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Numerical Study of Water Droplet Impact on a Surface Using a Sharp Approach for Interface Modeling

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ABSTRACT: In this research, water droplet impact process on a solid surface is simulated using a sharp approach for interface modeling. This approach is based on the solving momentum and continuity equations and imposing appropriate jump conditions at the interface. The level set method is used for interface tracking and the ghost fluid method is used to impose jump conditions at the interface accurately. In this way, smearing of quantities across interface is prevented and discontinuities are preserved at interface. The accuracy of numerical procedure is approved via comparison of simulation results with experimental and numerical data. Simulation results show that the used numerical method in comparison with the volume of fluid method represents more accurate prediction of droplet behavior during impact process. The effect of contact angle between water droplet and surface on the impact process is investigated. For contact angles less than 90°, water droplet spreads on the surface after impact. But, for contact angles greater than 90°, droplet starts to recoil after spreading. In this case, it is possible that droplet rebound from surface after recoiling. Maximum spreading radius of droplet decreases by an increase in contact angle.

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1. Introduction

One of the important problems in numerical study of two phase flows is the modeling of droplet impact on a surface. This phenomenon can be observed in many industrial processes such as cooling, fuel injection and surface coating.

Many researchers studied droplet impact process on a surface. Gatne *et al.* [1] investigated about droplet impact on hydrophilic and hydrophobic surfaces experimentally. Nature of the surface plays an important role on the behavior of the droplet. Addition of surfactant decreases surface tension and leads to the more wetting of the surface. Shrikant *et al.* [2] compared static and dynamic models of droplet impact. They used volume of fluid method for interface tracking. They concluded that on hydrophobic surfaces, static model can represent a more accurate prediction of droplet spreading. Klitz *et al.* [3] used a combination of volume of fluid and smeared out level set methods for three dimensional simulation of droplet impact. They considered four different contact angle based on the static model and simulated droplet impact successfully. Zhang *et al.* [4] studied droplet impact process using phase field method. They showed that the Reynolds number has the dominant effect in the spreading stage. But in the recoiling stage, the role of the Weber number is more important.

In the previous studies, droplet impact modeling was based on the smearing of quantities across an interface with a specific thickness. Kang *et al.* [5] represented a sharp approach for interface modeling using the level set and ghost fluid methods. In this research, droplet impact is modeled using the sharp approach. Simulation results are compared with the available results based on the volume of fluid method and smeared out formulation.

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2. Methodology

In this study, droplet impact on a surface is simulated. Fig. 1 shows the computational domain and boundary conditions. Governing equations are incompressible continuity and

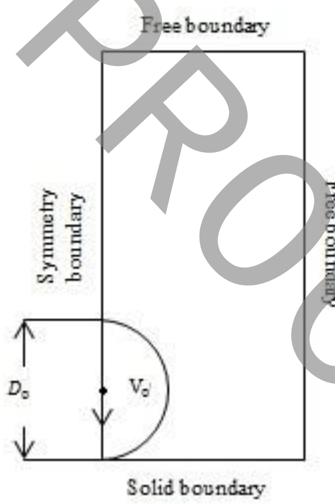

Fig. 1. Schematic of the problem

momentum equations in axisymmetric case. Appropriate jump conditions are imposed at the interface, when governing equations are solved.

A staggered grid is used for discretization of governing equations. Flow equations are solved using the projection method [5]. The 3rd order Total Variation Diminishing (TVD) Runge-Kutta method is used for temporal discretization. Convective and diffusion terms are discretized using Weighted Essentially Non-Oscillatory (WENO) and central approximation, respectively [5]. The level set method is employed for interface tracking [5]. In this method, interface is considered as zero level set of a smooth scalar function. Using the ghost fluid method, appropriate jump conditions are imposed at the interface [5,6]. So, discontinuity of various quantities is preserved at the interface and interface is modeled in a sharp manner. Contact angle between droplet and surface is applied based on the static model. In this model, a constant contact angle is considered within the impact process.

3. Results and Discussion

For validation of the numerical model, water droplet impact on a surface with a contact angle of 110º is simulated. The droplet has a diameter of 3 mm and an impact velocity of 1.39 m/s. Grid with a resolution of $R_0 / \Delta x = 90$ is used in all simulations.

