Optimal guidelines for the design of a micro single phase heat exchanger

Motivation & Objectives
This is a numerical study into the thermo-fluid dynamics occurring inside single phase rectangular copper heat exchangers comprising rectangular channels with water as the working fluid. The implemented model accounted for conjugate heat transfer through the heat exchanger and the temperature dependence of the physical properties of the materials used. The numerical model was validated against results published previously in the literature. In particular, through a parametric study of the problem, we were able to clarify the competing demands of hydraulic and thermal effectiveness with respect to the channels aspect ratio and fin width.

Governing equations
The three-dimensional heat transfer characteristics of the heat sink were analysed numerically by solving the conjugate heat transfer problem involving simultaneous determination of the temperature field in both the solid and the liquid regions. The two modes are coupled by continuity of temperature and heat fluxes at the interface between the solid and the liquid.

Solid region:
- Fourier's law \( k \nabla^2 T = 0 \)
- Continuity \( \nabla \cdot \mathbf{v} = 0 \)

Liquid region:
- Navier-Stokes \( \rho \left[ \frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} \right] = -\nabla p + \eta \nabla^2 \mathbf{v} + \rho g \)
- Energy \( \rho c_p \left[ \frac{\partial T}{\partial t} + (\mathbf{v} \cdot \nabla) T \right] = \nabla \cdot (\kappa \nabla T) + \sigma \mathbf{v} \cdot \mathbf{v} \)

Channel geometry
The device comprises a copper wall and a rectangular channel with water as working fluid. The bottom of the channel is heated by a constant heat flux and the top wall is taken adiabatic. Symmetry is taken into account to simplify the geometry. The channel height and total height are kept constant while the channel width (Wch) and fin width are taken as a parameters and changed from respectively 100 \( \mu \)m to 1700 \( \mu \)m and 170 \( \mu \)m to 320 \( \mu \)m.

Results validation
The fully developed friction factor and Nusselt number are calculated for all geometries and operating conditions. The results obtained were validated against other results previously published in the literature. The friction factor and Nusselt number vary similarly to the standard correlations developed for macro-channels but differ from the microchannel studies. This suggests that further research should be carried out by also taking into account the channel roughness which is believed to be a critical factor at the microscale level.

Single channel temperature profile
An analysis of the temperature profile within a single channel provides the weaknesses of this type of channel. We can first notice that the hottest point is below the outlet of the channel (Fig. 1 and Fig. 2). Indeed, the heat flux is higher at the inlet because the temperature gradient is higher between the wall and the liquid. The bottom heat flux induces a loss of symmetry in the solid region and the fluid region. The temperature gradient within the liquid region leads to different dynamic viscosities. Fig. 3 shows the importance of taking into account a viscosity that is temperature dependent. The pressure drop is therefore higher for higher heat fluxes as the induced viscosity is lower (higher temperature).

Total pressure drop and maximum temperature reached within the device
The total pressure drop (Fig. 1) across the channel is plotted against the Reynolds number and the channel aspect ratio (Channel height/Channel width). Higher Reynolds numbers lead to higher pressure drops and higher aspect ratios also lead to higher pressure drops. This plot is to be compared with the maximum temperature reached within the device, which gives the temperature at which the electronic components (or other) can be cooled down.

Higher temperatures are obviously reached by high Reynolds numbers and the low aspect ratios (wide channels). The two plots show the trade off encountered when cooling down electronic packages, i.e. we need very high pumping powers to get very low temperatures. We can find a good compromise for a channel aspect ratio of 8 and a Reynolds number of 400.