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A MICROCHANNEL HEAT EXCHANGER FOR ELECTRONICS COOLING APPLICATIONS

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Microchannel Cooling System

Microchannel cooling is a popular solution to high heat rejection requirements of today's high power electronic devices. These systems are capable of rejecting large heat loads while being relatively small in size. The objectives of this project were to analyze the heat transfer and fluid flow performance of an existing microchannel heat exchanger (MCHX) through computational fluid dynamics and experimental techniques. Performance optimization was also explored through modification of microchannel geometries.

An existing MCHX used by the nLight Photonics Corporation for cooling of their high-power diode laser bars was first analyzed. Systems with modified parallel microchannel geometries were also examined. Deionized water at a rate of 200 ml/min is used as the working fluid in this system. Heat fluxes of over 600 W/cm² are applied to the heat input surface by the diode laser bar and must be rejected by the MCHX for successful operation.

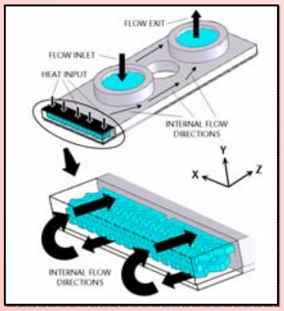


Figure 1: Schematic of the existing microchannel heat exchanger

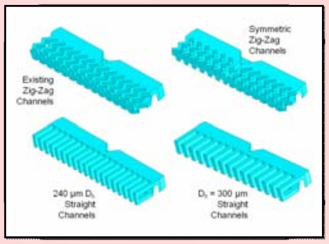


Figure 2: Parallel microchannel portion of existing and modified geometries

CFD Results

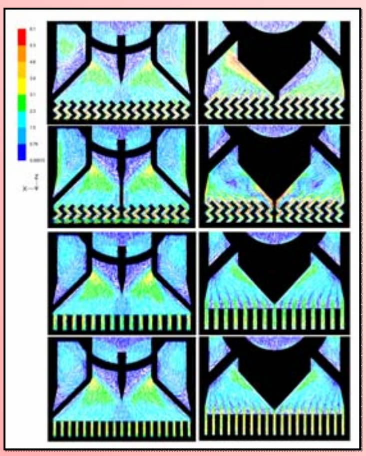


Figure 3: Velocity vector fields (m/s) at y = 0.45 mm (left) and y = 1.05 mm (right) from the bottom of the MCHX

Maximum temperatures of about 71 °C were seen on the exterior of the MCHX in the heat input region. The rest of the MCHX was at temperatures in the range of the water flowing through it, between 24 and 31 °C.

Velocity fields in the x-z plane of the MCHX representing the flow fields in the upper and lower layers of the heat input region are compared in Figure 3. The flow through the existing MCHX (top row) was found to be unbalanced due to the asymmetrical geometry of the zig-zag parallel microchannels. The geometry was redesigned to be symmetric (2nd row) which resulted with increased performance due to symmetric, balanced flow through the parallel channels.

Straight parallel microchannel geometries were then created and analyzed through CFD. Flow through 300 (3rd row) and 240 (bottom row) micron hydraulic diameter channels was examined. Significant increases in fluid flow performance were found through these designs. As shown in Table 1, the system pressure drop was reduced by over 60%.

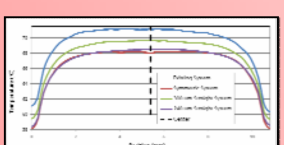


Figure 4: CFD temperature profiles at the top front edge of the MCHX

Temperature profiles across the width of the MCHX at the top front edge of the heat input surface are compared in Figure 4. An asymmetric temperature profile on the surface of the existing MCHX resulted from the unbalanced flow through the parallel zig-zag channels. Improved heat transfer performance was achieved through the modified designs. All profiles resulting from modified geometries were symmetric and the best performance (lowest average temperature) was seen in the symmetric zig-zag and 240 micron hydraulic diameter systems.

