DROP IMPACT ON (SUPERHEATED) SURFACES: HIGH-SPEED COLOR INTERFEROMETRY ALLOWS TO QUANTIFY THE ROLE OF AIR & VAPOR LAYER

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Summary A drop impacting on a solid surface deforms before the liquid makes contact with the surface, due to the pressure buildup under the droplet. We directly measure the time evolution of the air layer profile under the droplet using high-speed color interferometry, obtaining the air layer thickness before and during the wetting process. Based on the time evolution of the extracted profiles obtained at multiple times, we account for the wetting mechanism and bubble entrapment [1]. The vapor layer profile between an impinging droplet and superheated surfaces is also experimentally quantified with the present technique [2]. These profile measurements offer a benchmark for theories of drop impact. In addition, we study the dimensionless maximum spreading ($\gamma = D_m/D_0$) of the droplet as a function of Weber number (We) in the film boiling regimes [2].

INTRODUCTION

Drop impact on solid surfaces, beside its inherent beauty, has been playing an increasingly important role in industrial processes as diverse as ink-jet printing, spray cooling, and spray coating. Since it was first studied in 1876 by Worthington [3], the phenomenon has received tremendous attention from researchers, yet our understanding of this subject is still far from being complete (see review article [4]). A challenge in studying this problem arises from widely different time and spatial scales of the involved effects. Another difficulty comes from determining relevant physical parameters that govern the impact dynamics. For example, beside apparent parameters such as the surface roughness and wettability, the liquid viscosity, surface tension, and density, it was recently discovered that the ambient pressure is also crucial as it dictates the splash threshold after impact [5]. This finding and subsequent studies [6-9] suggest that the air layer between an impinging droplet and a solid surface may have significant effects on the impact's outcomes. Hence, it is essential to understand how the drop and the surface interact through the air layer. There is, however, a lack of detailed measurements of the air layer thickness at the earliest time of impact, as well as the formation of the entrapped bubbles.

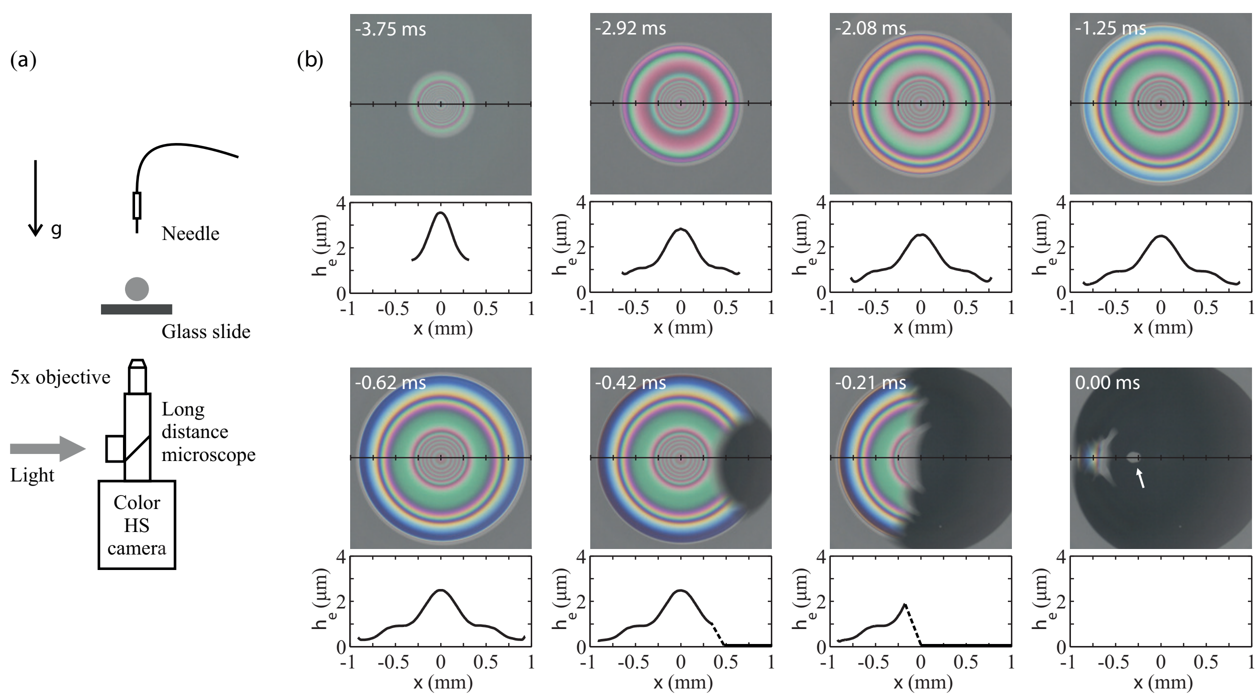

Figure 1. (*a*) Schematic of the experimental setup (not drawn to scale) used to study droplet impact on smooth surfaces. (*b*) Snapshots of interference patterns obtained just before and during drop impact and their corresponding calculated profiles ($V = 0.22$ m/s, $D = 2$ mm). The time $t = 0$ is defined as moment of total wetting.

