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Heat transfer correlation models for electrospray evaporative cooling chambers of different geometry types

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ABSTRACT

Development of future electronics for high speed computing requires a silent thermal management method capable of dissipating a broad range of heat generated from application-specific integrated circuits, while keeping the skin temperature below 45 °C. Electrospray evaporative cooling (ESEC) chambers show promise because of their ability to dissipate a broad range of heat within a relatively small size. However, the development and the optimization of ESEC chambers are currently restricted, in part due to the lack of sufficient empirical heat transfer correlations. This paper investigates empirical heat transfer correlations for ESEC chambers with three different geometry types. Since the unstable multi-jet behavior of an ESEC chamber is similar to that of a free-surface traditional impinging liquid jet, these correlations are based on the traditional impinging liquid jet's empirical correlations, yet are modified to factor in the electric field effect. The results show that the heat transfer enhancement ratio correlations and the Nusselt number correlations for different ESEC chambers cover more than 83% of the experimental data, within ±10% deviation. The sensitivity analysis results and experimental data prove that the variation in the enhancement ratio is sensitive to that of the potential and the flow rate. It is not sensitive to the geometric factor of the same ESEC type. This paper presents a natural convection correlation for chip-scale, heated, flat surfaces when the Rayleigh number is below 3000. Further investigation is necessary to extend these heat transfer correlations to cover additional parameters for different thermal management applications.

1. Introduction

High heat flux density generated from the Army's sophisticated electronic systems is expected to escalate in a non-linear trend, especially for crucial defense systems, such as unmanned aerial vehicles (UAVs), radar, signal processing units, circuit boards, power modules, RF devices, power transmission devices, and communications and satellite systems. This increase in high heat flux density is due to defense systems needing to perform multi-purpose tactical missions processed by advanced onboard defense electronics, which contain dense microprocessors and will generate heat fluxes that exceed the capability of current commercial air and single-phase liquid cooling technologies. Without appropriate thermal management solutions, these sophisticated defense systems will not function sufficiently well for future missions. Therefore, an emerging integrated solution for future thermal management of defense systems is essential to increasing operation efficiency and to optimizing and ensuring top performance of the most important defense systems.

One leading thermal management solution for small form factor electronics is electrospray evaporative cooling (ESEC), which relies on Coulomb force for energy-efficient fluid atomization, has great potential to precisely control the formation of droplet sizes and droplet distribution. Hence, ESEC can be adapted to create a uniform temperature over the surfaces of electronic devices to optimize heat transfer performance, while keeping the skin temperature below 45 °C. In addition, since the ESEC chamber has no moving parts, its reliability is expected to be higher than that of traditional rotary fans. ESEC chambers are a silent, package-level thermal management solution that is suitable for mobile electronics and future electronics because the manufacturing processes are compatible with current semiconductor manufacturing processes. The cost can be reduced, and the heat transfer performance is expected to be better than cooling from outside of the packaged integrated circuits.

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