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Non-dimensional numerical study of droplet impacting on heterogeneous hydrophilicity/hydrophobicity surface

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ABSTRACT

Heterogeneous hydrophilicity/hydrophobicity surface involves many applications such as dropwise condensation, but droplet dynamics on such surface is not well understood. Here, droplet impacting on heterogeneous surface was described by non-dimensional conservation equations. The volume of fluid (VOF) method tracked the gas-liquid interface. A set of parameters such as impacting velocity, drop size etc. were combined to form three key non-dimensional parameters of *We*, *Oh* and β_i (size ratio of hydrophilic dot to drop). Numerical simulations agreed with impacting outcomes on uniformly hydrophilic or hydrophobic surface in references. For drop dynamics on heterogeneous surface, the regime maps containing complete-drop, single-drop-pinching-off and multi-drops-pinching-off were demonstrated over a wide range of $We = 1–100$, $Oh = 0.001–1$ and $\beta_i = 0.5–10$. The increased β_i enlarges the complete drop regime. The single-drop-pinching-off mode involves combined wall adhesion and surface tension induced short wave mechanism, while the multi-drops-pinching-off mode is caused by the propagation and interference of capillary waves from both ends of an elongated liquid column. The superposition principle was found for the first time: drop patterns include an adhesion part on the wall, similar to that on a hydrophilic surface, plus a rebounding part, similar to that on a super-hydrophobic surface. Spreading diameters are increased by β_i at smaller *We* and moderate or larger β_i, but they are not influenced by hydrophilic dot sizes at large *We*, under which inertia force thoroughly suppress effects of surface tension and wall adhesion. The present findings of this paper are helpful to design hydrophilic/hydrophobic surface and ensure droplet completeness during the impacting process.

1. Introduction

Super-hydrophobic surfaces are characterized as having low surface energies and water contact angles (WCA) greater than 150°. These surfaces exhibit the lotus effect to have applications such as dropwise condensation, self-cleaning and oil-water separation [1–5]. Alternatively, hydrophilic surfaces exhibit WCA less than 90°. Hydrophilic materials are encountered in our daily life and they are also ubiquitous in nature (e.g., plant and tree leaves, Nepenthes pitcher plant) [6]. Combining the two states of hydrophilicity and hydrophobicity on the same surface opens exciting new functionalities and possibilities in a wide variety of applications from dropwise condensation, cell, droplet, and hydrogel micro-arrays for screening to surface tension confined microchannels for separation and diagnostic devices [7–13]. The important concept for these applications is to form micro/nano droplet array on the combined surface. The cell embedded in droplet array should not be crossed infected. In other words, droplets should not be mutual interfered. The requirement of "*one cell, one well*" should be satisfied [14].

Recently, droplet formation on super-hydrophobic surface patterned with hydrophilic dots has drawn a lot of interest. The phenomena and related mechanisms are not well understood at this stage. This paper tries to answer the question of how to satisfy the requirement of "*one cell, one well*" by non-dimensional numerical simulation. Fig. 1 shows the studied problem. A droplet with its diameter of d_0 impacts on the hydrophilic dot, having a diameter of d_i. The maximum spreading diameter is d_{max}. The drop will have a stabilized diameter of d_s (see Fig. 1b). The ordered hydrophilic dots form the dot array. The distance between two centers of hydrophilic dots is d_p.

Fig. 2 shows top and side views of the impacting process. Two drops are not interfered if $d_p > d_{max}$ (see Fig. 2a). Alternatively, the two drops may be interfered if $d_p < d_{max}$ (see Fig. 2b). Another important issue is to ensure the non-breakup during drop impacting process. Fig. 2c is a perfect case with complete drops on the patterned surface. However, if a daughter drop is generated, a