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EXPERIMENTS

In Fig. 1a, we show a schematic of the experimental setup for the present work. We generate water drops by using a syringe pump to push liquid out of a fine needle. The drop falls on a microscope glass slide (average roughness ≈ 10nm). The drop typically has diameter $D \approx 2\,\text{mm}$ and its velocity can be adjusted by varying the needle's height H. We capture the drop impact from the bottom with a color high-speed camera connected to a long working-distance microscope and a 5X objective. The field of view achieved by this combination is 2 mm. We illuminate the impact area from below by supplying white light from a high-intensity fibre lamp to the microscope's coaxial light port. Light of the same wavelength coming from the bottom, upon reflection from both surfaces of the air film between droplet and glass plate forms interference patterns recorded by the camera.

RESULTS

We develop a high-speed color interferometry technique (see Ref. [1] for the details) to directly measure the complete air layer profile and its evolution under an impacting drop. In Fig. 1b, we show interference patterns obtained during drop impact ($V = 0.22$ m/s and $D = 2$ mm) and their corresponding thickness profiles of the air layer. The profiles show that the dimple's height gradually reduces, while the liquid continues spreading in the radial direction. At $t = -0.42$ ms, the liquid starts wetting the glass surface at one point along the rim of the air layer and then propagates to the other side; the wetting process happens faster along the rim where the air thickness is smallest and finally traps air bubbles (indicated by an arrow at $t = 0$ ms). For experiments done under the same conditions, although the time that wetting occurs varies, we observe the same bubble-trapping dynamics, that is, the wetting front propagates faster at the rim and finally enclose the air pocket underneath the drop. Additionally, entrapped bubble size as a function of the Stokes number is experimentally quantified and compared with theory and numerical simulations [10].

Next, we extend the study to droplet impact dynamics on *superheated* surfaces, and directly measure the vapor layer thickness between an impacting droplet and superheated surfaces [2]. We show that the dimensionless maximum spreading γ of impacting droplets on the heated surfaces (Figure 2) shows a universal scaling with the Weber number We ($\gamma \sim We^{2/5}$) – regardless of surface temperature and of liquid properties – which is much steeper than for the impact on non-heated (hydrophilic or hydrophobic) surfaces ($\gamma \sim We^{1/4}$) [11]. The origin of this steeper scaling is the vapor shooting out under the impacting droplet and dragging liquid along.

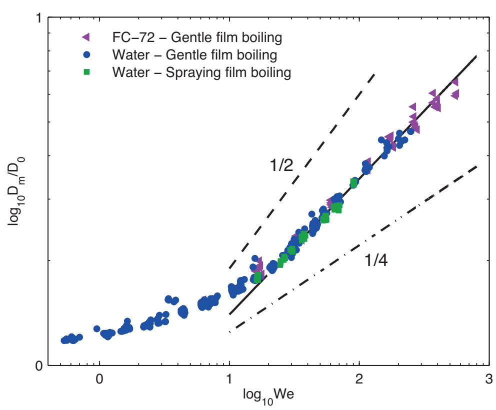

Figure 2. Log-log plot of the maximum spreading diameter normalized by the drop's diameter ($\gamma = D_m/D_0$) versus the Weber number (We) for impact in both gentle and spraying film boiling regimes. FC-72 in the gentle film boiling regime (solid left triangles), water in the gentle film boiling regime (solid circles), water in the spraying boiling regime (solid squares). The surface temperature $250^o\text{C} \leq T \leq 560^o\text{C}$. The solid line represents the best fit for the experimental data for $We > 10$ in the present study with the slope 0.39. The dashed line represents the scaling $D_m/D_0 \sim We^{1/2}$ resulting from the balance between the drop's initial kinetic energy and its surface energy at maximum deformation. The dashed-dotted line represents the scaling $D_m/D_0 \sim We^{1/4}$ resulting from a momentum argument [11].

CONCLUSION

In conclusion, we have used high-speed color interferometry to measure the complete profile and its evolution of the air layer (and vapor) under an impacting drop. From the experimental measurements, we account for the wetting mechanism which results in entrapment of bubbles after impact. Our results offer a benchmark for theories of drop impact. In addition, we also experimentally study droplet impact dynamics on heated surfaces [2].

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