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RESEARCH PAPER

Phase-field simulation of impingement and spreading of micro-sized droplet on heterogeneous surface

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Abstract A numerical investigation on the impingement and spreading of a micro-sized droplet with nonzero impact velocities on a surface with heterogeneous wettability is presented in this paper. The numerical model was implemented through phase-field simulation with finite element formulation. A simple scheme based on interfacial phase-field function gradient was proposed to track the velocity of contact line which was required to specify the dynamic contact angle based on hydrodynamic theory and molecular kinetic approach. For a circular pattern with a higher wettability than the surrounding surface, the impinging droplet final spread diameter decreases with an increasing wettability contrast. The droplet conforms to the circular patterns with smaller diameters up to a threshold, which is dictated by the wettability of the surface surrounding the pattern. Impact velocity of the droplet affects the maximum spread diameter but not the final conformability to a wettability pattern. Impingement and anisotropic spreading of a droplet on a stripe pattern was also demonstrated in a three-dimensional simulation. The high wettability contrast between the inner and outer regions of the stripe pattern confines droplet spreading and elongates the droplet in the direction of the stripe. These simulations demonstrated the conditions for a jetted micro-sized droplet to be confined to a specific area through wettability patterning, which can potentially improve the precision of current inkjet printing technology.

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Keywords Phase-field method · Finite element method · Wettability · Heterogeneous surface · Droplet impingement

List of symbols

Ca_s	Spreading capillary number
Cn	Cahn number
D	Initial diameter of droplet (m)
D^*	Dimensionless droplet spread diameter
D_h	Diameter of circular pattern (m)
D_h^*	Dimensionless diameter of circular pattern
Fr	Froude number
f_o	Characteristic frequency of molecular displacement (Hz)
f_o^e	Equilibrium frequency of molecular displacement when retarded only by solid–liquid interaction (Hz)
f_ε	Defect force per unit length (N m^{-1})
G	Chemical potential (Pa)
g	Gravitational acceleration (m s^{-2})
$\mathbf{g}$	Gravitational acceleration vector (m s^{-2})
$\mathbf{g}^*$	Dimensionless gravitational acceleration vector
H	Droplet height (m)
H^*	Dimensionless droplet height
h	Planck constant (m^2 kg s^{-1})
k_b	Boltzmann constant (m^2 kg s^{-2} K^{-1})
L	Macroscopic characteristic length (m)
L_m	Microscopic characteristic length (m)
$\mathbf{n}$	Normal vector to surface
Pe	Peclet number
p	Pressure (Pa)
p^*	Dimensionless pressure
Re	Reynolds number
r	Radial displacement (m)
T	Temperature (K)
t	Time (s)

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