Validation Study on FELMI for a Gas-Liquid-Solid Flow

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To understand the three-phase flows in the sloshing molten fuel pool formed during a postulated Core Disruptive Accident (CDA) of a Sodium-cooled Fast Reactor (SFR), applicability of FELMI is proved through numerical examples.

Keywords: DEM-VOF, FELMI, Molten Fuel Pool, Coarse Grained DEM

1. Introduction

Motivated by benefiting the fast reactor severe accident evaluation, numerical simulations were conducted to investigate the gas-liquid-solid flows in the sloshing molten fuel pool formed during a postulated Core Disruptive Accident (CDA) of a Sodium-cooled Fast Reactor (SFR). In this study, the applicability of the coarse-grained DEM-VOF is demonstrated to simulating the three-phase flow.

2. Numerical methods and calculation conditions

In the present study, the motion of solid particles is tracked by the Discrete Element Method (DEM) and gas-liquid interface is simulated by the Volume of Fluid (VOF) model. A combination of the Sign Distance Function (SDF) and Immersed Boundary Method (IBM) is implemented to reconstruct the arbitrary wall boundaries. This combined SDF/IBM wall boundary makes the calculation simple, yet accurate. The feasibility of FELMI (Mori & Sakai, 2021), including the SDF/IBM wall boundary models, has been fully verified.

The computational domain was a cuboid volume filled with liquid. In the original case, 540,000 particles with a diameter of 0.2mm were generated uniformly first, and then fell under gravity to form the initial packing structure. Air was injected from the bottom center of the computational domain. The CFD grid size was set equivalently in all the cases, and the grid size was sufficiently larger than the particle diameter. Ten cases had been performed, in which the cases were grouped according to the fluid viscosity. The liquid viscosity of high-viscosity group was ten times higher than that of the low-viscosity group. Each case group consisted of five different particle configurations, namely the original particle, the coarse-grained particle with coarse grain ratio being 2.0 and 3.0, and the simply magnified particles with magnification being 2.0 and 3.0.

3. Results and discussion

The simulation results show that the particles are widely distributed in the computational domain, regardless of the liquid viscosity. After being carried to the free surface, particles descend slowly in the liquid and move towards the center of computational domain. A small portion of particles will be transported to the free surface again by rising bubbles. These phenomena were successfully captured by the coarse-grained particle cases. On the other hand, the distribution of simply magnified particles is obviously not as wide as that of the original ones, and they descend rapidly after being brought to the free surface. These results show that the coarse-grained model successfully reproduces the characteristics of particle motion in sloshing molten fuel pool, while simply magnifying particles fail to do so. It is concluded that the FELMI successfully simulate the three-phase flow in high-viscosity system and the applicability of coarse-grained model is well demonstrated.

Acknowledgement

This study was financially supported by JSPS KAKENHI 21K19760.