Experimental characterization of heat dissipation produced by multiple drop impacts on a textured surface

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Research background

Drastic miniaturization of electronic components and massive use of intensive computing in the world has created an urgent demand for innovative cooling techniques to maintain the electronic devices safely below the damage limit temperature. This is also a major challenge to reduce energy and liquid coolant (mainly water) consumption. Today, heat dissipation from supercomputer chips is of the order of 100 W/cm^2, which exceeds the capabilities of single-phase (air and liquid) cooling technologies. Developers are focusing therefore their attention on two-phase cooling techniques, which exploit both the coolant's sensible and latent heat to dissipate greater amounts of heat. Among them, spray cooling appears to offer the best balance between a high heat flux removal, a uniform cooling over large areas, and a large inventory of liquids [1].

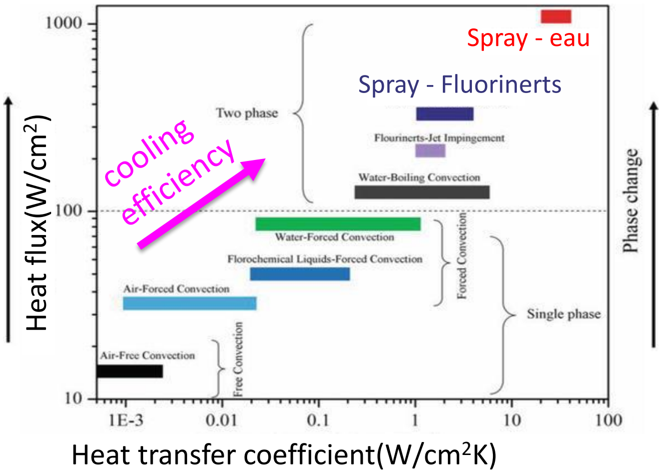

Figure 1: Comparison of the performances of different cooling technologies [2]

A comprehensive knowledge of the physical phenomena that occur when droplets impinge on a hot surface, is expected to help improving the design spray cooling systems. Today, predicting the cooling performance of a spray is hardly possible due the dependence on multiple parameters related to the fluid flow and the surface and fluid properties.

Research objectives

The goal of this research project is to gain in the understanding of the physical phenomena that control spray cooling of hot surfaces. So far, research work in the group was mainly on single drop impacts and the film boiling regime. Models inferred from this research work incorporate a substantial number of physics, but their usability at the spraying scale is a major concern. When multiple droplets impact the surface, hydrodynamics and thermal interactions between neighbor droplets adds some complexities compared to a single drop impact. An upscaling in the modeling will be done by studying configurations of incremental complexity.

Experiments will start from the single drop impact, then rapidly continues to the intermediate scale involving a cluster of droplets (still small but representative of certain interaction effects), and finally reaches the spray scale.

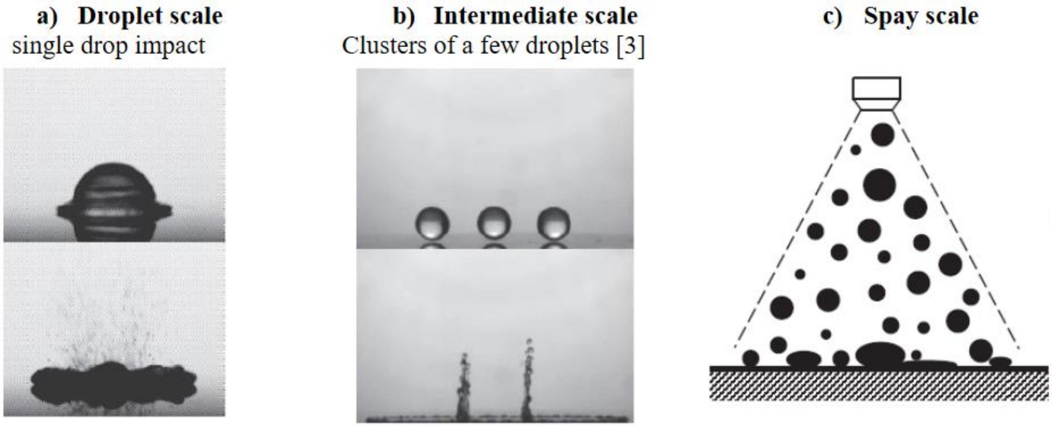

Figure 2: Scales considered in the studies of spray cooling. From the fundamental study of single drop impact to the interactions in clusters of droplets to a whole spray

- *Study of droplet clusters*

  At the intermediate scale, the goal will be to investigate heat transfer and hydrodynamics of the impact of a small cluster of interacting droplets. Basically, the interactions between the droplets can be of different type. They can be of a hydrodynamic type: the liquid lamella of a spreading drop collides with that of a neighboring or preceding droplet. Interactions can also involve conjugate heat transfer within the solid wall. The cooling induced by a drop locally changes the wall temperature for neighboring and upcoming droplets. To be relevant, experiments will have to consider impacts of adjacent droplets (typically two and three droplets) that can occur at the same time (like in Figure 2) or that can be temporally shifted.