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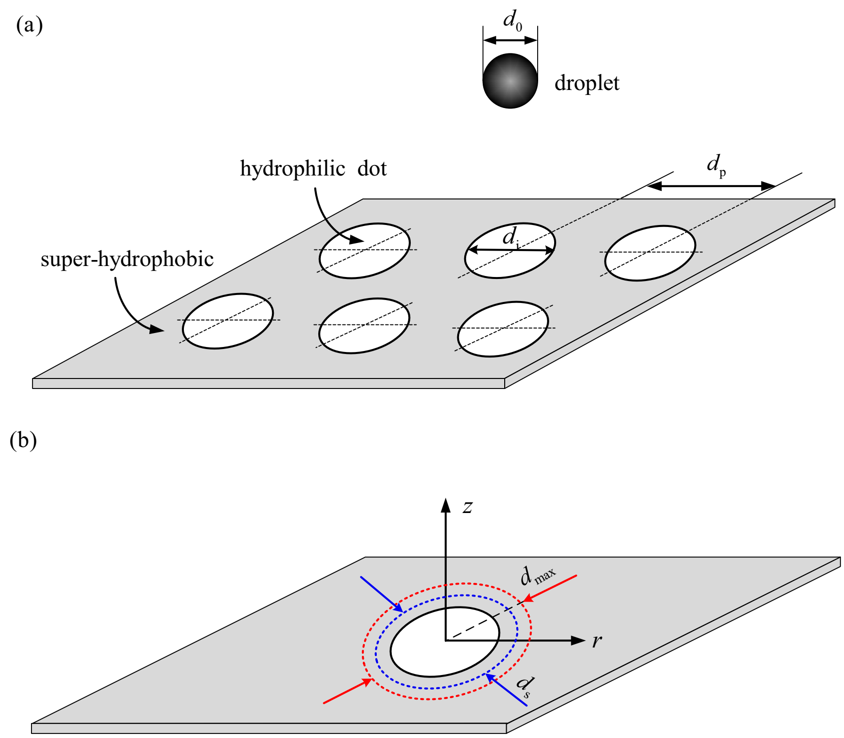

Fig. 1. A drop impacts on hydrophobic surface patterned with hydrophilic dots (d_0 is the initial drop diameter, d_i is the hydrophilic dot diameter, d_{max} is the maximum spreading diameter, d_s is the stabilized drop diameter, d_p is the distance between two hydrophilic dots).

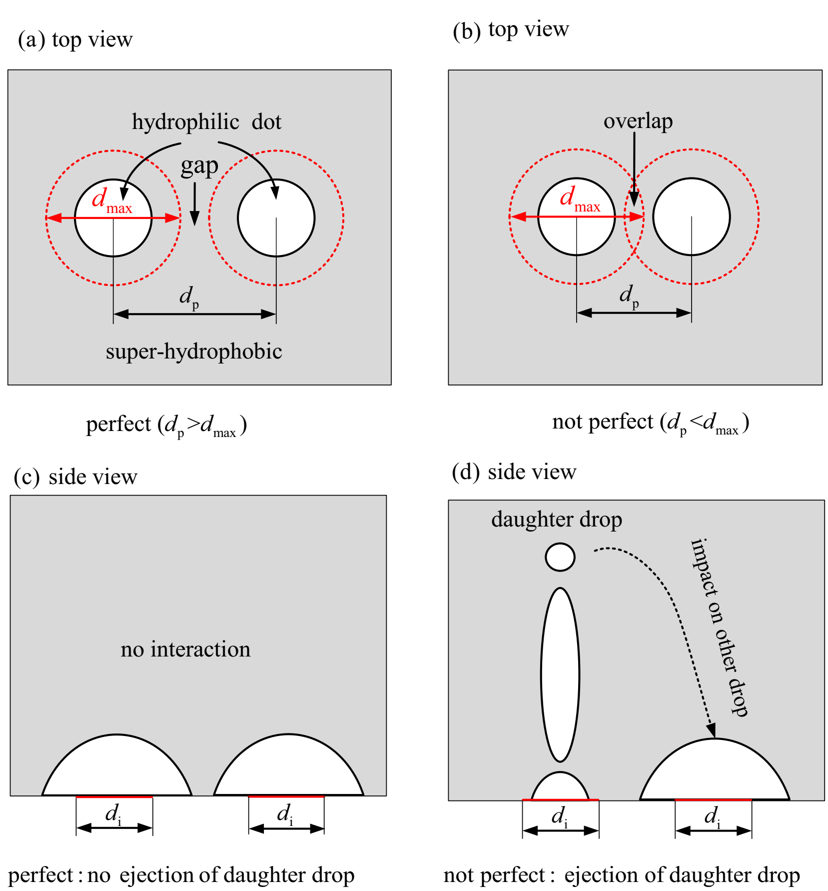

Fig. 2. The interaction or non-interactions between two drops during their impacting on the hybrid surface.