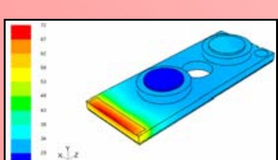


Figure 5: Temperature profile (°C) on the exterior surfaces of the MCHX

Table 1: CFD simulations results summary

Geometries ->	Existing System (zig-zag channels)	Symmetric Geometry (zig-zag channels)	Straight Channels D_h = 300 µm	Straight Channels D_h = 240 µm
System Pressure Drop, bar (% compared to existing)	1.01	0.98 (- 3.0%)	0.31 (- 69.3%)	0.38 (- 62.4%)
Average Temperature at Heat Input, °C (% compared to existing)	66.9	64.2 (- 4.0%)	65.8 (- 1.6%)	64.6 (- 3.6%)

Experimental Facility & Results

A test rig was configured for experimental analysis of the existing MCHX. A heating-cooling loop with control and measurement components capable of operating the system under conditions similar to the CFD simulations was configured.

Precise instrumentation, including resistance temperature detectors (RTDs) and pressure transducers, was used to collect time averaged data from the system during steady-state operation. The experimental data was then compared to the CFD simulation data.

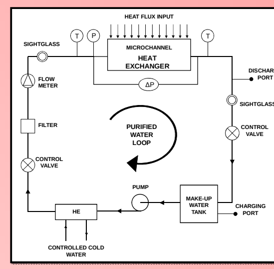


Figure 6: Experimental facility schematic

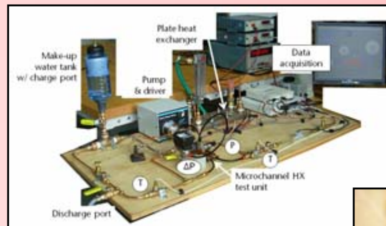
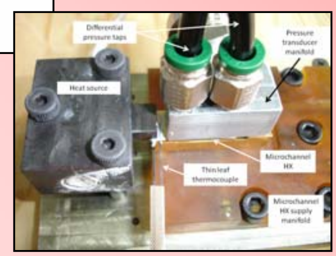


Figure 7: Experimental facility (left) with magnified microchannel cooler test unit (below)



Agreement between CFD simulation and experimental pressure drop data was found qualitatively. The CFD simulation over-predicted the system pressure drop by about 15% at lower flow rates. However, the CFD predictions diverged from the experimental data at higher flow rates with as much as 70% difference. The system pressure drop trends were similar with second order polynomial curves fitting the data, although linear trends had originally been expected since Reynolds numbers were in the laminar regime, ranging from 300 to 1600. Further experimentation and refined CFD simulations will be necessary to find better agreement between the data sets.

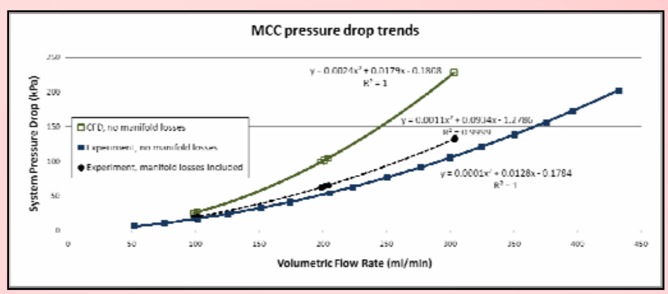


Figure 8: CFD and experimental pressure drop results

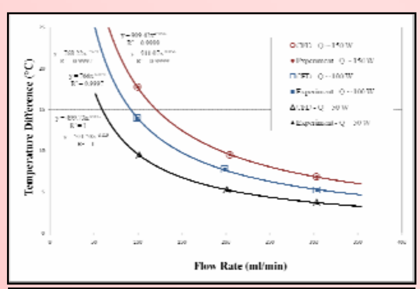


Figure 9: CFD and experimental working fluid temperature change results

Very good agreement was found between CFD simulation and experimental fluid temperature change data. As shown in Figure 9, the trends from the two data sets or almost perfectly matched. An experimentally measured temperature value of the MCHX heat input surface is necessary for a more thorough heat transfer performance comparison, and that data will be collected in future experiments.

Conclusions & Recommendations

The results of this study are beneficial in the design and optimization of microchannel cooling systems. From the results of this study, three recommendations can be formulated: 1) all geometrical designs should be symmetrical when incorporating multiple fluid paths, 2) an optimal balance between heat transfer surface area and resulting system pressure drop should be found in order to maximize both heat transfer and fluid flow performance, and 3) purified water is still a good choice as working fluid in MCHEs compared to other available cooling fluids.