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Lattice Boltzmann Simulation of Surface Impingement at High-Density Ratio

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In this work, a novel two-phase lattice Boltzmann method has been employed to study droplet impact dynamics in the presence of a surrounding lighter phase. All the simulations were conducted in a three-dimensional Cartesian coordinate system, with the density ratio of the liquid phase to the gas phase fixed at 50. First, simulations of binary droplet collisions are conducted to validate the methodology for $20 < We < 80$. Three different types of outcome, namely, coalescence collision, separating collision, and stretching collision, are presented. Secondly, the normal impact of a liquid drop impinging on a perfectly smooth dry surface is simulated at various liquid Weber and Reynolds numbers. Results are shown to compare the spread factor dependence on impact velocity, liquid density, liquid viscosity, surface tension, and surface wetting characteristics. The results are validated with experimental data. Two different outcomes are obtained: deposition and splashing breakup. The transition to splashing is found to be dependent on the liquid Weber and Reynolds numbers.

Nomenclature

a, b, T = free parameters determining ϕ
B = impact parameter
D = diameter of the droplet
d = diameter of the liquid lamella
E_i, F_i, H_i = coefficients in equilibrium distribution functions
$\mathbf{e}_i$ = particle velocity
f_i = particle distribution function for an order parameter
f_i^{eq} = equilibrium particle distribution function for f_i
g_i = particle distribution function for predicted velocity $\mathbf{u}^*$
g_i^{eq} = equilibrium particle distribution function for g_i
h = height of the liquid lamella
h_i = particle distribution function for pressure
L_x, L_y, L_z = dimensions of the computational domain
Oh = Ohnesorge number
p = pressure
p_0 = equation of state function determining ϕ
Re = Reynolds number
t = time in LBM unit
t^* = dimensionless time defined as tV/D
$\mathbf{u}$ = corrected velocity of a two-phase fluid
$\mathbf{u}^*$ = predicted velocity of a two-phase fluid
V = impact velocity
We = Weber number
X = vertical distance between the centers of the two droplets
Δt = time step
Δx = lattice spacing
$\delta_{\alpha\beta}$ = Kronecker delta
ε = convergence criteria
η = surface wetting force
θ_w = static contact angle
κ_f = constant parameter determining the width of interface
κ_g = constant parameter determining the strength of surface tension
μ = viscosity
ξ = direction normal to the interface
$\xi_{\max}$ = maximum spread factor
ρ = density
$\bar{\rho}$ = averaged density
σ = surface tension
τ_f = relaxation time for f_i
τ_g = relaxation time for g_i
τ_h = relaxation time for h_i
ϕ = order parameter to distinguish two phases
ψ = bulk free-energy density
Ω = wetting potential
Ω_i = collision operator

Subscripts

G = gas phase
L = liquid phase
α, β, γ = Cartesian coordinates

I. Introduction

THE collision of droplet(s) on solid or liquid surfaces is a phenomenon that occurs widely in nature. Impact of drops on solid surfaces is a very common phenomenon in many modern engineering applications ranging from ink-jet printing to spray cooling, internal combustion engines to spray painting and plasma spraying, and more recently in microfabrication and microchannels [1]. Experimental investigations have been carried out extensively to study the mechanism of droplet impact and the subsequent spreading process on a dry/wet surface [2–4]. These have been directed toward studying the heat transfer to a droplet that falls on a dry hot surface [2] and subsequently breaks off into daughter drops, droplet spreading behavior on a rough surface and the formation of a water sheet [3], and impact of a single drop on a thin liquid film to delineate the parameter range for which the drop can deposit on the film, or splash forming a crownlike structure which grows with time and may lead to subsequent pinch-off of a small secondary droplet from the rim of the crown [4]. Numerical investigations of a droplet splashing phenomenon have primarily been focused toward impact dynamics on a wet surface with a variable thickness of the liquid layer [5–9].

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