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Modelling of large-scale bubbling gas-solid fluidised beds using the Discrete Bubble Model
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Abstract
In many industrial applications of bubbling gas-solid fluidised bed reactors, such as in gas-phase polymerisation reactors, the macro-scale circulation patterns induced by bubble coalescence determines to a large extent the overall heat removal rate and thus the overall production capacity. A 3D Discrete Bubble Model (DBM) has been developed to describe the complex hydrodynamic phenomena prevailing in these dense gas-solid fluidised bed reactors. In the DBM, an Euler-Lagrange model, the bubbles are modelled as discrete spherical elements and are tracked individually using Newton’s second law during their rise through the emulsion phase. The emulsion phase is considered as a continuum, for which the continuity and Navier-Stokes equations are solved. The DBM requires closures to model the behaviour of individual bubbles (in the presence of many other bubbles) and the emulsion phase rheology, which can be derived from experiments or from simulations with more fundamental discrete particle or continuum (Euler-Euler) models. Simulation of the entire industrial scale reactor with these more fundamental models would however lead to unacceptably long calculation times to sufficiently resolve all the bubbles.

Although the DBM idealises the bubbles as perfect spheres, its strong advantage is that no a priori assumption is required on the bubble encounter frequency, an important factor determining the bubble coalescence rate. As a first step, bubble coalescence is simplified assuming 100% coalescence efficiency for a bubble-bubble encounter if the bubble diameter is smaller than a pre-described maximum bubble diameter. Bubble encounters with a bubble with a diameter larger than this maximum do not result in coalescence but collide, approximating the dynamic equilibrium between bubble break-up and bubble coalescence. More detailed closures for bubble coalescence and bubble break-up could in principle be easily implemented in the DBM. Due to the bubble coalescence the bubbles can grow to diameters much larger than the size of a Eulerian grid cell required to accurately resolve the emulsion phase velocity patterns. The DBM originally developed for and widely used in the field of gas-liquid columns has been modified to cope with bubbles with a diameter much larger than the size of a Eulerian cell.

The DBM has been used to simulate a square bubbling dense gas-solid fluidised bed (1.0 m x 1.0 m x 3.0 m) with physical properties resembling those encountered in industrial olefin polymerisation reactors at elevated pressure. A comparison of the results of simulations ignoring bubble coalescence and simulations taking bubble coalescence into account clearly demonstrated the dominant effect of bubble coalescence on the large-scale circulation patterns prevailing in large-scale bubbling fluidised beds (see Fig. 1). The effects of the superficial gas velocity and the bed aspect ratio on the time-averaged velocity and porosity profiles have been studied. In general it can be concluded that the DBM is able to capture the salient features of the hydrodynamics of industrial scale fluidised beds.

Figure 1. Influence of bubble coalescence; Snapshots of the column (a) with and (b) without bubble coalescence. The corresponding time-averaged axial emulsion phase velocity profiles at half the column height have been plotted in (c).