Simulation of polydisperse bubbly flows: An investigation on physical and numerical aspects

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Submitted to the Department of Applied Science and Technology (DISAT) in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Chemical Engineering

Abstract

This thesis aims at the Eulerian-Eulerian computational fluid dynamics (CFD) simulation of gas-liquid bubbly flows coupled with the Population Balance Modelling (PBM) with the main focus on investigating some physical and numerical aspects.

The Eulerian-Eulerian framework is currently the most viable approach for the CFD simulation of large-scale disperse gas-liquid flows. Differently from more complex methods, the Eulerian-Eulerian approach does not resolve explicitly the interfaces between the bubbles and the liquid phase. Instead, the physical phenomena occurring at the interface, i.e. mass, momentum and heat exchanges between the phases, are taken into account by means of some closure relations. Restricting the discussion to hydrodynamic simulations, the closure relations to describe the momentum exchange between the phases are interfacial forces, e.g. drag, turbulent dispersion, lift and wall lubrication. The predictions of Eulerian-Eulerian CFD simulations of bubbly flows depend strongly upon the choice of formulations employed for modelling these forces, among which the lift and wall lubrication forces have been the subject of ongoing investigations to overcome the lack of accurate modelling or clear physical explanation. This thesis makes use of a set of experimental data provided by the Helmholtz-Zentrum Dresden-Rossendorf to assess the performance of some available closure relations. The experimental data belongs to the measurements conducted in TOPFLOW facility for a large-scale developing turbulent bubbly flow. Two sets of models are selected, differing in the relations for the lift and wall lubrication forces. Additionally, the lift coefficient of each set is replaced with a constant value optimized to achieve the best agreement with the experiments. The results verify the need for employing negative lift coefficients in the case of large bubbles (> 5 mm). In addition, it is shown that the geometric approach to consider the wall effect results in a slightly better agreement than a standard relation, which assumes the asymmetric drainage around bubbles near the

wall. Eventually, optimizing the lift coefficient highlights the importance of investigating spatially developing flows to draw general conclusions on the applicability of closure relations.

The second part of the thesis deals with coupling the PBM and CFD in order to predict the evolution of the bubble size distribution. In this regard, a literature review is presented on the methods for the solution of the PBE with a particular attention to quadrature-based moment methods, since they are perfectly compatible with the Eulerian framework. Among these methods, the quadrature method of moments is chosen as the solution method for the CFD-PBM simulation of the TOPFLOW facility. The main challenge observed in conducting the simulations is the realizability issue, arising when high-order discretization schemes are used. Therefore, a new finite-volume scheme based on 2$^{\text{nd}}$-order total variation diminishing (TVD) schemes is proposed for the solution of moment transport equations by quadrature-based moment methods. The proposed scheme is capable of preserving important properties of the transported moments, such as realizability and boundedness. The idea behind the scheme is to limit the flux of all the moments at each face of the computational cell with the same limiter value, hence being called the equal-limiter scheme. It is compared with other realizable schemes developed for the moment transport equations in several one- and two-dimensional examples. The corresponding results show the advantages of the equal-limiter scheme in improving the accuracy of the numerical prediction, avoiding under- and over-shoots in the solution and keeping the moments realizable at the same time. Eventually, the equal-limiter scheme is employed to conduct the CFD-PBM simulations of the TOPFLOW facility with two different choices for the equal limiter. The first choice is more conservative, by which the minimum of the flux limiters of all the transported moments is selected. In this case, the TVD criteria for all the transported moments are respected, however, the scheme can reduce to the 1$^{\text{st}}$-order upwind scheme when the smoothness of the profiles of the moments are considerably different. The second choice for the equal limiter is the average of the flux limiters of all the transported moments, which improves the order of accuracy of the solution at the expense of not fulfilling the TVD criteria for some of the transported moments. Nevertheless, the simulation results show negligible under- and over-shoots due to this violation of TVD criteria. Finally, satisfactory predictions are obtained for the radial and axial profiles of the Sauter mean diameter in the TOPFLOW facility by conducting the CFD-PBM simulations, in which the equal-limiter scheme with the choice of the average limiter is employed. In addition, the reasons behind the observed discrepancies between the predictions and experimental measurements are discussed. The thesis concludes by summarizing the results and suggesting some future works.