SIMPPÉ

PhD Topic

(Doctoral School EMMA)

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TITLE : Study of heat transfer characteristics at the impact of a droplet onto a heated wall near the critical heat flux

SUPERVISION

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Place where the PhD will take place : LEMTA, Vandoeuvre-lès-Nancy, France

CONTEXT:

With the increasing use of computer technology, the number of datacenters is expected to continue to grow rapidly. Almost all the electric power supplied to electronic equipment (servers, networks and storage means) is converted into thermal energy by Joule effect, which implies having efficient cooling systems to prevent potential damage to the circuit components. At the world scale, the consumption of datacenters is roughly 300 TWh, which almost corresponds to the 2/3 of the electric consumption of France and 50% of its emissions of greenhouse gases. In this context, innovative and low environmental impact methods are required to dissipate high thermal fluxes.

Spray cooling has several advantages: compactness, uniformity of heat removal and small fluid inventory. In some of the envisaged solutions, a non-electrically conductive liquid is sprayed directly on the electronic components, while in some others, the liquid impinges a surface (in close contact to the electronic component) which is specifically designed to enhance heat exchanges. Most of the studies reported in the literature have been focused on correlating between the spray characteristics (mean droplet diameter, velocity) and the efficiency of spray cooling. However, the application range of these empirical correlations is usually limited to a small number of cases. To develop more global and predictive models of spray cooling, fundamental investigations dealing with individual impact of droplets onto a heated surface are also very valuable.

TOPIC DEVELOPMENT:

Many open questions remain about the phenomena of drop impact onto a superheated solid surface. Depending on the surface temperature, several heat transfer regimes can be encountered: a regime where evaporation and convection predominate, nucleate boiling, transition boiling, and film boiling. These different regimes are associated with different heat transfer mechanisms at the solid surface (figure 1). They also correspond to different behaviors of the impinging droplet. For instance, the transition between breakup and rebound of the impinging droplet, the size of secondary emitted droplets, the wetting and the formation of a liquid film, are totally different in these boiling regimes. The frontiers between these different regimes and the intensity of heat and mass transfers are still poorly known.

Innovative non-intrusive measurement techniques are currently under development by the team "Transfers in Fluids" in order to characterize heat transfer when a single droplet impinges onto a hot solid surface. Techniques based on Laser Induced Fluorescence (LIF) and Infrared Thermography (IRT) recently succeeded in obtaining instantaneous images of the temperature field within the droplet and at the surface of the solid wall (see figures 2 and 3). By solving an inverse heat conduction problem within the solid wall, it was also possible to reconstruct the heat flux extracted at the wall by the droplet. These spatially and temporally-resolved imaging techniques will now be used to gain insight into the mechanisms associated with heat and mass transfers and to develop models, which is the main objective of this PhD thesis. Until now, experimental investigations were focused on the film boiling regime, which is characterized by the formation of a thin vapor layer (Leidenfrost effect) between the liquid drop and the solid surface (figures 1 and 2). However, this situation is not desirable for an efficient cooling since the vapor layer reduces drastically heat conduction to the liquid. Investigations will be therefore extended to other boiling regimes where the droplet behavior is significantly different. The emphasis will be placed more particularly on the regime of transition boiling. In this boiling regime, the bubble formation is so rapid that a vapor film begins to form at the solid surface. However, at any point on the surface, the conditions may oscillate between film and nucleate boiling. This situation is very sensitive to the wetting properties (surface topology, material) of the surface. As the fraction of the total surface covered by the vapor with increasing surface temperature, the heat flux decreases in the transition boiling with increasing the surface temperature (figure 4). Also, there is a maximum of heat flux called the critical heat flux (CHF), which limits in practice the thermal flux that can be extracted in cooling systems. Studies will be undertaken in order to characterize the effect of a structuration of the solid surface on CHF. Micro/nano patterning of solid surface will be achieved in cooperation with Jean Lamour Institute, a laboratory in Nancy specialized in material science. Since CHF also depends on the nature of the liquid, several liquids will be considered, for example, fluoroketones which are excellent liquid coolant and electric insulators.

