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C3Po1C-04: A mesoscopic approach for simulating boiling phase change of liquid hydrogen

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Liquid hydrogen has garnered unprecedented attention due to its unique advantages in low-carbon energy economies and the realm of high-thrust and environmentally friendly space propulsion systems. The boiling phase change is a fundamental and inescapable physical process in every aspect of liquid hydrogen storage, transportation, and vaporization applications. Accurate prediction of boiling characteristics is crucial for the design, verification, operation, and diagnostics of related industrial equipment and processes. However, precise numerical simulation of boiling phenomena, especially including the initiation of nucleation, is difficult using conventional multiphase flow models such as the Volume of Fluid (VOF) and level set. These approaches often relay on empirical correlations, which typically deviate from physical basis for different specific scenarios. In addition, different from other cryogenic fluids, liquid hydrogen exhibits an even more complex phase change mechanism due to its unique physical properties, such as extremely low density, low viscosity and high wettability. In this work, a numerical model based on the mesoscopic lattice Boltzmann (LB) method is developed to simulate the boiling process of hydrogen. The high-accuracy fundamental equation of state for hydrogen proposed by Leachman et al. is integrated into the LB method for the first time, which significantly improves the thermophysical property data accuracy that reflects the non-ideal fluid's behavior. A film evaporation numerical experiment is used to validate the proposed model. A boiling simulation of liquid hydrogen on a two-dimensional smooth and flat surface is performed, which successfully renders the nucleation, growth, and detachment of hydrogen bubbles. The findings provide insights into the nucleation mechanism of liquid hydrogen at the mesoscopic level.

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