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A THREE-PHASE MIXTURE APPROACH FOR THE SIMULATION OF SELF-AERATED FLOWS WITH HIGH CONCENTRATION OF BUBBLES

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Abstract. The interaction of a highly turbulent free surface with the surrounding air leads to the incorporation of bubbles of variable sizes into the flow in a process known as air entrainment. Air entrainment is a common phenomenon in hydraulic structures such as spillways, chutes and dissipation structures, as well as in natural flows like highly steep mountain rivers, breaking waves and hydraulic jumps. In the case of spillways and steep channels, the high concentration of air lead to an increase in the bulk of the flow known as bulking. Existing approaches have modelled the bubbles as a passive scalar, using a source term represented by an air-entrainment function (Souders and Hirt (2004); Ma et al. (2011)). The passive scalar approach neglects the volume of air and therefore is incapable of representing bulking. In this study, a three-phase mixture approach is employed to simulate self-aerated flows with high concentrations of bubbles. The governing equations are derived from the mass and momentum conservation of each phase. The traditional Volume-of-Fluid method is reformulated to account for the volume of the bubbles, coupling the interface tracking algorithm with the bubble transport equation. Additionally, the air entrainment function is discarded and a new method to calculate the source term that requires no calibration is employed. The Volume-of-Fluid phase-fraction equation and the bubble transport equation are solved using a modified version of the Multidimensional Universal Limiter for Explicit Solution (MULES) method that accounts for the nature of each equation as well as the relationship between them. A new term in the pressure equation accounts for the effect of the slip velocity between the water and bubble phase into the mixture velocity fields. The model was calibrated and validated using the experiments of a plunging jet from Chanson et al. (2004) and the experimental data from Felder and Chanson (2013) for stepped spillway. Good agreement of bubble distribution and bulking was obtained.