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Uncertainty Quantification of Heat Transfer in a trapezoidal micro-channel with a semi-circular cross-section

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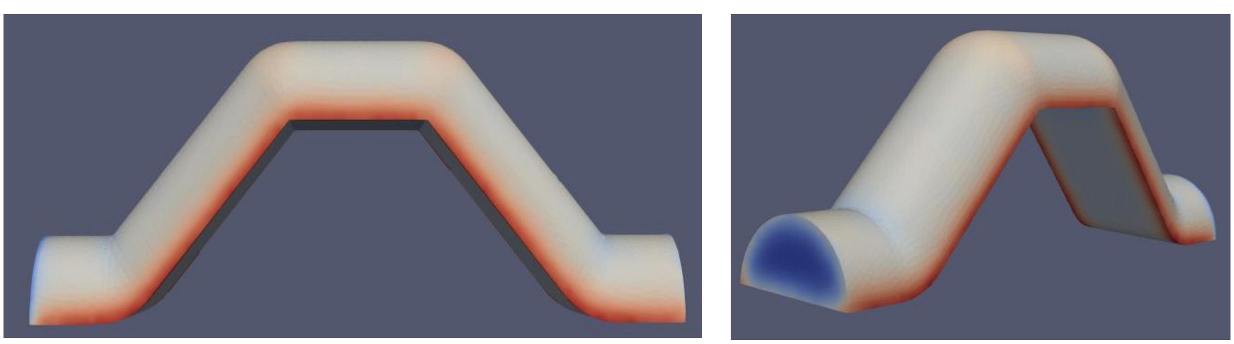
With the rapid development in Micro-Electro Mechanical Systems (MEMS) and VLSI technology, the use of micro-channels as heat exchangers has gained popularity. Micro-channels of various shapes and forms have been developed in order to reduce the space consumed in integration of mechanical and electrical systems while increasing the area for heat transfer. In this work, we analyse one such unique micro-scale heat exchanger with a semi-circular cross-section and a trapezoidal geometry as shown in the figure below. Several such elements are eventually put together in series to form the final heat exchanger. The dimensions of this heat exchanger element (the cross-section and the lengths) are of the order of few micrometers, which makes it difficult to account for and detect operational errors. Moreover, with fluid (water in this case) moving inside this channel for exchange of heat, the accurate measurement of temperatures becomes critical and involves considerably sophisticated instruments and techniques. With Computational Fluid Dynamics (CFD), the simulation of such scenarios has gained immense pace and finite-element techniques for CFD simulations (using OpenFOAM, Ansys etc.) remain state-of -the-art. However, CFD deploys a deterministic method which relies upon approximations at several stages (meshing, numerically solving Navier-Stokes equations etc.), which leads to an inherent uncertainty in the output obtained from CFD simulations. Our work essentially aims to quantify this uncertainty in this specific scenario of a trapezoidal micro-channel.



Variation in the inlet velocity of water, initial temperature and the channel diameter is considered and the corresponding aberrations in the average temperature at the outlet of the channel are observed. Latin Hypercube Sampling of the input parameters was carried out followed OpenFOAM simulations with the sampled parameters as inputs. The “buoyantSimpleFoam” solver was used. Post this, a Gaussian Process Regression (Kriging) was performed to determine the uncertainty that propagates in the output due the uncertainty or fluctuation in the input parameters. Our simulations, show that the variation in the above mentioned model parameters (diameter, inlet velocity and initial temperature) leads to significant uncertainties in the average outlet temperature and hence eventually in the amount of heat transfer taking place through the channel and it’s effectiveness. Corresponding Monte Carlo simulations were also run, and a comparative study of the uncertainties obtained was performed. The fluctuations in the inlet velocity and channel diameter are observed to cause higher deviation of the average outlet temperature from the mean value as compared to variations in the initial temperature.