Mechanistic studies on bubble and droplet dynamics in turbulent flows

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Highlights

- Breakup of bubbles and droplets due to vortex interaction revealed.
- Time scale difference in deformation and breakup of drop and bubble in agreement with experiments.
- Elucidating the effects of viscosity and density ratios on the breakup.
- Unique insights into internal flow through the bubble neck during deformation and breakup.

1. Introduction

This work investigates the basic mechanisms responsible for gas bubble and droplet breakup under turbulent flow conditions, by means of novel transient high-resolution CFD simulations and includes validation by measurements. Although important progress has been made over the last 70 years, lack of appropriate experimental methods and insufficient simulation capability, has held back research resulting in slow progress in the understanding of bubble and drop breakup in turbulent flows. Recent advancements show that the stochastic behavior can be simulated by use of three dimensional and transient analysis in respect to the fluid particle deformation rate, breakup time, fragmentation pattern [1]. This is a crucial and significant step which potentially allows in-depth analysis of the interplay between turbulent vortices and the fluid particles. Thereby allowing detailed insights into the complex phenomena and ultimately reliable breakup rate models to be established.

In this work the methodology is developed to allow wider range of fluid properties to be explored and the interfacial dynamics to be quantified, including pressure distributions, vortices and internal flow field for which theoretical models have been proposed in the literature [2].

2. Methods

High resolved simulations using a multiphase volume of fluid method coupled with large eddy simulations of the turbulent flow were developed and validated with experimental results obtained for identical geometry and hydrodynamic conditions. The experimental setup included a flow reactor and high-speed imaging system for analyzing the bubble and droplet behavior in turbulent conditions. Simulations were performed using a dynamic adaptive meshing strategy combined with an interface reconstruction scheme. Bubbles and droplets were patched randomly within the domain and data was analyzed after simulations were run for a period more than the characteristic timescale of the largest vortices. Using a high-performance computing system feasible computation time was obtained. Each simulation required 2-3 weeks, and in total 2 million core hours were spent. Both breakup and non-breakup cases were sampled and postprocessing of the flow field provided the details of the interactions between the bubbles, droplets and vortices.

3. Results and discussion

Deformation and multiple fragmentations of bubbles and droplets were observed with high resolved simulations and validated with the experimental findings. The bubble and droplet deformation and breakup occurred at different timescales and the statistics of breakup event were significantly different. To the best of our knowledge this is the first time air bubbles have been successfully modeled using high resolved simulations under turbulent conditions and validated with experimental data. Both gas bubbles and liquid droplets showed continuous deformation, but with different times scales. The dodecane-water system, illustrated in Figure 1a, required on an average a significantly longer time for breakup and resulted in more daughter fragments than the air-water system. In the air-water system, an internal flow was observed before the breakup occurred. This resulted in un-equal sized daughter fragments which agreed with experimental U-shaped daughter size distributions. Notably, the size of the smallest fragments were only a few microns in size (marked with arrows in Figure 1), which makes it likely to be undetectable during experimental measurements. Thereby quantification of the number of daughter fragments in simulations could potentially be more accurate than experimental measurements that are constrained by the resolution of the imaging system and the contrast between the two phases. Additionally, the results from simulations of a viscous system, octanol-water, showed that longer threads are formed during deformation which explains the large number of daughter fragments formed, up to 50. Similar observations were made in the experiments with the octanol-water system under the same hydrodynamic conditions.

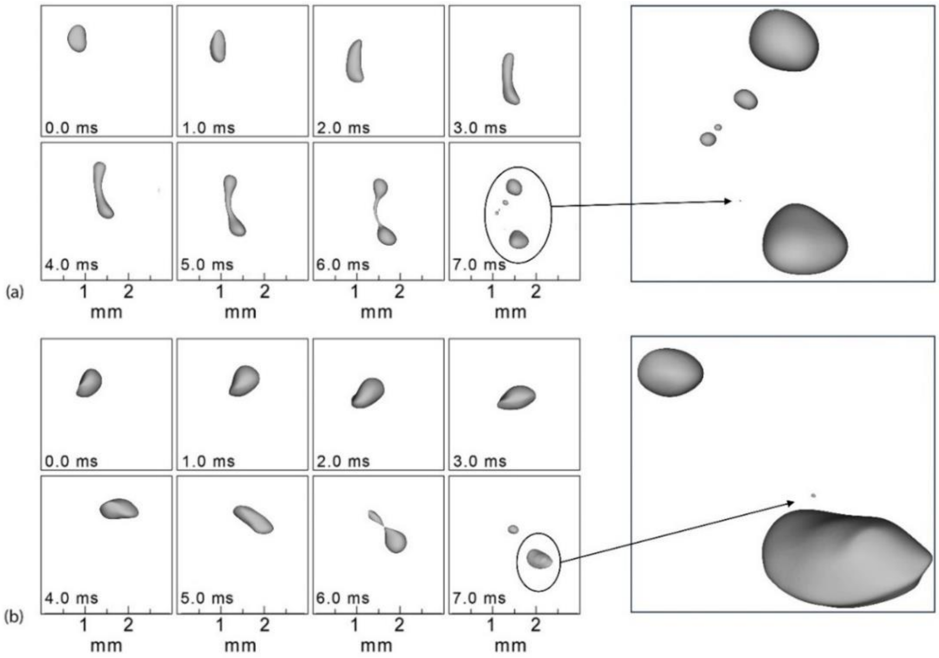

Figure 1. Simulated breakup dynamics of (a) dodecane droplet and, (b) air bubble in water.

Postprocessing and analysis by means of pressure distributions, interfacial momentum transport and vortex identification explained how and why large differences occurred due to the differences in viscosity ratio and inertia. These results are expected to help formulating reliable models for CFD analysis of multiphase flow reactors, so called subgrid kernels.

4. Conclusions

Mechanistic insights into bubble and droplet breakup were successfully achieved by model development and using high resolved simulations. The simulation results agreed well with experimental measurements and showed how breakup depends on the viscosity ratio and inertia of the multiphase system. High resolved simulations provided excellent time and space resolution and could reach beyond the best possible resolution of the experimental setups reported in the literature. Consequently, the developed modeling strategy is expected to have a significant impact on the development of breakup rate models in the future. This is likely to provide the tools needed to improve research in the field, and continuous advancements of computer cluster accelerates this progress further.

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References

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Keywords
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