Trajectory-Based Breakup Modelling for Dense Bubbly Flows

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Highlights

- A novel model to predict bubble breakup is formulated and implemented
- The history of each bubble is accounted for individually
- The results are validated with experimental data

1. Introduction

Bubbly flows are important in many applications. In oxidation reactions for example, oxygen has to be dissolved in the reactive liquid phase. To predict the mass transfer from a gaseous phase into a liquid phase, knowledge about the sizes of the dispersed bubbles is indispensable. The sizes of bubbles are influenced by two mechanisms: bubble breakup and bubble coalescence. In this work, the focus lays on the development of a model to predict the breakup of gaseous bubbles taking into account the deformations they experience along their respective trajectory individually, compare Figure 1. The developed model is tested in stirred tank reactors (STR) of sizes ranging from the small lab scale with a working volume of 3 L to the large industrial scale with a total volume of 15 m³. In this work, the results for a mid-sized STR with a volume of 200 L are presented.

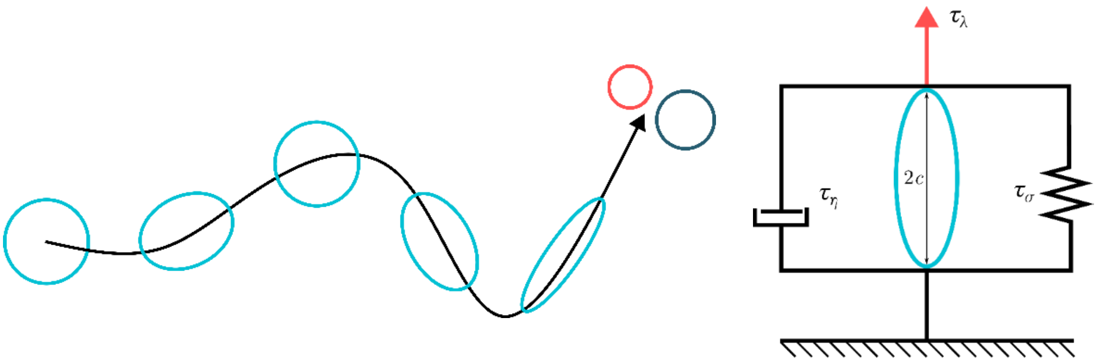

Figure 1. Deformation of a bubble along its trajectory, eventually leading to breakup (left) and Kelvin-Voigt element (right)

In the course of the Collaborative Research Centre (CRC) 1615 "SMART Reactors" of the German Research Foundation (DFG), new reactor types are invented to face climate change and to react on differing educt qualities, caused by the shift from fossil to renewable raw material. This work is part of the subproject B06 "Systematic multiscale modelling and design approach for SMART reactors" of the CRC which focusses on the identification and modelling of compartments inside of various reactors. For the correct numerical estimation of compartments, the knowledge of the flow regime is essential, and thus is the correct prediction of bubble sizes, as Rosseburg et al. have shown [1].

2. Methods

Each bubble is assumed to be a prolate rotational ellipsoid with the three semi axes $a = b \leq c$ and is modelled as a Kelvin-Voigt element, compare Figure 1, which was proposed by Lagisetty et al. [2]. Taking the resulting stresses of a spring, a damper, and the surrounding flow yields the basic equation of the proposed model, namely the Trajectory-Based Breakup Model (TBBM)

$$\tau_\sigma + \tau_\eta = \tau_\lambda.$$

Hereby, the spring mirrors the stabilising effect induced by the interfacial tension and the damper mirrors the effect induced by the bubble's viscosity. In this work, the outer acting tension is based on the largest stretch which is achievable by calculating the largest eigenvalue of the local rate-of-strain tensor. Since the rate-of-strain tensor is unconditionally indefinite, the largest eigenvalue of the Cauchy-Green-Strain-Tensor is calculated [3] due to its beneficial properties as symmetric, positive definite matrix. All deformations take place under the assumption of volume conservation.

3. Results and discussion

The TBBM is implemented in M-Star CFD and simulations are carried out for an STR with a volume of 200 L. The liquid phase is DI water with a phosphate buffered solution. The gaseous phase is air. For validation, the resulting bubble size distribution is compared with both, experimental data and simulative data obtained by utilising the breakup model by Kawase and Moo-Young [4], which is the default model in M-Star CFD for bubble breakup. The results are shown in Figure 2, indicating, at least for the shown process conditions, a very good match between the experimental data and the bubble sizes calculated with the TBBM.

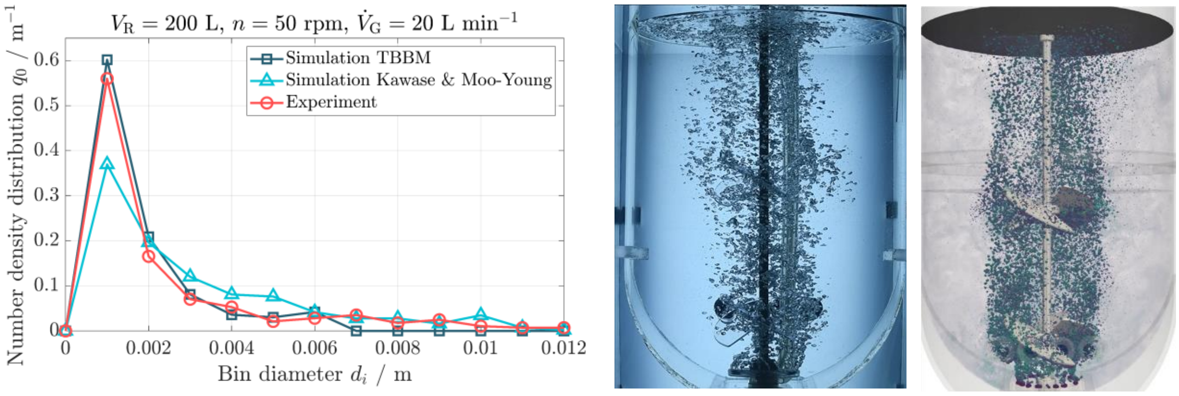

Figure 2. Bubble size distributions (left), experimental image (middle), and simulative image (right) [5]

4. Conclusions

The TBBM, a new model to predict the bubble breakup was developed, implemented in M-Star CFD and tested for a wide range of STRs. The shown results indicate a rather good match between model and experimental data. Due to some modelling assumptions, the number of small bubbles may be overpredicted. This and other aspects will be accounted for in the future work, focussing on improving and expanding the TBBM further.

4. Acknowledgements

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References

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