Numerical Simulations of Bubbly Flows in Industrial Applications

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1. Introduction

Dispersed gas-liquid two-phase flows are encountered in a variety of industrial processes such as the large-scale production of synthetic fuels and base chemicals employing bubble column reactors. Despite their widespread industrial application the detailed understanding of the fluid mechanics prevailing in bubble column reactors is unfortunately lacking (Tomiyama, 1998), which can be related to the inherent complexity of the underlying physical phenomena in (dense) bubbly flows such as bubble-liquid interaction (including turbulence) and bubble-bubble interaction (including coalescence and break-up).

Flows encountered in bubble columns are inherently unsteady (Sokolichin and Eigenberger, 1994) and display a wide range of time and length scales and as a direct consequence therefore we adopted a multi-level modelling approach consisting of several levels (see Fig. 1) each with its own particular strong point. At the lowest level (*i.e.* the smallest time and length scale) we use the Front Tracking (FT) approach originally developed by Tryggvason and co-workers (Unverdi and Tryggvason, 1992) to study the behaviour of a single bubble or a few (interacting) bubbles. The idea is that simulations

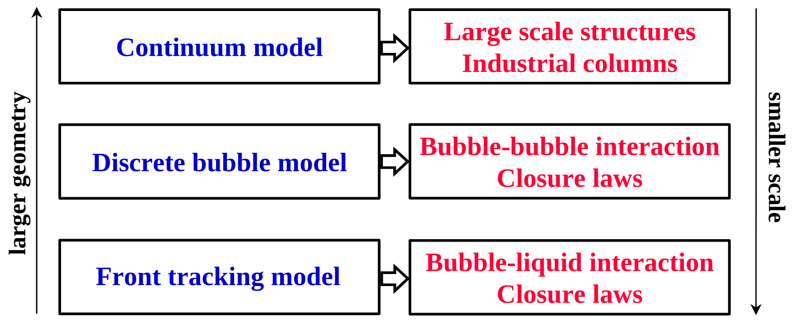

Figure 1. Multi-level approach for modelling of dispersed gas-liquid two-phase flow. For each level of modelling the typical application area is indicated.

using the FT approach should generate insight in the behaviour of a single rising gas bubble or the behaviour of a few rising gas bubbles and provide closures for bubble-liquid interaction. At the intermediate level (*i.e.* the intermediate time and length scale) we use the Euler-Lagrange (EL) or discrete bubble approach, which is particularly suited to account for bubble-bubble and/or bubble-wall encounters. Because, contrary to the FT approach, the flow field at the scale of an individual bubble is not resolved, closure laws for bubble-liquid interaction (drag, lift and added mass) have to be provided. At the highest level (*i.e.* the biggest time and length scale) we use the Euler-Euler (EE) or continuum approach, which is particularly suited to model bubbly flows in industrial scale bubble columns. Similar to the EL approach closures for bubble-liquid and bubble-bubble interaction have to be provided.

Subsequently the three levels of modelling will be discussed in more detail together with some illustrative computational results, which have been obtained from the respective models.

2. Front Tracking model

To model complex multiphase free surface flows a Front Tracking method based on direct numerical simulation has been introduced by Unverdi and Tryggvason (1992). Contrary to other numerical models developed to simulate multiphase flows, like the Level Set or Marker and Cell methods (Welch *et al.*, 1965) and Volume of Fluid methods (Nichols and Hirt, 1971; Youngs, 1982, 1987), the Front Tracking method uses an unstructured dynamic mesh to represent the interface surface and tracks this interface explicitly by the interconnected marker points. The Lagrangian representation of the interface avoids the necessity to reconstruct the interface from the local distribution of the fractions of the phases and, moreover, allows a direct calculation of the surface tension forces without the inaccurate numerical computation of the interface curvature, as is required in the Continuum Surface Force-method (CSF) introduced by Brackbill *et al.* (1992).

For incompressible bubbly flows the Navier-Stokes equations describing the fluid motion inside and outside the bubbles can be combined into a single vector equation for the fluid velocity $\bar{u}$ in the entire domain when accounting for the local volumetric surface tension forces $\bar{F}_\sigma$, since the transport equation for the colour function F, indicating the local instantaneous liquid fraction, can be reduced to a passive scalar equation. Thus, the governing conservation equations for unsteady, incompressible, immiscible, Newtonian, two-fluid flow systems are given by:

$$\left(\nabla \cdot \bar{u}\right) = 0 \tag{2.1}$$

$$\frac{\partial}{\partial t}\left(\rho \bar{u}\right) + \left(\nabla \cdot \rho \bar{u}\bar{u}\right) = -\nabla p + \rho \bar{g} + \left(\nabla \cdot \mu\left[\left(\nabla \bar{u}\right) + \left(\nabla \bar{u}\right)^T\right]\right) + \bar{F}_\sigma \tag{2.2}$$