Simulation of Droplet Impingement on a Solid Surface By the Level Set Method

J. Hu[1], R. Jia[1], K. Wan[2], X. Xiong[3]

[1]Department of Mechanical Engineering, University of Bridgeport, Bridgeport, CT, USA
[2]Mechanical and Industrial Engineering, Northeastern University, Boston, MA, USA
[3]Department of Electrical Engineering, University of Bridgeport, Bridgeport, CT, USA

Abstract

The dynamic behavior of droplet impingement on a solid surface is important to many engineering applications, such as rain drops on automobile windshields, inkjet deposition and metal deposition in manufacturing processes, spray cooling of electronics, and spray coating for various applications. The droplet can spread, splash, and rebound after hitting a solid surface. The resulting phenomena and the final shape of the droplet on surface depend on several parameters, including the properties of droplet and the impacted surface, including the droplet impact velocity, the droplet size, the angle of attack to the surface, the droplet physical properties, the surface wettability, and surrounding pressure [1].

Significant research has been dedicated to study the droplet impingement under various conditions, experimentally, numerically, and analytically [2]. Sikalo and Ganic [2] conducted experiments to study droplet impact of three different fluids on various surface conditions, including dry and wet surfaces, smooth and rough surfaces, hydrophilic and hydrophobic surfaces, and horizontal and inclined surfaces. Tanaka et al. [3] numerically investigated the droplet impact using a two dimensional (2D) lattice Boltzmann method (LBM). Gupta and Kumar developed a 3D LBM model to simulate the spreading behavior of a droplet colliding with a solid dry surface at low impact velocity.

This paper is aimed to study the dynamic behavior of droplet impinge onto a solid dry surface with different surface wettability using the COMSOL Multiphysics® software.

A two dimensional axisymmetric model is set up in COMSOL to simulate the two-phase laminar flow. The computational domain is shown in Fig. 1. Open flow boundary conditions are adopted for the top and side air domain boundaries. The bottom wetted wall boundary condition is used to model the solid surface with different surface wettability. Static contact angle and slip length can be varied to represent different solid surfaces. Level set method is used to track fluid interfaces. The non-conservative level set method is found to have significant mass loss when the mesh is not fine enough, thus conservative level set method is used.

A dynamic process of a water droplet collides with a hydrophobic surface of 135o of contact

angle is illustrated in Fig. 2. The volume fraction of fluid and fluid velocity vectors demonstrates the dynamic interaction of droplet with a solid surface. Droplet tends to spread on the surface driven by the downward momentum, but has difficulty to spread further due to the high contact angle, which leads to a quick rebound. Figure 3 shows a schematic sketch of a droplet spread on a surface. The time evolution of droplet wet diameter and droplet maximum height will be studied for a range of droplet impact conditions and solid surfaces wettability. The simulated results will be compared with experimental results of Sikalo and Ganic [2].

The dynamic process of droplet impingement is complex and the mechanism of droplet and surface interaction is not fully understood. The accurate simulation of droplet impingement is computationally expensive. This project is also aimed to evaluate the multiphase models. We hope to find a set of parameters for reasonable accuracy at afford cost. The established droplet impingement model can be further combined with heat transfer and phase change models for many import applications, such as spray cooling and laser metal deposition.

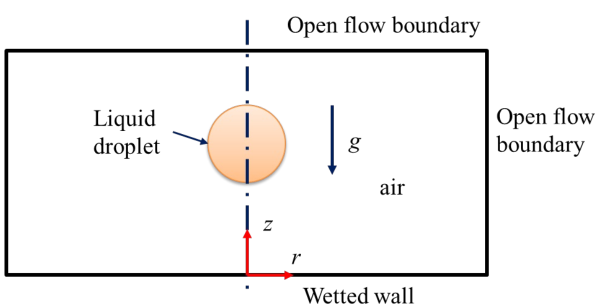
Reference

1. Amit Gupta and Ranganathan Kumar, Droplet impingement and breakup on a dry surface, Computers and Fluids, 39, 1696-1703 (2010).

2. S. Sikalo and E.N. Ganic, Phenomena of droplet-surface interactions, Experimental Thermal and Fluid Science, 31, 97-110 (2006).

3. Y. Tanaka, Y. Waashio, M. Yoshino, and T. Hirata, Numerical simulation of dynamic behavior of droplet on solid surface by the two-phase lattice Boltzmann method, Computers and Fluids, 40, 68-78 (2011).

Figures used in the abstract



Schematic of computational domain

Figure 1: Schematic of computational domain.

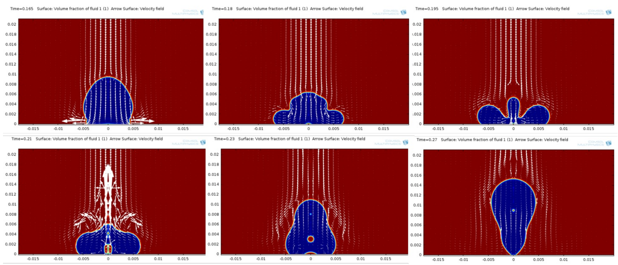


Figure 2: Evolution of a droplet impingement process from spread to rebound.

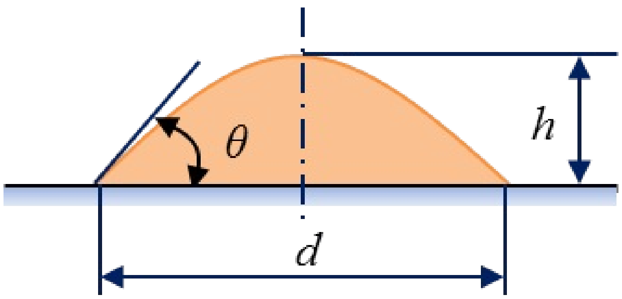


Figure 3: Schematic of droplet attached to a surface: θ, contact angle; h, droplet height; d, droplet wet diameter.