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Experimental and numerical investigation of confined oblique impingement configurations for high heat flux applications

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ABSTRACT

Breakthroughs in recent cutting-edge electronic technologies have become increasingly dependent on the ability to safely dissipate large amount of heat from small areas. Improvements in cooling methodologies are therefore required to avoid unacceptable temperature rise and at the same time maintain a high efficiency. Jet impingement is one such cooling scheme which has been widely used to dissipate transient and steady concentrated heat loads. The configuration examined in the present paper aims at wall-integrated inclined impinging jets in a confined environment. Coolant outlet is perpendicular to the plane of the impinging jets and is along the cross-flow direction. The main objective of the present work is to gain insight both experimentally and numerically into designing and analysis of a jet impinging cooling scheme for high heat density applications systems such as micro- and meso-scale electronic systems and trailing edge of a turbine blade. An overall enhancement of 150%–200% in the maximum heat transfer coefficient has been recorded both experimentally and computationally due to impingement and associated swirl. Results are presented to show the effect of the wall induced swirl and the associated enhanced heat transfer mechanism. The presence of fins between the jets further increases the cooling area and adds additional conduction area. The present scheme is therefore expected to provide alternatives for overcoming the existing heat distribution and cooling problems in high heat flux dissipating devices.

1. Introduction

Breakthroughs in recent cutting-edge electronic technologies have become increasingly dependent on the ability to safely dissipate large amount of heat from small areas. Improvements in cooling methodologies are therefore required to avoid unacceptable temperature rise and at the same time maintain a high efficiency. Jet impingement is one such cooling scheme which has been widely used to dissipate transient and steady concentrated heat loads. Some of its conventional applications are in cooling turbine blades and electrical equipments, drying of paper and textiles, and annealing of metals. Jet impingement has also been widely used to maintain relatively low, steady temperatures in devices which dissipate enormous heat fluxes such as lasers and x-ray anodes. Jet impingement can be implemented in three basic forms: free jet in which a fluid jet is issued in a less dense ambient, submerged jet in which fluid jet is issued in a similar or same fluid ambient and confined jet in which a fluid jet is confined between the orifice plate and a heated wall. Over the last decade, jet impingement has also become a viable candidate for high-powered electronic and photonic thermal management solutions and numerous jet impingement studies have been aimed directly at electronics cooling [1–6].

A general review about impinging jets on solid surfaces is given by Martin [7]. Basic investigations on single impinging jets with and without cross-flow were conducted for example by Goldstein and Behbahani [8], Lee et al. [9] and Spring et al. [10]. Metzger and Korstadt [11], Florschuetz et al. [12], Huang et al. [13], Lauffer et al. [14] and many others published heat transfer characteristics of impingement jet arrays. Womac et al. [15,16] have shown that higher heat transfer coefficients result from submerged jet conditions than from free-surface jet conditions for $Re \geq 4000$. The presence of a confining top wall in jet impingement causes lower heat transfer coefficients, thought to be caused by the recirculation of fluid heated by the target plate [17,18]. Huang et al. [19] suggest that confinement promotes a more uniform heat transfer distribution for the area enclosed by a non-dimensional radial distance from the stagnation point (r/D) of 5. The key parameters

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