

## ABSTRACT

The rapid advancement of high performance tiny electronic devices has been sparked by the growing dependence of modern human life on digitization and artificial intelligence. To ensure dependable performance during the full designated operating regime as well as a satisfactory life term, designers now face the additional problem of thermal management due to the sharp increase in the power density requirements for such equipment. Heat generation is an irreversible process, and it must be removed for components to function continuously. Since the temperature rise in the circuits is the primary cause of component failures, the thermal energy generated during operation needs to be effectively reduced for the components to operate continuously. As a result, a significant amount of study has been focused on the evaluation of alternative working fluids as well as the creation and augmentation of effective cooling strategies over the past ten years. The high area-to-volume ratio of a miniaturised or mini-channel heat sink (MCHS) and the favourable thermophysical properties of the medium have been identified as two factors that make this option particularly enticing.

Both numerical and experimental appraisal of  $s\text{CO}_2$  is presented in the present thesis. Thorough numerical investigation has been performed to explore the steady-state, as well as transient characteristics of  $s\text{CO}_2$ . The applicability of macrochannel scaling laws explored to study the thermalhydraulic characteristics of five different supercritical fluids flowing through minichannel. Comparing supercritical fluids to single-phase and even boiling channels, supercritical fluids consistently have a higher heat transfer coefficient. As a result of the forced scaling, a significant degree of similarity has been seen in the visual character of the dimensionless momentum and heat fields as well as local recirculation patterns across the fluids. The scaling model, however, falls short when it comes to defining dimensionless groups since there are noticeable differences between local Reynolds number and local and area-averaged Nusselt number. For enhancing the used scaling methods, it is advised to take into account the Prandtl number profiles and dimensionless thermal conductivity with dimensionless enthalpy.

With a focus on the impact of local buoyancy, the numerical characterisation of thermal hydraulics of supercritical carbon dioxide flowing through a horizontal minichannel is investigated. It is discovered that buoyancy-induced local recirculation, which results from density stratification, has a significant impact on both azimuthal and axial profiles. Due to thermal asymmetry, the average heat transfer coefficient over the bottom half of the surface is substantially higher than the same over the top half, allowing for delayed heat transfer degradation there. This discrepancy increases at larger heat fluxes but decreases with pressure. The maxima in average heat transfer coefficient corresponds to the pseudocritical temperature. Increased heat transport is aided by larger mass flux, with the peak occurring downstream. Finally, a buoyancy parameter that accurately describes the loop performance is established in accordance with the macrochannel literature.

Flow of  $s\text{CO}_2$  is prone to heat transfer deterioration, therefore, modulation of the thermalhydraulic characteristics of the miniaturized heat sink by geometric alteration is mandatory. In order to determine an ideal orientation and design, the current thesis evaluates the response of a square minichannel by including rectangular obstructions. The primary variable is a performance assessment criterion, which is defined as a combined change in both heat transfer coefficient and pressure drop as a result of geometric adjustment. The installation of the obstructions significantly increases the turbulent mixing between the fluid layers, resulting in a smaller temperature difference between the wall and the fluid and an improved heat transfer coefficient. A relatively lower level of temperature is maintained within the baffled section, thereby delaying the appearance of heat transfer deterioration. However, obstructions significantly increase pressure losses, making careful selection of the dimensions necessary. The most practical choice has been determined to be the employment of three pairs of baffles. Along with a thorough thermalhydraulic analysis of the role of the operating variables with the ideal

design, desirable values of the height, thickness, and inclination angle for individual plates in this orientation have also been determined.

It is apparent that flow obstructions improve heat transfer performance of minichannel heat sinks but at the cost of higher pressure drop. Therefore, it is necessary to compare the thermalhydraulic performance of various flow obstacle shapes. The installation of airfoil shaped flow obstacles in a CO<sub>2</sub>-driven heated minichannel with a square cross-section is being investigated computationally. The use of obstacles is found to be efficient over the whole range of supply flow rate with three or more pairs, but advantageous only over a small range of Reynolds number for single and two pairs of airfoils. Performance is enhanced overall by increasing the separation between adjacent airfoils and the breadth of each obstacle, as well as by vertical orientation. The performance of an airfoil-shaped flow obstruction is superior to a rectangular one for a variety of geometric configurations, according to a study of their thermalhydraulic performance. A multi layer feed forward NN (MLFF-NN) is trained by the back propagation (BP) technique for the successful prediction of the supercritical mini channel heat sink (MCHS) performance corresponding to various geometric configurations of the heat sink and the model is able to predict the performance for several test cases with satisfactory level of accuracy.

To enlarge the corresponding experimental database for sCO<sub>2</sub> flow through minichannels experiments have been performed under heating conditions. The governing parameters are mainly the heat flux ( $q''$ ), mass flux ( $G$ ), operating pressure ( $p$ ), and inlet temperature ( $T_{in}$ ) of the supercritical carbon dioxide. The wall temperature measurement of the test section was performed using an infrared thermal imaging camera to capture continuous wall temperature variation in the axial direction. The comparison of experimental data with simulated results showed similar qualitative trend with largest deviation of 7.69% which is very near the uncertainty value of  $\pm 7\%$ . In order to reach pseudocritical point with the same inlet temperature, the system needs to be heated for a longer period of time, which causes a delay in peak HTC, albeit with substantially increased magnitude. Because pseudocritical temperature is reached earlier and there is less asymmetry in the flow domain as a result, the impact of a change in system pressure is significantly less noticeable at larger heat fluxes. It is also reasonable to infer that pressure has less of an effect on HTC than does heat flux.

The stability behaviour and flow acceleration caused by variations in the non-linear thermophysical parameters have a significant impact on the supercritical fluids' capability to transfer heat. With an emphasis on the impact of flow oscillation, numerical analysis has been done to examine the transient properties of sCO<sub>2</sub> at supercritical pressures. A wide range of system parameters, including time period of oscillations, operating pressure, amplitude of the wall heat flux, and mass flow, have been used in the transient simulations. It is discovered that axial profiles are significantly affected by flow acceleration-induced local oscillation, which results from the fluctuation in thermophysical characteristics. Lower response times and longer transient behaviour are caused by higher mass flux. Higher operating pressure subsided fluctuation in both mass flow rate and wall shear stress, indicating that higher operating pressure can aid to reduce system instability, which is caused by the combined effect of reduced viscosity and velocity variation at higher pressure.