On the Role of Interfacial Forces for the CFD-PBM Simulation of Boiling Flow

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Highlights

- Interfacial forces play a crucial role in determining the gas phase dynamics.
- Turbulent dispersion is necessary to predict correctly the spreading of the gas phase.
- Wall force is essential to reproduce radial profiles of gas volume fraction.
- Lift coefficient can be optimized to improve agreement with experiments.

1. Introduction

The development of reliable Computational Fluid Dynamics Population Balance Models (CFD-PBM) to simulate boiling flows is extremely beneficial due to the importance of such flows in numerous industrial processes. Indispensable elements of virtually all boiling flow models are the closures employed to describe phase coupling, especially when resorting to the Euler-Euler framework in the context of industrial-scale simulations. This technique treats the two phases (the continuous liquid phase and the polydisperse gas phase) as interpenetrating continua, in which the interface is not tracked. Instead, the interaction between the phases is taken into account by phase coupling via interfacial forces, namely drag, lift, turbulent dispersion and wall lubrication, each expressed by a closure model in the momentum balance equations. However, the closure models are developed based on theoretical and/or experimental analysis where generally only one bubble is studied under a set of controlled conditions. This fact necessitates the identification of the role played by each individual interfacial force and the assessment of the accuracy of the available closure models. In this regard, just to cite an example, one of the controversial topics is the lift force mostly due to its different behavior with respect to bubble size and shape [1]. This study aims at investigating the effect of interfacial forces for boiling flow in the bubbly flow regime, with special attention to the lift force.

2. Methods

The experimental setup to be simulated is the TOPFLOW facility at HZDR center, Figure 1(c), in which upward air/water experiments were performed for a set of different gas and liquid superficial velocities. The Euler-Euler two-fluid model solver of OpenFOAM software v4.1 was used to simulate the setup discretized with O-grid type mesh. The first part of the simulations focused on analyzing the effect of different interfacial forces on the radial profile of air volume fraction and air velocity at different axial locations. The models used for drag, turbulent dispersion and wall lubrication forces were those proposed by Tomiyama et al. [2], Burns et al. [3] and Hosokawa et al. [4], respectively. In addition, the lift force was estimated using constant coefficient in the expression for the shear-induced lift force model. A preliminary study revealed that employing the mentioned models yielded physically acceptable behavior in the results for all the available test cases. At next stage, the effect of lift coefficient on the results was examined by varying its value in the range recommended by Tomiyama et al. [1].

3. Results and discussion

As mentioned previously, different interfacial forces were employed in the simulations to study their effect on the predicted results by using monodisperse approach wherein bubble sizes were fixed a-priori based on the experimental value. Radial profiles of the air volume fraction for a particular experimental condition are shown in Figure 1(a), each obtained by inclusion of different interfacial forces. In case of employing only the drag force, the bubbles remained attached to the wall since they were injected at the wall and there was no

force to move them radially. Surprisingly, addition of the lift force changed the profile only slightly. It might be related to either the unsatisfactory water velocity profile due to the accumulation of the bubbles at the wall or the value of the lift coefficient. Inclusion of the turbulent dispersion force improved the results considerably in such a way that the gas phase was distributed towards the center of the column. Nevertheless, both of these radial forces failed to reproduce the air volume fraction peak observed experimentally close to the wall that is a distinctive feature of such flows. However, the peak appeared in the predicted results only by adding the wall lubrication force, thus showing the importance of wall effects for this type of flow. The lift coefficient was then varied according to the recommendations of Tomiyama et al. [1] to examine its effect on the predicted results. The rationale behind finding an optimal value for this parameter was our observation that small changes in the lift coefficient could considerably change the predicted results obtained from the monodisperse approach. For the experimental condition of Figure 1(b), a satisfactory prediction was achieved by setting the lift coefficient to 0.16. It is notable that this value is much smaller than the one calculated by Tomiyama correlation [1] using the corresponding average bubble size of 4.25mm. Despite the promising results achieved by monodisperse approach, further studies will be conducted by activating PBM and by considering bubble polydispersity in order to improve model predictions for experimental conditions in which monodisperse approach does not perform accurately.

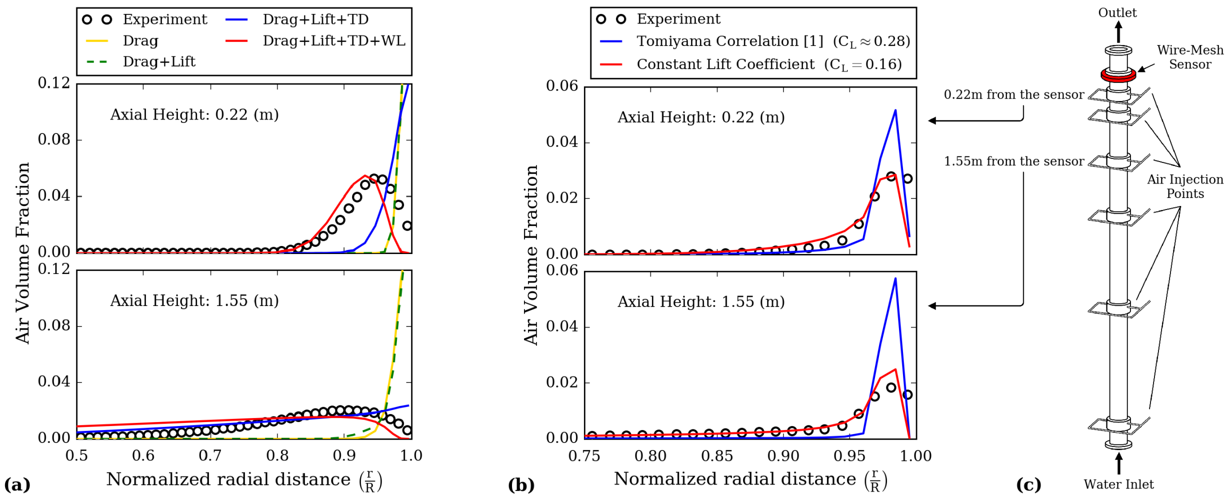

Figure 1. (a) Effect of interfacial forces on radial profile of air volume fraction for condition: U_L= 0.405 (m/s) and U_G= 0.0062 (m/s); (b) Effect of lift coefficient on radial profile of air volume fraction for condition: U_L=1.017 (m/s) and U_G=0.0025 (m/s); (c) Sketch of the experimental setup consisting of a pipe with nominal diameter of 20cm equipped with lateral gas injectors

4. Conclusions

An experimental setup with similar hydrodynamic behavior of boiling flows in bubbly regime was simulated using the Euler-Euler two-fluid model coupled with a PBM. Analysis of the effect of different interfacial forces showed that inclusion of drag, lift, turbulent dispersion and wall forces in the simulations is essential. Moreover, the potential of optimizing the lift coefficient to achieve acceptable results was verified, particularly when the monodisperse assumption is employed. Comparison of the lift coefficients yielding satisfactory results with those calculated by Tomiyama correlation [1] reflects the limits of this correlation for monodisperse simulations of this system. Future simulations will focus on the effect of interfacial forces considering different bubble sizes by adopting polydisperse approach via PBM.

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Keywords
Boiling flow; Two-fluid model; Interfacial forces.