Application of the SPH method for the simulation of ultrasound assisted liquid/gas foam disintegration

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ABSTRACT

Many industrial processes, especially in the field of chemical engineering and food processing, suffer from unintended and often uncontrollable occurrence of foams in production plants. As part of a newly instituted research cluster, the Institute of Fluid Mechanics aims at mitigating these issues using purely physics-based countermeasures. A highly promising concept among these is the breaking of foam lamellae by ultrasonic resonance excitation. In the present work, the detailed mechanisms of this effect have been studied by numerical investigations using the smoothed particle hydrodynamics method.

The simulation of bubbles and foams using SPH has been frequently published [1–7], often with a focus on computer animations. Furthermore, the weakly compressible SPH formulations allow for a description of sound wave propagation [8–11]. The current work is aimed at combining both aspects based on the open source package PySPH, which already contains formulations for multi-phase fluids, surface tension [12–14] and open boundaries. The simulation domain (a rectangular column) contains an initial level of liquid with air entering through a porous plate at the bottom (velocity inlet) and exiting at the top (pressure outlet). The individual bubbles rise to the upper surface of the liquid and cohere to form a foam layer. Depending on the set values of material properties, this layer enters a steady state between growth by bubble addition and natural decay. Using this steady state as reference, the interaction with sound waves is simulated (i) globally, (ii) with a discrete emitter in the gas phase, or (iii) in the liquid phase and finally (iv) with an array of discrete emitters arranged to induce locally increased sound pressure by focusing. The implementation of sound propagation in PySPH was supplemented according to the formulation of Zhang et al. [9,11]. Using this setup, a parametric study was performed, covering the influence of emitter position, sound frequency and intensity and fluid properties. It was confirmed, that the eigenfrequency of bubbles within the foam (foam cells) is elevated compared to freely floating bubbles in liquid. The efficiency of foam disintegration with ultrasound emission in the liquid phase proved to be increased compared to emission in air.

The simulations have been validated in a lab-scale foam generator of identical geometry and analogous operation. The evaluation of foam generation, cell size distribution, natural and forced decay was performed by digital image processing. For the detection of resonance excitation of foam lamellae, a high-speed camera was used. This validation showed good agreement of the simulation with respect to the governing mechanisms. A further refinement is expected from future implementations of improved surface tension approaches (e.g. inter-particle force models) and an extension of the liquid phase description to non-newtonian rheology.

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