# EXPERIMENTAL AND NUMERICAL INVESTIGATIONS OF MICRO-SCOPIC GAS-LIQUID FLOWS

by


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# Certificate

This is to certify that the thesis entitled '**EXPERIMENTAL AND NUMERICAL INVESTIGATIONS OF MICRO-SCOPIC GAS-LIQUID FLOWS**' being submitted by **Ms. Swapna Singha Rabha** to the Indian Institute of Technology, Delhi for award of Doctor of Philosophy is a record of bonafide research work carried out by her under my guidance and supervision in conformity with the rules and regulations of Indian Institute of Technology, Delhi.

The research report and results presented in this thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

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# Abstract

Many engineering applications involve gas–liquid flows. In past, continuum and discrete particle models were developed to simulate large-scale dispersed gas-liquid flows. The predictive capabilities of these model are jeopardized by the lack of adequate closure models that can account for the effects of bubble shape/ size on different 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 aforementioned forces. The research presented in this thesis was carried out with the objective of improving the understanding of effects of bubble size/shape and neighboring bubbles on the drag and lift forces.

Experimental investigations of rise behavior of mono-dispersed and poly-dispersed bubbles in the quiescent and sheared liquids were performed to investigate the effects of bubble diameters ($1.2 \leq d_B \leq 11.2$ mm), gas volume fractions ($0.01 < \alpha_G < 0.2$) and liquid viscosity on the bubble rise velocity and the drag and the lift coefficients. The drag and lift forces acting on a single isolated bubble, bubbles in a single chain and bubbles in multiple chains were investigated. The bubble size and the liquid properties considered in the present work correspond to the spherical, ellipsoidal and wobbling bubble regimes.

Numerical simulations of rise behavior of single and multiple bubbles were performed using the Volume of Fluid (VOF) method. The numerical simulations of rise of single isolated bubbles, bubbles rising in a single chain

and mono-dispersed (homogeneous) bubbles in quiescent liquids were preformed and predictions were validated using the measured bubble rise velocities. The effects of bubble diameter ($3.3 \leq d_B \leq 5.5$ mm) and gas volume fractions ($0.054 \leq \alpha_G \leq 0.16$) on the rise behaviour of homogeneous bubble swarms rising air-water and air-glycerol systems was investigated. Finally, the numerical investigations of the lift force acting on a single isolated bubble and multiple bubbles in a linear shear flow of liquids with different properties were performed. In particular, the effects of bubble diameter ($2.84 \leq d_B \leq 8$ mm), gas volume fraction ($0.03 \leq \alpha_G \leq 0.14$) and liquid viscosity ($\mu_L$ = 0.001 and 0.019 kg $m^{-1}s^{-1}$) on the rise behavior of mono-dispersed (homogeneous) and poly-dispersed (heterogeneous) bubbles in the ellipsoidal and wobbling shape regimes ($1.1 \leq Eo \leq 11.65$; $- 5.4 \leq \log Mo \leq -10.5$) were investigated.

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