Numerical Modeling of Single-Phase Fluid-Flow in Wavy Micro-Channels

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INTRODUCTION

- Due to increase in power density of modern electronic chips, there is a need of a higher heat flux removal capabilities.
- An approach based on microchannels for high-heat flux applications was suggested by Tuckerman and Pease [1].
- Aim is to perform a CFD study of the convective heat transfer on a single-phase fluid flow in wavy microchannels (Figure 1) to investigate heat transfer enhancement in these systems.
- Numerical simulations are coupled to a methodology based on local and global energy balances in the device [2] and employ the heat transfer rate instead of Nusselt numbers.

MODELING AND COMPUTATIONAL METHODS

- Governing equations

Fluid flow in wavy channel:

$$\nabla \cdot \mathbf{u} = 0$$

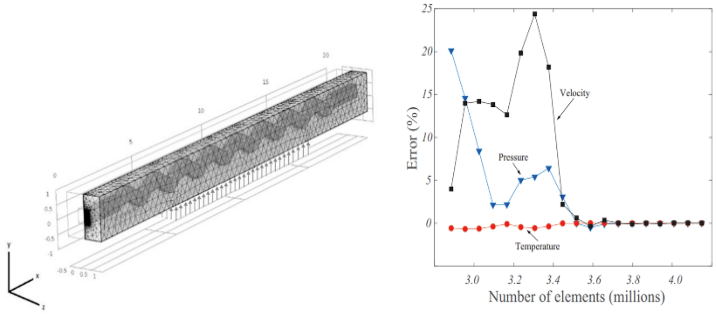
$$\rho_f (\mathbf{u} \cdot \nabla)\, \mathbf{u} = -\nabla p + \mu_f \nabla^2 \mathbf{u}$$

$$\rho_f c_{p,f} (\mathbf{u} \cdot \nabla) T = k_f \nabla^2 T$$

Solid (copper substrate):

$$k_s \nabla^2 T_s = 0$$

- Discretization and solutions of the governing equations were obtained via the finite element method (FEM).
- For each geometry under analysis, 3-D unstructured meshes with four-node tetrahedral elements were used.
- Close to the walls the mesh contains hexahedral elements enabling a sharp fluid-solid interface representation.
- The resulting system of algebraic equations is computed iteratively with the generalized minimum residual (GMRES) solver.
- 3.6 million elements are used in the computational domain comprising both solid and fluid region (Figure 1).



(a) Typical mesh of channel and solid block domains.

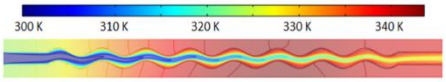
(b) Numerical results from grid size.

Figure 1. Typical mesh of computational domain and grid independence tests.

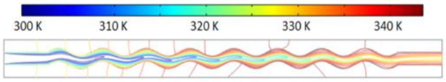
RESULTS

- Steady-state conjugate heat transfer model.

(a) Streamlines.



(b) Temperature contours.



(c) Isotherms.

Figure 2. Results for *A*=150 µm and *Re* = 100.

Fig. 2(a), flow patterns evolve from uniform flow at the inlet into periodic patterns with streamlines being closer to each other near the channel centerline, and into a new-uniform flow near its outlet.

Figs. 2(b) and 2(c), the temperature field transitions from a uniform profile and develops (but not in a periodic fashion) as the fluid travels along the channel advecting energy toward the outlet.

- Local and global energy balances in the device (see Figure 3).

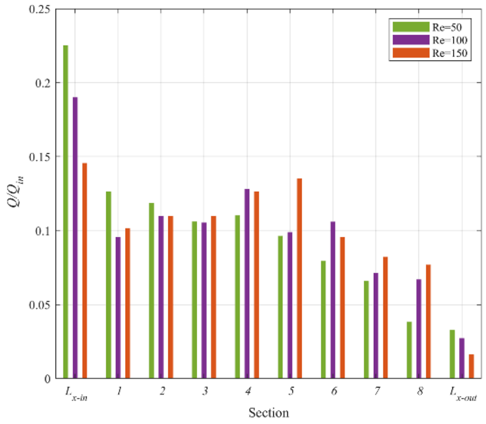


Figure 3. Fraction of influx heat rate transferred at each section for A= µm.

CONCLUSIONS

Results show that wave amplitude is not important, but the Reynolds number *Re*, plays a key role in the heat transfer enhancement of the device and in both the fluid and solid block temperature that are achieved.

REFERENCES:

[1] D. Tuckerman, and R. Pease, “High-performance heat sinking for VLSI”. Electron Device Letters, IEEE, 2(5), pp. 126–129 (1981).
[2] J. Cobian-Iniguez, A. Wu, F. Dugast, and A. Pacheco-Vega, “Numerically-based parametric analysis of plain fin and tube compact heat exchangers”, Applied Thermal Engineering, 86, pp.1–13, (2015),