An Improved Surface Tension Model for Numerical Simulation of Interfacial Flow by Smoothed Particle Hydrodynamics Method

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Summary Based on previous surface tension model, an improved surface tension model is developed. The interface particles used in the surface reconstruction consist of the interface particle, its right nearest neighbor, and its left nearest neighbor. And the transformed coordinate system used in the surface reconstruction is specified as the coordinate system in which the y axis is the norm vector of the surface. The above two steps involve only few extra computations. The computing efficiency of the improve surface tension model is unaffected. The oscillation of square drop and binary collision of two drops are investigated numerically. In the simulation, the density ratio is up to 797 . The numerical results show that the improved surface tension model is more stable, more accurate, and symmetric.

INTRODUCTION

Surface tension force acts on the interface and the interface tends to become as small as possible. The phenomena involved with surface tension exist in our daily life and have wide applications in industrial processes, such as pendant drop on the eaves, famous Worthington jet, ink-jet, and thermal spray coating.

SPH method has been applied to simulate the fluid flow with free surface. Nugent[1] first developed van der Waals (vdW) model which gives rise to an attractive, central force between the particles with an interaction range. Meleán[2] applied the vdW model to simulate the oscillation of the deformed drop without tensile instability, the head-on and off-center binary collision. Morris[3] developed the SPH formulation for the CSF model, in which the interface is tracked implicitly by simulating the advection of the color function. Hu and adams [4] presented an CSF model for the SPH method and applied it into the incompressible multi-phase flow such as droplet oscillation, contact angle, droplet deformation in shear flow, Rayleigh-Taylor instability.

In this paper, an improved surface tension model is developed for simulating interfacial flow with SPH method. The calculation of surface tension force is based on the geometric information of interface[5]. The improved model is more stable, more accurate and symmetric.

Numerical Model

In my previous work[5], the surface tension model is given as following. The SPH particles on the interface are detected dynamically. Based on the detected boundary particle, the interface is reconstructed locally by Lagrangian interpolation polynomial. Then the curvature and the norm vector of the interface can be calculated accuratelly. The surface tension force is obtained.

Before the reconstruction of the interface, the coordinate system has to be transformed. The local coordinate origin is the average point of the neighbors of the boundary particle. Then the interface is reconstructed locally. The advantage of the transformation of the coordinate system is that the reconstructed interface in the local coordinate system is guaranteed to be one valued.

Furthermore, the surface tension model is improved by the following way. The interface particles used in the interface reconstruction consist of the interface particle, its right nearest neighbor, and its left nearest neighbor. And the transformed coordinate system used in the interface reconstruction is specified as the coordinate system in which the y axis is the norm vector of the interface.

Through the above steps, the interface is reconstructed and the curvature and the norm vector of the interface can be calculated accurately. The surface tension force is the product of the surface tension coefficient, the curvature and the norm vector of the interface. The surface tension force can be obtained accurately according the above method.

Result and Discussion

The improved method for simulating surface tension in 2D is numerically investigated. The validation of the method is given in the following.

1.Oscillation of square drop with density ratio of 797.88

Oscillation of drop with initial shape of square is simulated. 10000 SPH particles are used in the simulation and the smoothing length is 0.0025. The density of the drop is 797.88 and the coefficient of surface tension is 0.02361. The side length of square drop is 0.075. The density of the surrounding gas is 1.0. The drop has viscosity of 0.001 and the gas has viscosity of 0.000018. Fig.1 shows the snapshots of oscillation of drop with initial shape of square. Due to the surface tension force, the drop deforms at the corners at first. The square drop evolves into the shape of flower, four point star, unstable circle, and round corner square. Due to the viscous dissipation, the drop becomes a stable circle finally.

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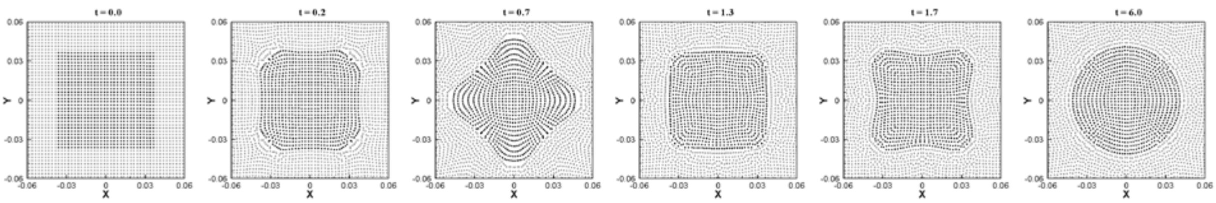
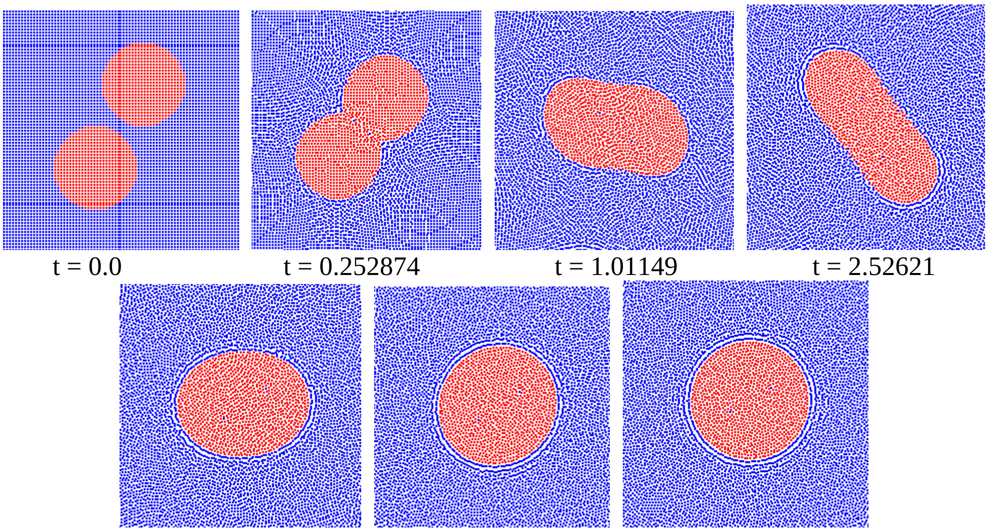


Fig. 1. The oscillation of 2D drop with initial shape of square with density ratio of 797.88

2.Off-center binary collision

Off-center binary collision is simulated by the improved method and the program is parallelized by using of parallel applications infrastructure JASMIN[6]. The drop radius is 0.0375. The smoothing length is 0.0025. The drop density is 797.88 and the surrounding fluid density is 1.29. And the coefficient of surface tension is 0.02361. The drop has viscosity of 0.001 and the gas has viscosity of 0.000018. The relative velocity is 0.04. The impact parameter is 0.5. Fig. 2 shows the snapshots of off-center binary collision. Initially two drops approach to each other. The liquid bridge forms and enlarges with time during the collision. The coalesced drop elongates along the direction of angle 45^{o}. The point symmetric shape of coalesced drop induces the rotational motion. Due to the viscous dissipation, the coalesced drop evolves into a stable circle.



t = 0.0 t = 0.252874 t = 1.01149 t = 2.52621

t = 6.25104 t = 9.77357 t = 11.3641

Fig. 2. Off-center binary collision with density ratio of 618.

CONCLUSIONS

The improved surface tension model has been applied to simulate surface-tension-driven interfacial flow. The calculation of surface tension force is based on the geometric information of interface. Numerical simulations are performed to validate the improved method. The numerical results show that the improved surface tension model is more stable, more accurate, and symmetric.

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