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Localized and Time-Resolved Velocity Measurements of Pulsatile Flow in a Rectangular Channel

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Abstract : The exploitation of flow pulsation in micro- and mini-channels is a potentially useful technique for enhancing cooling of high-end photonics and electronics systems. It is thought that pulsation alters the thickness of the hydrodynamic and thermal boundary layers, and hence affects the overall thermal resistance of the heat sink. Although the fluid mechanics and heat transfer are inextricably linked, it can be useful to decouple the parameters to better understand the mechanisms underlying any heat transfer enhancement. Using two-dimensional, two-component particle image velocimetry, the current work intends to characterize the heat transfer mechanisms in pulsating flow with a mean Reynolds number of 48 by experimentally quantifying the hydrodynamics of a generic liquid-cooled channel geometry. Flows circulated through the test section by a gear pump are modulated using a controller to achieve sinusoidal flow pulsations with Womersley numbers of 7.45 and 2.36 and an amplitude ratio of 0.75. It is found that the transient characteristics of the measured velocity profiles are dependent on the speed of oscillation, in accordance with the analytical solution for flow in a rectangular channel. A large velocity overshoot is observed close to the wall at high frequencies, resulting from the interaction of near-wall viscous stresses and inertial effects of the main fluid body. The steep velocity gradients at the wall are indicative of augmented heat transfer, although the local flow reversal may reduce the upstream temperature difference in heat transfer applications. While unsteady effects remain evident at the lower frequency, the annular effect subsides and retreats from the wall. The shear rate at the wall is increased during the accelerating half-cycle and decreased during deceleration compared to steady flow, suggesting that the flow may experience both enhanced and diminished heat transfer during a single period. Hence, the thickness of the hydrodynamic boundary layer is reduced for positively moving flow during one half of the pulsation cycle at the investigated frequencies. It is expected that the size of the thermal boundary layer is similarly reduced during the cycle, leading to intervals of heat transfer enhancement.

Keywords : Heat transfer enhancement, particle image velocimetry, localized and time-resolved velocity, photonics and electronics cooling, pulsating flow, Richardson's annular effect
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