ABSTRACT

Heat transfer at the micro-scale offers numerous advantages: higher heat transfer coefficients, large surface-area-to-volume ratios. Scaling down heat exchange devices to micro-scale is not trivial, as experimental observations suggest significant deviations from conventional macro-scale models. Extensive theoretical and experimental investigations pointed towards specific scaling effects, which increase with the reduction in device size in relative magnitude. Critical scaling effects are *surface roughness* and *conjugate heat transfer*. In essence, micro-scale models of heat exchange devices can still be developed in the framework of the continuum hypothesis, albeit the scale effects are incorporated. The present work aims to build scale-invariant models of such devices.

Initially, the influence of surface roughness is explored. Roughness is modelled using two pathways, using a numerical approach based on a correlated Gaussian distribution, and generating a digital surface replica of an actual minichannel sample; using optical surface profilometer. Both models, alongside a smooth channel, have been subjected to 3D CFD studies to reveal the influence of roughness on microflows.

Subsequently, conjugate heat transfer is analyzed. It starts with a 1D analytical model for a microchannel heat sink wherein a new flux re-distribution is proposed. Next, two axial conduction incorporated models for a *rectangular*, *cylindrical* heat sink have been developed. The analyses reveal axial conduction-induced non-linearities as the causative factor behind certain reported Nu anomalies. Heat exchangers analysis, starts with the counter-current type. The validity of conventional heat transfer coefficients at miniaturised scales have been proven. Extending the analysis to cross-flow exchangers, a 3D analytical model also including the wall thermal resistance is developed.

Reciprocating flow has been proposed as a means to dampen the effect of axial heat transfer. An experimental set-up capable of generating flow reciprocation over a heated channel is built to capture the cyclic steady-state temperature profile in the solid. The resulting bell-shaped temperature distribution, and the phenomena are studied intricately using a numerical model. The results lead to a recommendation on the choice of oscillation frequency for a particular channel geometry to maximize the advantage of flow reciprocation.

Keywords: microchannel, surface roughness, axial conduction, analytical modelling, heat sinks, cross-flow heat exchanger, reciprocating flow