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Two-Dimensional Lattice Boltzmann Model for Droplet Impingement and Breakup in Low Density Ratio Liquids

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Abstract. A two-dimensional lattice Boltzmann model has been employed to simulate the impingement of a liquid drop on a dry surface. For a range of Weber number, Reynolds number and low density ratios, multiple phases leading to breakup have been obtained. An analytical solution for breakup as function of Reynolds and Weber number based on the conservation of energy is shown to match well with the simulations. At the moment breakup occurs, the spread diameter is maximum; it increases with Weber number and reaches an asymptotic value at a density ratio of 10. Droplet breakup is found to be more viable for the case when the wall is non-wetting or neutral as compared to a wetting surface. Upon breakup, the distance between the daughter droplets is much higher for the case with a non-wetting wall, which illustrates the role of the surface interactions in the outcome of the impact.

AMS subject classifications: 76T10

Key words: Lattice Boltzmann, droplet impingement, spread factor, breakup.

1 Introduction

Impingement of liquid droplets onto a dry surface can be observed in natural and modern engineering phenomenon such as rain drops on the surface of the earth, atomized fuel on the piston of an internal combustion engine, in ink-jet printing, spray cooling and recently in microfabrication [1]. A variety of mechanisms underlying the impact of liquid droplets on a dry surface, and the subsequent spreading behavior, have been

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highlighted through a variety of experimental investigations [2–10]. The breakup of the parent droplet into daughter droplets, and the difference in the dynamics of a single drop impact with a dry wall as compared to that of a train of drops has been demonstrated as well [4]. Scheller and Bousfield [5] showed that the contact angle effect on the spreading film diameter is negligible for droplet $Re > 10$, and that the maximum spread factor follows the correlation given by

$$\xi_{\max} = 0.61(Re^2 Oh)^{0.166}. \tag{1.1}$$

Rioboo et al. [6] showed that during the receding process, the perturbations merge leading to a rebound of the droplet for the case of water drops impacting a wax surface. However, for cases where no rebound was noticed, the diameter of the spreading film either remained constant or increased depending on the wettability of the surface used.

In addition to the experimental work, droplet impact dynamics has also been the subject of considerable numerical investigations [11–16]. However, much of the numerical work has been focused on simulations of droplet impingement on a surface covered with a thin liquid film [11–15]. Using the volume-of-fluid (VOF) method, Josserand and Zaleski [11] developed a criterion to scale the transition between splashing and deposition of liquid droplets on a thin liquid film. The VOF method has also been employed to identify the conditions leading to the entrapment of vapor bubbles as a result of capillary wave formed as a result of the droplet impact [12]. Lee and Lin [13] have developed and applied a high density ratio lattice Boltzmann model to simulate the splashing and deposition of droplets on a thin film. Mukherjee and Abraham [14, 15] extended the earlier model [13] to simulate the deposition and splashing behavior for an axi-symmetric domain. In a separate study, droplet spreading behavior for very low Oh and subsequent rebound on a dry surface for low density ratios was also investigated [16].

Impact of a droplet on a dry surface may be vastly different from that on a thin film, and is likely to be dependent on the density ratio of the two fluids, especially in high pressure systems where the parameter has a low value. The final shape and spreading of the liquid drop also depends on a range of parameters, like the impact velocity (U), the size of the droplet (D), the angle of attack to the surface, the physical properties of the liquid drop and the surrounding pressure.

The objective of this work is to (a) illustrate the applicability of a two-dimensional lattice Boltzmann method (LBM) in simulating droplet impingement on a dry surface, (b) to elucidate the mechanisms involved in the collision and subsequent relaxation of liquid droplets, and (c) to identify the physics of droplet breakup mechanism for low density ratios. Based on the conservation of energy, a criterion based on Reynolds number, Weber number, and the density ratio is developed to predict whether the collision of a liquid droplet would result in its breakup into daughter droplets. In addition, the physical behavior as a result of droplet collision may depend on whether the surface is hydrophobic or hydrophilic, rough or smooth, and dry or wet. This work also briefly explores the effect of the interaction between a liquid and the wetting characteristics (hydrophilic or hydrophobic) of a surface, and its influence on the breakup process.