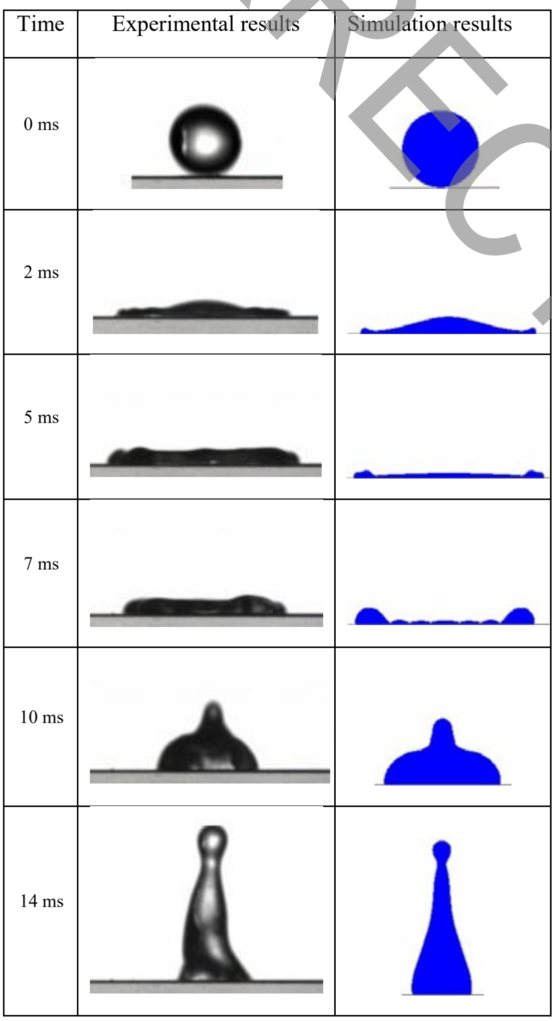

Fig. 2. Comparison between simulation and experimental [1] results

Fig. 2 represents the simulation results in comparison with the experimental results [1]. First, due to inertial force, droplet spreads on the surface. Viscous and interfacial forces resist against droplet spreading. At the maximum spreading, surface tension force is dominant and the droplet starts to recoil. After recoiling stage, due to inertial force, the droplet tends to rebound from the surface. As it is observed, numerical model can reproduce droplet profile during impact different stages, successfully.

Fig. 3 shows the non-dimensional droplet spreading diameter $\left(D(t)/D_0\right)$ versus non-dimensional time $\left(\tau = tV_0/D_0\right)$. Agreement between simulation and experimental results [1] is satisfactory. Also, the simulation results are more accurate rather than the numerical results of Shrikant *et al.* [2]. This can be due to the difference between numerical methods. Shrikant *et al.* used a smeared out formulation for interface modeling based on the volume of fluid method.

Fig. 4 represents droplet spreading factor $\left(D_{max}/D_0\right)$ versus contact angle. Spreading factor decreases by increasing contact angle. In fact, at higher contact angles the wettability of droplet decreases.

4. Conclusion

In this research, droplet impact on a surface is simulated using a level set based sharp interface method. Using this approach, discontinuity of quantities is maintained across interface. To the knowledge of the authors, previous works are based on the smeared approach for interface modeling. The numerical method can reproduce droplet profile during impact process, successfully. Also, the level set based sharp interface method in comparison with the volume of fluid method represents more accurate prediction of droplet behavior during impact process. Droplet spreading reduces by increasing contact angle. In fact, at higher contact angles, droplet wettability decreases.

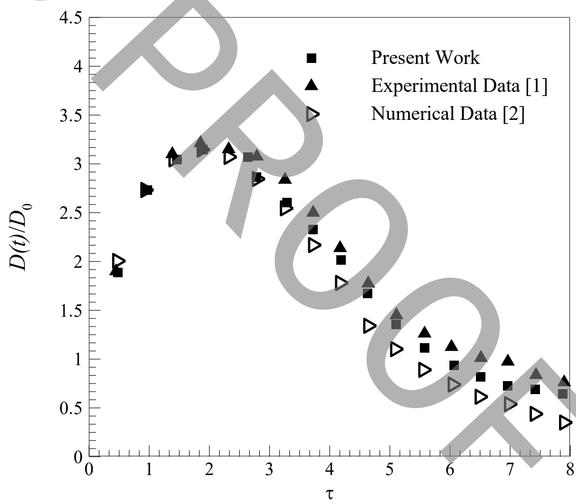

Fig. 3. Variations of droplet spreading diameter versus time

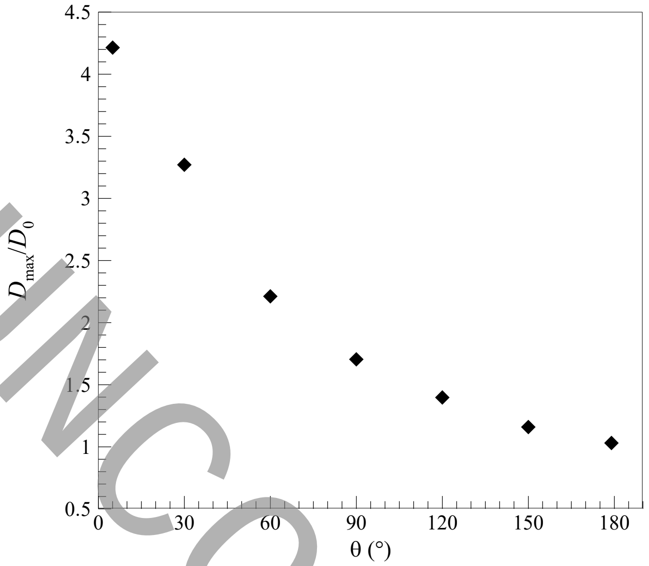

Fig. 4. Variations of droplet spreading factor versus contact angle

References

[1] Gatne, K. P., 2006. "Experimental Investigation of Droplet Impact Dynamics on Solid Surfaces". PhD Thesis, University of Cincinnati.

[2] Shrikant, A. B., Milind, A. J., Raj, C., and Jude, O. I., 2013. "On Computational Modeling of Dynamic Drop Surface Interaction during Post-Impact Spreadin of Water and Aqueous Surfactant Solution". MSc Thesis, University of Cincinnati.

[3] Klitz, M., and Griebel, M., 2014. "Numerical Simulation of Droplets with Dynamic Contact Angle". PhD Thesis. University of Bonn.

[4] Zhang, Q., T. Z., Qian, and X. P., Wang., 2016. "Phase field simulation of a droplet impacting a solid surface". *Physics of Fluids,* 28, 022103.

[5] Kang, M., R. P., Fedkiw, and X. D., Liu, 2000. "A boundary condition capturing method for multiphase incompressible flow". *Journal of Scientific Computing*, 21, pp. 323-369.

[6] Liu, X. D., R. P., Fedkiw, and M., Kang, 2000. "A boundary condition capturing method for Poisson's equation on irregular domains". *Journal of Computational Physics*, 160, pp. 151-178.