Proceedings of the 18th UK Heat Transfer Conference
9-11 September 2024, Birmingham
UKHTC2024-083

PROBING HYDRODYNAMIC AND THERMAL BEHAVIOUR OF VOLATILE DROPS IMPACTING HOT SURFACES NEAR THE LEIDENFROST POINT

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1. ABSTRACT

The present contribution investigates hydrodynamic behaviour of a volatile drop (FC-72) impinging onto a heated substrate and accompanying heat transfer in the vicinity of the Leidenfrost point, the temperature above which liquid drops are lifted by their own vapour due to instant evaporation. A combination of temperature sensitive paint (TSP) and high-speed cameras allowed to capture drop impact and local surface temperature distributions simultaneously. The experiment successfully captured temperature variations which indicated wetting/ drying regions over a range of temperatures across the Leidenfrost point.

2. INTRODUCTION

Transition between film boiling and nucleate boiling is a key design parameter for drop-based cooling applications e.g., spray cooling. However, the prediction of boiling transition is highly challenging due to the lack of understanding of local and transient hydrodynamic and thermal nature. Kita et al. reported their experiment and detailed analysis, suggesting that local wetting may exist in the Leidenfrost regions, and its area could increase when approaching a transition to the nucleate boiling regime [1]. Therefore, appropriately modelling the local wetting and thermal behaviour during boiling transition is crucial, which calls for detailed experimental insights. An experimental system was designed to allow imaging of both drop impact and accompanying heat transfer in the vicinity of the substrate surface, using a temperature sensitive paint (TSP). As our current TSP can only be operated at relatively lower temperatures, imaging tests were performed with a low boiling point refrigerant, i.e., FC-72. This contribution reports some successful thermal images indicating local wetting/ dry regions, which can be linked to the outcome of drop impact.

3. METHDOLOGY

To capture temperature distributions at the surface, a sapphire window of 50 mm diameter and 5 mm thickness was painted with a 3 µm layer of ruthenium-based phosphorescent compound which acts as the TSP [2]. The emission intensity is known to decrease at higher temperature due to thermal quenching and therefore can be used to infer

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the temperature at the painted surface after an appropriate calibration. To protect the TSP layer from the test liquid and external lights, the surface was further coated with a 1 µm aluminium layer.

Our experimental setup is illustrated in Fig. 1. The sapphire substrate was mounted on a copper block whose temperature can be regulated by cartridge heaters. An inverted microscope was constructed underneath the substrate to excite the TSP with a UV LED (Thorlabs SOLIS-405) and capture its emission by a high-speed camera (Photron FASTCAM Mini AX100). A drop of FC-72 (boiling point at 56 °C) was ejected by a syringe, resulting in the drop diameter $d \approx 2$ mm and the Weber number $We = \rho u^2 d/\sigma \approx 20$, where ρ is the density, u the velocity and σ the surface tension. Another high-speed camera (Phantom Miro Lab110) was used to capture drop impact on the surface.

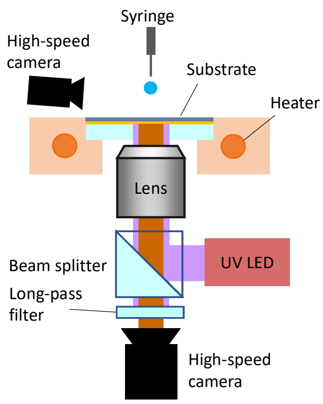

Fig. 1 Experimental setup.

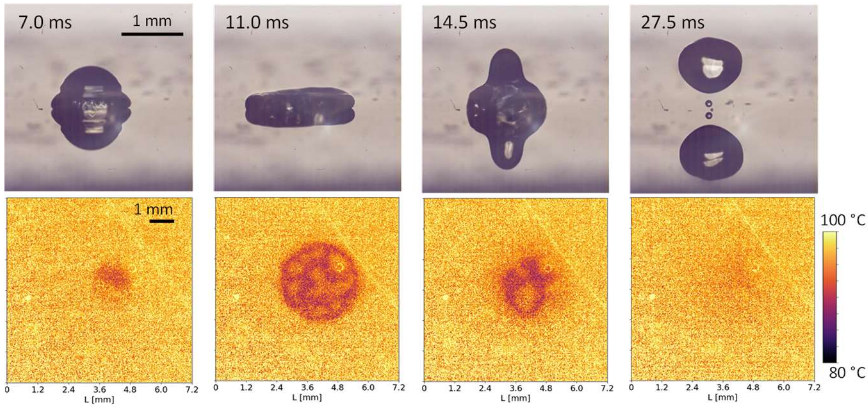

Fig. 2 Snapshots of a FC-72 drop (upper) impacting the substrate and temperature distributions of the TSP layer (bottom). The initial substrate temperature is 98 °C.

4. RESULTS

Fig. 2 presents snapshots of impact behaviour of a FC-72 drop on the substrate heated at 98 °C, which was slightly above the Leidenfrost temperature under the experimental condition, along with temperature distributions obtained from the TSP visualisation. Evidently, surface temperature decreased significantly in regions the drop impacted the substrate, indicating an initial wetting even above the Leidenfrost regime. During the spreading stage (i.e., 11.0 msec), number of warm spots, corresponding to dry areas, were identifiable. Nucleate boiling continued until the drop retracted due to the surface tension while at the second impact and afterwards, no wetting regions were observed.

5. CONCLUSIONS

The present paper have successfully demonstrated the potential of hydrodynamic and thermal imaging of drops impacting a hot surface at a reasonable spatiotemporal resolution, which could provide insight into transition of boiling regimes during spray cooling.

REFERENCES

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