Simulation of Liquid Droplet Impingement on Horizontal Surface by Moving Particle Semi-Implicit Method and CIP Method with Level Set Technique

Shane Park, Ki Yeoul Seong, Gyoo Dong Jeun, Hyun Sun Park
Hanyang University, Department of Nuclear Engineering, 17 Haengdang Sungdong, 133-791, Seoul, Korea, Phone: +82-2-2290-0463, Fax: +82-2-2294-4800, Email: psi@thlab.hanyang.ac.kr, sskyein@thlab.hanyang.ac.kr, thlab@hanyang.ac.kr

Royal Institute of Technology, Department of Energy Technology, Drottning Kristinas Väg 33A, 10044, Stockholm, Sweden, Phone: +46-8-790-9256, Fax: +46-8-790-9197, Email: sun@energy.kth.se

1. Introduction

Analytical study of droplet deformation when the droplet impinged onto horizontal surface is proposed. This analytical work is performed by a computational fluid dynamics (CFD) code which enables to simulate the interface between two-phases. Accurate analysis of the liquid droplet interacting with a solid surface will provide an essential input to understand the dynamic process of droplet impingement which encounters in spray cooling process in many industrial processes. One of important application is also in the analysis of reflooding process of LOCA in nuclear reactor. The present work is, however, limited to an adiabatic process, i.e., no heat transfer between the liquid droplet and solid surface. However, hydrodynamic aspects of the liquid drop deformation during the impingement are still essential to investigate the subsequent heat transfer during the process.

2. Methods and Results

2.1 Governing Equations

Due to the isothermal hypothesis, the dynamics of liquid is controlled by following equations

$$\frac{\partial\rho}{\partial t}=\left(\vec{u}\cdot\nabla\right)\rho=-\rho\nabla\cdot\vec{u} \tag{1}$$

$$\frac{\partial\vec{u}}{\partial t}+\left(\vec{u}\cdot\nabla\right)\vec{u}=\vec{g}+\frac{1}{\rho}[-\nabla p+\nabla\cdot\left(\mu D\right)+\sigma\kappa\delta\left(d\right)\vec{n}] \tag{2}$$

$$\frac{\partial p}{\partial t}+\left(\vec{u}\cdot\nabla\right)=-\gamma p\nabla\cdot\vec{u} \tag{3}$$

where $D=\vec{u}+\nabla\vec{u}^{T}$ is the viscous stress tensor, $\vec{u}=(u,v,w)$ the fluid velocity, $\rho=\rho(\vec{x},t)$ the fluid density, $\mu=\mu(\vec{x},t)$ the fluid viscosity, p the pressure, γ is the specific heat ratio, and $\vec{g}$ the gravitational force. The last term in the right hand side of Eq.(2) is the surface tension force, whose effect is modeled in terms of singular source function. We denote σ as the surface tension, δ as the Dirac delta function, κ as the curvature of the interfaces, and $\vec{n}$ as the unit outward normal vector at the interfaces.

2.2 MPS Method

In MPS method, the motion of each particle is calculated through interactions with neighboring particles covered with the kernel function. This method has been shown to be successful in dealing with large deformation of interface in free surface flows (Koshizuka and Oka, 2000; Yoon et al., 2001; Ikeda et al., 2001). This method is based on a fully Lagrangian description. Numerical diffusion does not arise because convection terms are not discretized. Differential operators, such as gradient, divergence and Laplacian, in governing equations are transformed to equivalent particle interactions using a weight function. Grids are not necessary, hence, large deformation of interface can be analyzed without grid tangling. A semi-implicit algorithm is employed for analyses of incompressible flows. The incompressibility constant is implicitly satisfied on fluid by solving a Poisson equation of pressure, while the other terms are explicitly calculated.

2.3 CIP and Level Set Method

The CIP method solves general convective diffusion differential equations by dividing them into non advection and advection phases. Level set algorithm is used to capture the moving interface. The code is based on the general Navier-Stokes flow equations and coupled with a high-order numerical scheme CIP and Level set front tracking algorithm. The effects of the interfaces on the flow (surface tension) are accounted for in this approach.

2.4 Results

The target for the proposed work focuses on the analysis of droplet deformation during the droplet impingement on flat surface. The cases of this work are listed in Table 1.