- *Study at the spray scale*

  A spray adds further complexity compared to the cluster of droplets. For a high rate of drop impact, a continuous liquid film can form on the surface, the thickness of which can have a significant influence on spray cooling. Several spray nozzles will be selected to achieve differentiated test conditions in terms of liquid flowrate and Sauter mean diameter. The expected results will be a comprehensive database that will be used to estimate cooling performances of sprays as a function of the spray characteristics.

Research methodology

The research work is mainly experimental and is intended for a candidate with a strong interest in experiments and optical measurement methods. Advanced measurement techniques are developed in the research team, which will help for the experiments. Beside rapid shadow imaging to characterize the droplet shape and spreading during the impact [4], the temperature of the solid surface can be monitored by high-speed infrared thermometry [5] at several thousand frame per second (figure 3). Laser-induced fluorescence [6] is used to obtain instantaneous images of the liquid temperature during the spreading of the droplets (figure 4). New approaches will have to be developed to study the complex fluid flow and mixing when droplets merge at the impact. An idea is to seed the droplets with different fluorescent dyes to measure their relative concentrations in the liquid.

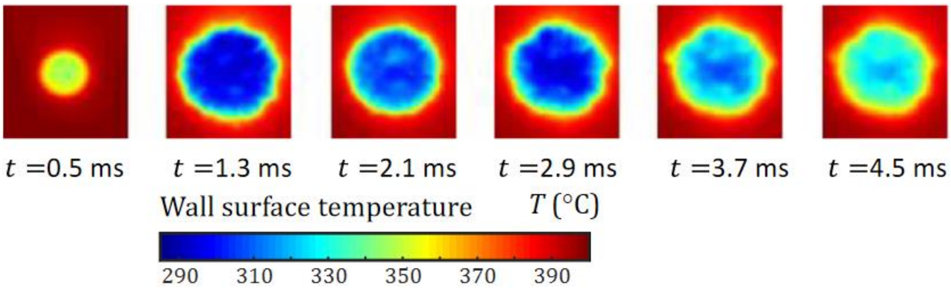

Figure 3: Time evolution of the solid surface characterized by infrared thermography [5]

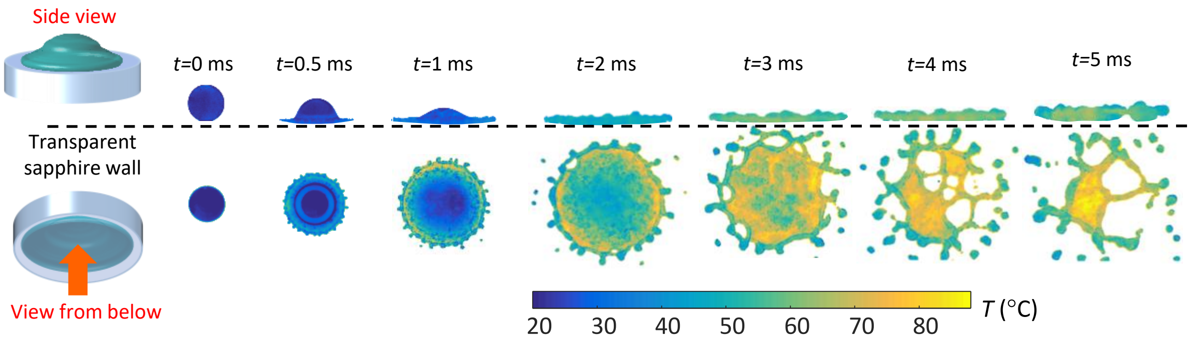

Figure 4: Temperature field inside a water spreading over a sapphire wall heated at 600°C [6]

Level and advantage of the hosting institution on this project

We will provide state-of-the-art equipments, well in line with the needs of the project described above. Our laboratory, LEMTA (https://lemta.univ-lorraine.fr/milieux-fluides-rheophysique/transferts-dans-les-fluides/) has already the optical equipment necessary for the experiments planned in the project (high-speed camera in the visible and infrared domains, continuous wave lasers and pulsed lasers, sCMOS cameras…). In addition, the research team has many years of expertise in the field with many publications concerning drop impacts on superheated surface. Several studies have been conducted in recent years on single drops [6,7], monodisperse droplet streams [8] and sprays [9].

The PhD thesis is part of a project which started in November 2020.This project involves three laboratories (LEMTA, IJL and IMFT), in the fields of fluid mechanics, thermal engineering, interfacial phenomena and materials science. This project aims to improve the performances of spray cooling, especially by tailoring the properties of the solid surface through the addition of nano/micro-textures and a physicochemical functionalization.

Our Offer

We offer a challenging full-time PhD position, in an inspiring multidisciplinary environment.
A minimum gross salary of 1769 euros/month and 44 days of vacation. The appointment is for 3 years preferably from 1 October 2021.

Applications are invited for a MSc. degree in Mechanical and Thermal Engineering or a related discipline with excellent results. Prior knowledge in fluid mechanics, phase change phenomena is required. Ideally, the candidate should also have a solid background in optical techniques applied to fluids mechanics and IR thermography. We welcome candidates with strong communication skills who like to present their work at conferences and (project) meetings. Fluency in English (and/or in French) is required, both spoken and written.

Applications with a curriculum vitae and the name of two referee should be addressed to Dr. G. Castanet: guillaume.castanet@univ-lorraine.fr.

References

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