mono-dispersed/ poly-dispersed swarms of bubbles ($1 \leq d_B \leq 8$ mm) rising in quiescent liquids are presented.

Results and discussion

The experimental investigations on mono-dispersed/ poly-dispersed bubbly flow were carried out by injecting air bubbles through stainless steel needles in a glass column (height, H = 600 mm; width, W = 150 mm; depth, D = 150 mm) filled with water (de-mineralized). A high-speed digital camera (Fastec imaging, USA) capable of capturing 1000 fps was used to record the bubble trajectory. The average equivalent bubble diameter considered in the experiments were d_B = 0.635 (±0.005), 2.9 (±0.1), 4.85 (±0.1) and 7.5 (±0.1) mm. The average equivalent bubble diameter was calculated by taking an average of 20 oblate bubble diameters just after the detachment from the needles. The rise velocity of single isolated bubble of different sizes ($0.635 \leq d_B \leq 7.5$ mm) was well compared with the Clift et al. [4] to benchmark the measurements. The effect of the presence of neighboring bubbles on rise velocity of the bubbles was studied by injecting three, five and nine homogeneous streams of bubbles. A snapshot of rise of single isolated bubble, single stream of bubbles and nine streams of mono-dispersed bubbles (d_B= 4.85±0.1 mm) is shown in Figure 1. The homogeneous dispersions of four different bubble sizes d_B = 0.635, 2.9, 4.85 and 7.5 mm were considered for the experimental investigations. Figure 2 compares the probability density functions (PDFs) of rise velocities of single isolated bubble and of nine individual

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bubbles streams of same diameter (d_B = 4.85±0.5 mm). For a single isolated bubble, the velocity distribution was found to be narrow indicating that the fluctuation in the rise velocity was less. But as the number of bubble increases (N = 9), the velocity distribution of the individual bubbles becomes wider and the maximum in PDFs was found to be shifting towards higher velocities which clearly indicates increases in the interaction between the bubbles and as a consequence the fluctuation in the rise velocities were found to be increased. The effect of d_B on the PDFs of the rise velocities for individual bubbles in a mono-dispersed system was investigated and the results will be discussed in the full length manuscript.

The effect of number of bubble streams (N) on number-average drag coefficient (C_D) of the bubbles swarm was also studied. The C_D was calculated from the simplified form of the equation of bubble motion.

$$C_D(t)=\frac{4}{3}\left(\frac{\rho_L-\rho_G}{\rho_L}\right)gd_B\frac{1}{v_B(t)^2}$$

The effect of number of bubble streams (N = 1, 3, 5, 9) on C_D (based on number averaged bubble velocity) in homogeneous bubbles dispersion for d_B = 4.85±0.5 mm is shown in Figure 3. As the number of bubble increases, the drag coefficient C_D (based on number averaged bubble velocity) of the bubble swarm was found to be much smaller as compare to the C_{D0} of single isolated bubble. The effect of bubble diameter (d_B) and gas volume fraction (α_G) on C_D was also studied and the results will be presented in the full length manuscript.

The detailed investigations of the effect of bubble diameter, gas volume fraction and liquid viscosity on bubble velocity and number- and time- averaged C_D for both mono-dispersed and poly-dispersed systems will be presented in the full length manuscript. Such an information will facilitate the development of closures that can account for bubble size distribution, bubble–bubble interactions on the magnitude of drag force.

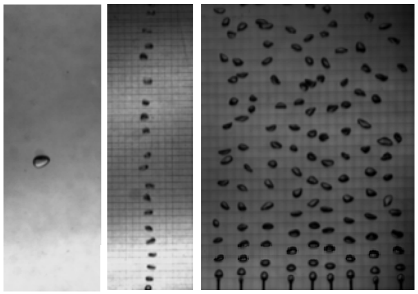

Figure 1. A snapshot of rise of single isolated bubble, single stream of bubbles and nine stream of bubbles (d_B = 4.85±0.5 mm).

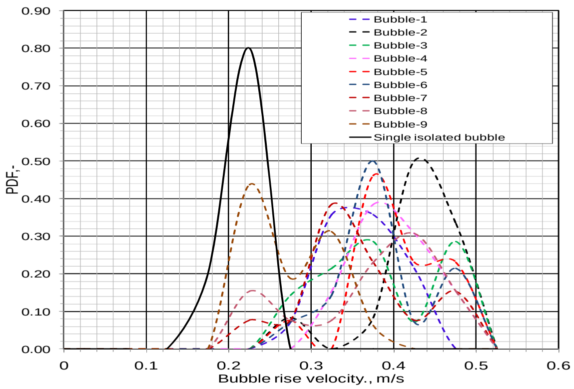

Figure 2. Comparison of PDFs of bubble velocity of a single isolated bubble (d_B = 4.85±0.5 mm) with that of nine streams bubbles of same d_B.

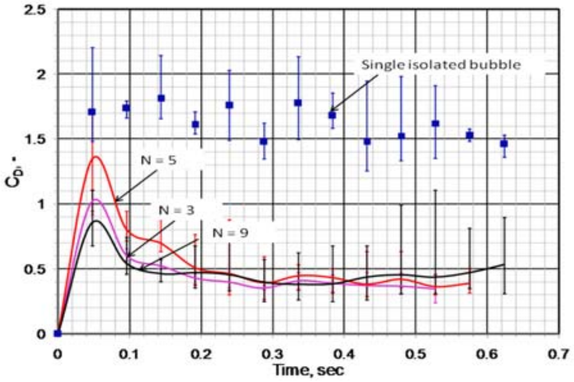

Figure 3. $C_D(t)$ of single isolated bubble and nine streams of bubbles (d_B = 4.85 ±0.5 mm)

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