Table 1. Calculation condition

A	Initial radius=0.000345 m=0.345㎜ density=1000 kg/m^3 Initial velocity=1.46 m/sec Viscosity coef.=10^{-6} kg/m.s Surface tension coef.=0.073 N/m

B	Initial radius=0.00148 m=1.48㎜ density=1000 kg/m^3 Initial velocity=1.36 m/sec Viscosity coef.=1.0064×10^{-6} kg/m.s Surface tension coef.=0.07603911 N/m

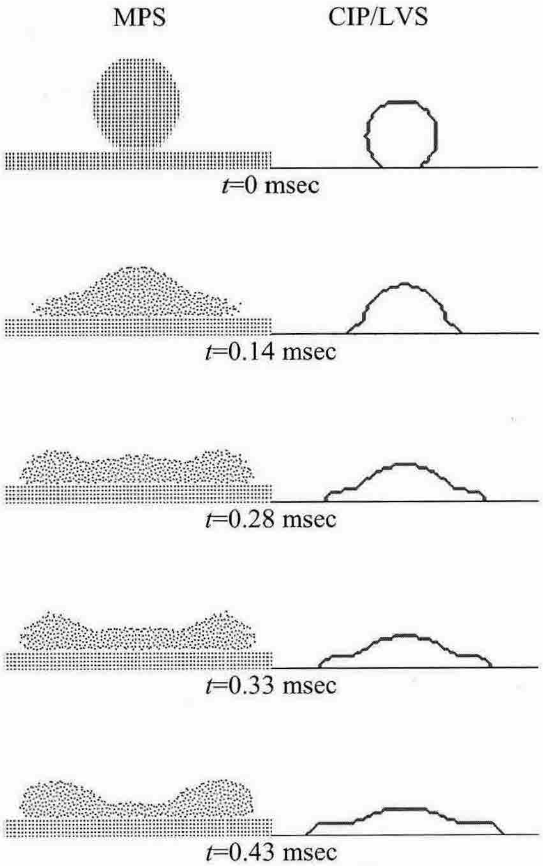
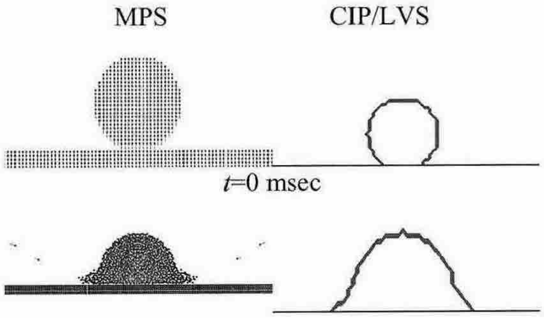


Figure 1. Comparison of MPS and CIP-Level Set Method for case A



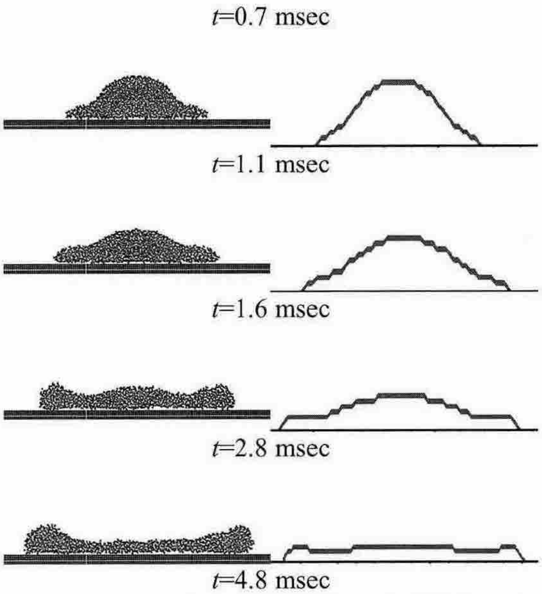


Figure 2. Comparison of MPS and CIP-Level Set Method for case B

3. Conclusion

This paper presented a theoretical study of the process of deformation of a spherical liquid droplet impinging upon a horizontal surface. The study accounted for the presence of surface tension during the spreading process. The results documented the effects of impact velocity, droplet diameter, surface tension, and material properties on the fluid dynamics of the deforming droplet.

REFERENCES

[1] Fukai, Y. Shiiba, T. Yamamoto, O.Miyatake, D. Poulikakos, C. M. Megaridis, Z. Zhao, Wetting effects on the spreading of a liquid droplet colliding with a flat surface: Experiment and modeling, Phys. Fluids 7, 236, 1995.

[2] H. Y. Kim and J. H. Chun, The recoiling of liquid droplets upon collision with solid surfaces, Phys. Fluids 13, 643, 2001.

[3] Fukai, Z. Zhao, D. Poulikakos, C. M. Megaridis, O. Miyatake, Modeling of the deformation of a liquid droplet impinging upon a flat surface, Phys. Fluids 5, 2588, 1993.

[4] S. Koshizuka and Y. Oka, Moving-Particle Semi-Implicit Method for Fragmentation of Incompressible Fluid, Nuclear Science and Engineering 123, 421-434, 1996.