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Eulerian–Lagrangian 3-D simulations of unsteady two-phase gas–liquid flow in a rectangular column by considering bubble interactions

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ABSTRACT

This work discusses the development of a three-dimensional Eulerian–Lagrangian CFD model for a gas–liquid flow in a rectangular column. The model resolves the time-dependent, three-dimensional motion of small gas bubbles in a liquid to simulate the dynamic characteristics of the oscillating bubble plume. Our model incorporates drag, gravity, buoyancy, lift, pressure gradient and virtual mass forces acting on a bubble rising in a liquid, and accounts for two-way momentum coupling between the phases. We use MUSIG model that provides a framework in which the population balance method together with the break up and coalescence models can be incorporated into three-dimensional CFD calculations. We use turbulent flow to describe liquid flow field. The standard κ–ε of turbulence is selected for calculating the properties of turbulent flow. The effect of aspect ratio of the column on the flow pattern, liquid velocity and gas hold-up profiles is discussed.

1. Introduction

Gas–liquid flows are encountered in a variety of applications. Dispersed gas–liquid flow in bubble columns is substantially unsteady and it can be simulated using Eulerian–Eulerian and Eulerian–Lagrangian approaches. In the Eulerian–Eulerian approach, each phase is considered as a continuum, which can interpenetrate with the other fluid phases. Several averaging methods (such as volume, time or ensemble averaging) are used to formulate governing equations. If the flow is turbulent, appropriate turbulence models (generally the two-equation models) are used. In the Eulerian–Lagrangian viewpoint, the continuous phase is treated in an Eulerian framework (using averaged equations) whereas the motion of individual or groups of bubbles is simulated by solving the force balance on each bubble. The courses of several bubbles or groups are computed in the control volume and averaged at the computational level. In the Eulerian–Eulerian viewpoint, the course construction and subsequent averaging are not carried out explicitly during the computations. Since these operations are implicitly carried out at the conceptual level while deriving the equations, this viewpoint requires less computational effort than the Eulerian–Lagrangian viewpoint. However, the discrete character of the underlying process is lost in the Eulerian–Eulerian viewpoint. The Eulerian–Lagrangian viewpoint offers the following benefits at the cost of increased computational efforts:

1. The bubble size distribution can be accounted in a simple manner, which allows a more accurate explanation of forces.
2. Bubble–bubble interactions (bubble coalescence and break up) can be accounted for in a realistic way.

In previous studies, unsteady gas–liquid flow in bubble columns were simulated using the Eulerian–Eulerian viewpoint [1–3,5,11,14,15,21,23]. Several attempts have also been made to simulate dispersed gas–liquid flow using the Eulerian–Lagrangian viewpoint [7–9,13,16,17]. The models based on the Eulerian–Lagrangian viewpoint could predict well the time-averaged properties such as gas and liquid velocity. In the present work, therefore, we studied the dynamics of gas–liquid flows using Eulerian–Lagrangian simulations in a rectangular bubble column with considering bubble–bubble interactions to study the effect of aspect ratio of the column on the flow pattern.

1.1. Previous works

Lapin and Lubbert [18] simulated unsteady gas–liquid flow in a rectangular bubble column. They simulated the motion of bubble groups by assuming that the groups have a fixed slip velocity. The momentum exchange between the gas and liquid phases was not considered and the coupling between the phases was achieved through the effective density of the mixture.

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