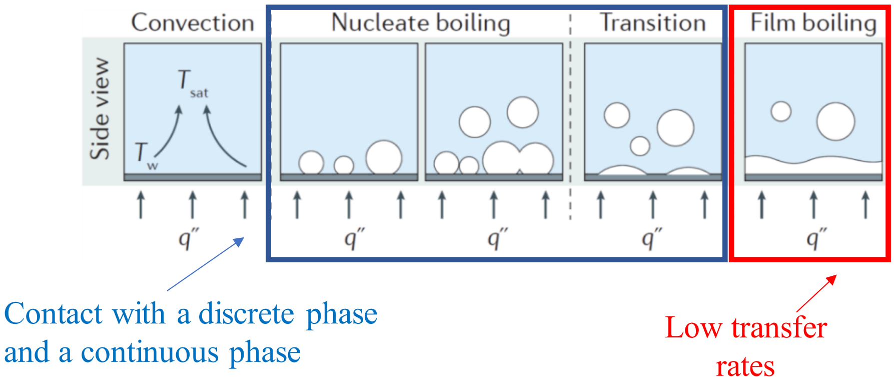

Figure 1: Boiling regimes and schematic view of the phenomena at the solid surface

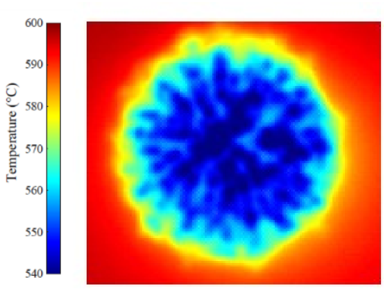

Figure 2: Surface temperature obtained by Infrared Thermography (IRT). Example of measurement carried out in the film boiling regime

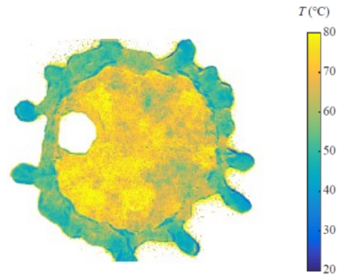

Figure 3: Liquid temperature measurements based on LIF imaging. Example of measurement carried out in the film boiling regime

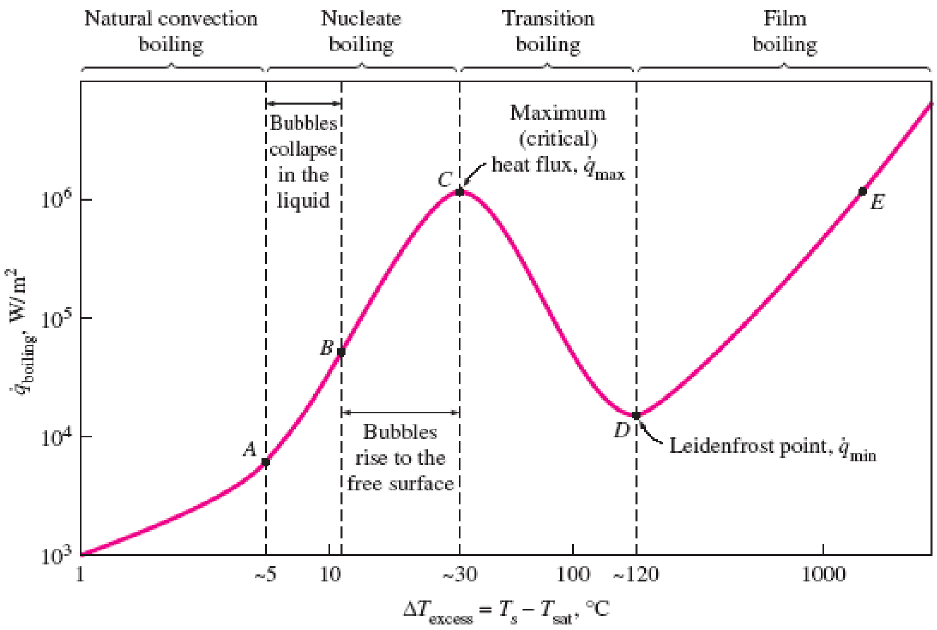

Figure 4: Example of boiling curve