SPH simulation of multi-phase flows with high density ratio at zero gravity

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ABSTRACT

Multi-phase flows with high density ratio play a significant role in a wide range of applications in environments of both normal and reduced gravity. The motion of drops and bubbles in a fluid medium in pipes and channels are of importance in material processes in reduced gravity environments [1]. Slug flow formation under zero gravity [2] and bubble separation from liquid medium aboard spacecraft due to the absence of a net gravitation [3] are other examples of multi-phase flows characterized by high density ratio under zero gravity condition.

The weakly compressible SPH (WCSPH) method is known to suffer from spurious fragmentation and unnatural voids at the phase interface in multi-phase flows with high density ratios. These phenomena get more severe in the absence of gravity or in reduced gravity environments, as the equation of state relating pressure to density in WCSPH, leads to negative pressure values, thereby introducing numerical instability. Therefore, in such flows special care must be taken to maintain a sharp phase interface [4].

In the present study, to alleviate these issues, we propose a simple SPH method based on a Riemann solver to simulate air-water hydrodynamics at zero gravity. The WCSPH method based on a low-dissipation Riemann solver [5] is adopted to realize pairwise particle interactions, along with new extensions to multi-phase problems with large density ratios. In this manner, the two phases are behaving as being decoupled; the light phase experiences an internal flow, while the heavy phase undergoes a free surface regime. In a weakly compressible frame, we use the same value for the artificial speed of sound in both the light and heavy phases with no need for a background pressure, which is different from the previous studies (e.g. [6, 4, 7]), and leads to larger time-step sizes. A new two-phase form of the density summation formulation is proposed to calculate the density of both the light and heavy phases. We do not use any stabilizing method to tackle the density discontinuity at the phase interface (e.g. [8, 9]), nor any artificial repulsive pressure force (see e.g. [4, 9]). Furthermore, density re-initialization schemes, deemed to be necessary in the literature (e.g. [6, 10]), are not required by the method resented herein. With the above-mentioned advantages in mind, the proposed multi-phase method is simple, robust and computationally efficient. The method demonstrates good results and is validated against available data sets in the literature.

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