Simulation of bubble-particle interaction using OpenFOAM

- Unified hydrodynamic and physico-chemical modelling

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Abstract

The interaction between gas bubbles and dispersed solid particles or droplets is a mechanism of major importance in many industrial processes. The characteristics of bubble-particle interaction (BPI) determine the collection of a dispersed phase, such as in mineral froth flotation, and changes in overall fluid rheology and dynamics, such as in the oil and gas industry. Process models in mineral processing rely heavily on fitted empirical constants and are often specific to a single process. The fundamentals of BPI are in fact little understood and process sub-models are based on so-called "hard sphere models". These hard sphere models however do not fit laboratory observations of the behavior of bubbles and particles nor have adequate predicting power for the industrial process.

The modelling effort of mineral froth flotation traditionally consists of two schools of thought; flotation is either considered a hydrodynamic mixing problem, or a physico-chemical process. However, both groups of phenomena are important and take place in the same space and time. During the 2009 NUMAP-FOAM Summer School [5] the basis of a more generic BPI model, *bpiFoam*, has been developed in OpenFOAM. In this study we share the on-going development of the *bpiFoam* solver.

In this work we use the finite volume/area interface tracking solver *bubbleInterTrackFoam*, which tracks the sharp air-water interface [1,2] using a dynamic mesh [3,4]. The bubble surface forces are dependent on deformation due to hydrodynamics, as well as the gradient of surfactant concentration on the bubble surface, the so-called Marangoni effect. The *bubbleInterTrackFoam* solver includes the Langmuir kinetic law to describe adsorption and desorption of soluble surfactant to and from the bubble surface [1]. Solid mineral particles are tracked as Lagrangian particles using *dropletFoam* [6]. When a particle collides with the air-water interface the position of the particle is corrected to the interface and the particle assumes the local bubble surface velocity. After attachment the particle slides along the bubble surface as long as a detachment criterion is not exceeded. As detachment criterion we use the modified Bond number, a function of particle density and size, centrifugal acceleration, surface tension, and contact angle. The authors are aware that the validity of the Bond number is questionable and a more appropriate criterion is under development. Mineral particles in froth flotation are characterized by a medium to high Stokes number, in the order of 0.1-10. In the collision-attachment algorithm of *bpiFoam* the Lagrangian particle obtains added mass, lift and drag forces, as well as inertia. In this manner the effects of particle inertia on the dynamics of the bubble-particle aggregate and bubble loading can be analyzed.

The obtained preliminary results are promising and show similarity to recent experimental observations of BPI using high speed imaging. Our first results also show the importance of dynamic air-water interface and evaluation of internal circulation. The boundary flow field has a major impact on the dynamics of bubble-particle aggregates and also the surfactant mass transfer characteristics. This is work in progress and qualitative validation will be made. The *bpiFoam* solver has great potential to give deeper insight in BPI in general and in the effects of different assumptions of boundary conditions and sub-models.

Key words: Multiphase flow, bubbles, particles, mineral froth flotation

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