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High-power electronics thermal management with intermittent multijet sprays

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ABSTRACT

Thermal management plays a crucial role in the development of high-power electronics devices, e.g. in electric vehicles. The greatest energy demands occur during power peaks, implying dynamic thermal losses within the vehicle's driving cycle. Therefore, the need for devising intelligent thermal management systems able to efficiently respond to these power peaks has become a technological challenge. Experiments have been performed with methanol in order to quantify the maximum heat flux removed by a multijet spray to keep the 4 cm^2 surface temperature stabilized and below the threshold of 125 °C. A multijet atomization strategy consists in producing a spray through the multiple and simultaneous impact of N_j cylindrical jets. Moreover, the spray intermittency is expressed through the duty cycle (DC), which depends on the frequency and duration of injection. Results evidence that: i) a shorter time between consecutive injection cycles enables a better distribution of the mass flow rate, resulting in larger heat transfer coefficient values, as well as higher cooling efficiencies; ii) compared with continuous sprays, the analysis evidences that an intermittent spray allows benefiting more from phase-change convection. Moreover, the mass flux is mainly affecting heat transfer rather than differences induced in the spray structure by using different multijet configurations.

1. Introduction

Thermal management is known to play a crucial role in the performance of high-power electronic devices, such as converters and inverters used in the powertrain of electric and hybrid vehicles. Power density requires high currents, implying high temperatures and demanding optimized thermal control to avoid equipment shutdown. However, there is also an effort to reduce the weight and volume of power electronic components and, consequently, reduce cost, emphasizing the serious limitations of the usual cooling techniques which use large heatsinks and ventilators. This is why direct liquid cooling has been identified as one of the most promising for developing innovative and intelligent thermal management (ITM) systems [1].

The magnitude of thermal loads which researchers are attempting to overcome is of the order of 150–200 W/cm^2 while keeping the devices' operating temperature controlled and below 125 °C [2]. However, none of the works reported so far on the cooling of power electronic devices took into account an active control of the cooling process required for the development of intelligent thermal management systems, particularly during periods of transient heat loads. The active control of heat transfer can be interpreted as a spatial control over droplet density, as suggested by Pavlova *et al.* [3], or as a temporal control over the vaporization rate using an intermittent spray by proper matching the frequency (f_{inj}) and duration of injection (Δt_{inj}) [4]. The later approach constitutes the cooling technique explored in this work and allows a cooling system capable of responding to transient heat dissipation requirements with liquid savings up to 90%, considering the same efficiencies reported for continuous spray cooling [4,5].

In Intermittent spray cooling (ISC), the parameter controlling heat transfer has been previously identified as the duty cycle ($DC = f_{inj} \cdot \Delta t_{inj}$) [4], through which one may control the time between consecutive injections and, consequently, the greater or lesser degree of saturation near the impinging surface, thus influencing the vaporization rate. However, the same DC can be obtained with different matches between the frequency and duration of injection, therefore, the question remains as to which is the best and most efficient choice. In the work reported here, the degree of interaction between multiple consecutive injection cycles associated with the frequency of injection is investigated, as well as its implications for the efficiency of the cooling process.

Furthermore, the spreading of the cooling liquid throughout the heated surface implies a careful choice of the atomization strategy. A tailored spray would break into small, well dispersed droplets, which, upon impact, should deposit on the surface for cooling

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