A MPS method with consistent high-order schemes for droplet simulations

*Guangtao Duan[1] and Mikio Sakai[1]

[1]Univ. Of Tokyo.

The particle shifting method and the surface tension model of the free surface particles are enhanced for the MPS method. Various droplet simulations with oscillation deformation, topological changes, and contact angles were performed to verify the developed method.

Keywords: Particle method; MPS; Free surface, Droplet; Surface tension; Particle shifting

1. Introduction

The corium jet may take place from the cracked reactor pressure vessel in a postulated severe accident. The corium jet may result in the atomization process, where the effect of surface tension is dominant. Developing a numerical method for free surface flow with strong surface tension or the droplet flow is of great significance to nuclear engineering and other engineering fields. The purpose of this study is to develop an accurate and stable particle method for simulating the droplet flow with the topological changes of free surfaces in both 2D and 3D.

2. Numerical methods

The developed particle method is based on the moving particle semi-implicit (MPS) method. The consistent discretization models in Ref. [1] is employed to enhance the accuracy. The advanced detection conditions for free surface particles based on error accumulation analysis in Ref. [2] is adopted to guarantee the stability at free surface. Based on the approach in Ref. [3], the surface tension is converted to a pressure boundary condition at free surface. To reduce the fluctuations due to the detected free-surface particles, a new particle shifting approach in the direction of surface normal is proposed in this study. The basic idea is to shift a free surface particle to the reconstructed free surface based on curve fitting. Meanwhile, the approach to specify an imaginary free-surface particle at the wall boundary is developed to consider the contact angle.

3. Simulations and discussion

First, the droplet-oscillation cases in 2D and 3D is simulated to verify the developed method. Second, the improvement of the surface normal particle shifting is demonstrated by the large deformation of squared droplet. The contact angle model is verified by the equilibrium droplet shapes on a flat wall in 2D and 3D. Finally, the capability of developed method for the topological changes of free surfaces is demonstrated by the droplet coalescence and droplet breakup from a faucet in 3D.

4. Conclusion

An advanced MPS method is developed to simulate the droplet flow by proposing a new approach of surface normal particle shifting to reduce surface fluctuations and a new contact-angle model for surface tension. Various droplet simulations verified the developed method and demonstrated the improvements of the surface normal particle shifting and the contact angle model. The developed method is capable to simulate the topological changes of free surfaces.

5. Acknowledgements

This research was partially supported by the MEXT Quantum Leap Flagship Program (MEXT Q-LEAP) under Grant No. JPMXS0118067246 and JSPS KAKENHI under Grant No. 19K15478.

References

[1] Duan G, Matsunaga T, Yamaji A, et al. Imposing accurate wall boundary conditions in corrective-matrix based moving particle semi-implicit method for free surface flow. Int J Numer Meth Fluids. 2021; 93: 148-175

[2] Duan G, Matsunaga T, Koshizuka S, et al. New insights into error accumulation due to biased particle distribution in semi-implicit particle methods. Comput Methods Appl Mech Eng. 2021: Under Review.

[3] Matsunaga T, Koshizuka S, Hosaka T, et al. Moving surface mesh-incorporated particle method for numerical simulation of a liquid droplet. J Comput Phys. 2020;409: 109349.