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Thermal Simulation in Multiphase Incompressible Flows Using Coupled Meshfree and Particle Level Set Methods

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Abstract

A particle–based numerical solver is presented, applicable to the simulation of heat transfer in multiphase immiscible flows including surface tension. In the context of meshfree methods, the Laplacian operator is recognized as the most numerically challenging ingredient of the heat equation. The well-known difficulty of approximating higher-order spatial derivatives with meshfree methods is herein addressed by adopting two advanced schemes in order to ensure second-order completeness. In addition, a fully second-order Lagrangian particle level set method is introduced for the first time to capture the location of the interface, i.e., moving and/or deformable boundaries of the continuum at each time-step. This leads to a more conservative solution, alleviating the mass loss during the simulation. Furthermore, a narrow band of the exterior geometric particles is exploited to form physical ghost particles to enforce the required boundary conditions. This novel approach ensures solver performance without the necessity of defining extra dummy particles for treating boundary conditions in meshfree simulations. Three benchmark problems are considered for evaluating the performance of the proposed solver against a benchmark analysis performed in `COMSOL Multiphysics®`.

Keywords: Meshfree methods; Multiphase flows; Heat transfer; Moving interfaces; Particle Level Set.

1 Introduction

Ever since its inception in the late 70s [1, 2], Smoothed Particle Hydrodynamics (SPH) has been applied to a diverse spectrum of applications, including, but not limited to, solid [3, 4, 5] and fluid [6, 7, 8] mechanics problems, even though the initial exploitation primarily pertained to astrophysics and gas dynamic problems. Thanks to the tremendous growth of computing power, there has been a renewed interest in applying SPH to sophisticated fields, beyond engineering applications, such as virtual reality surgery, movies special effects and computer graphics [9, 10, 11]. Interestingly enough, alternative particle models to simulate fracture and damage in solids have also been attempted in various works, as elaborated upon in [12, 13, 14].

Generally speaking, SPH methods have been extensively and successfully adopted by the Computational Fluid Dynamics (CFD) community as evidenced by the numerous applications [6]. The weakly compressible SPH (WCSPH) models, as the original formulation of SPH for fluid dynamics, comprise one of the most efficient strategies for solving incompressible fluid dynamical problems. Using WCSPH, the admissible density fluctuations of the fluid is bounded and kept relatively small, hence treating the fluid as quasi–incompressible. This may be achieved by employing a proper equation of state, which links density to hydrodynamic pressure. The interfacial flows simulation by Colagrossi and Landrini [15], the multiphase SPH investigations of macroscopic and mesoscopic flows by Hu and