Flow Analysis and Optimization of a Hierarchical Plate Heat Exchanger for an Adsorption Heat Pump

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Abstract

Introduction
Adsorption heat pumps are operated through a periodic temperature swing process of the adsorber(s), and energy release and uptake during the adsorption and desorption phases is highly unsteady. A goal in the further development of adsorption heat pumps is to increase the volume specific cooling power through intensification of heat and mass transfer in the adsorber. From the heat transfer point of view the heat transfer resistance to the fluid cycle and the thermal mass of the adsorber element (i.e. heat exchanger) have to be minimized, while keeping the pressure drop in the fluid cycle below an upper limit. To meet these requirements a hierarchical heat exchanger design is being developed, inspired by heat transfer structures in nature shown in figure 1.

Use of COMSOL Multiphysics®
One main goal of the optimization of a hierarchical structure is the uniformity of the flow distribution in the heat exchanger plane, in order to avoid hot spots on the heat exchanger surface during the process. Here - due to the complexity of the flow - simple calculations based on the assumption of piecewise laminar, fully developed flows does not lead to proper channel shapes (cf. fig. 3 and fig. 4). Therefore an optimization of the 3-D channel structures with stationary CFD calculations are performed. (The calculations were performed with the CFD Module applying the solver GMRES). The optimization of the two hierarchy levels (A and B (cf. fig. 1)) are performed separately. The optimization is based on the genetic algorithm (ga) implemented in MATLAB®. The channels studied here have rectangular cross sections where one side length is defined by a cubic polynomial. The optimization is performed in a two-step manner to improve the computational performance (fig. 2). In the first optimization step (I) a linear polynomial-shape is optimized, which initializes the second optimization step (II) where a cubic polynomial-shape is further optimized.

Results
The optimization results - so far - were calculated with total flow rates which are typical for an adsorption heat pump. The uniformity of the flow distribution to the respective perpendicular, parallel channel network is visualized by means of the Probability Density Function (PDF). The ideal case of perfectly uniform distribution of the flow to the parallel channel network would be a delta distribution. A significant improvement can be obtained for the hierarchy level A (fig. 3) as well as hierarchy level B (fig. 4).

From the computational point of view an improvement of the performance of the optimization procedure can be achieved with the two-step optimization methodology (sketched in fig. 2).

Conclusion

With the shape-optimization a significant improvement of the flow distribution can be achieved. With this a more uniform heat removal from the heat releasing surface can be obtained. The optimal shape basically differs from the channel shape, which is achieved by the assumption of laminar, fully developed flows and gives considerably better results. Therefore optimization with 3-D CFD calculations are essential to obtain the optimal channel shapes for a hierarchical plate heat exchanger.

Figures used in the abstract

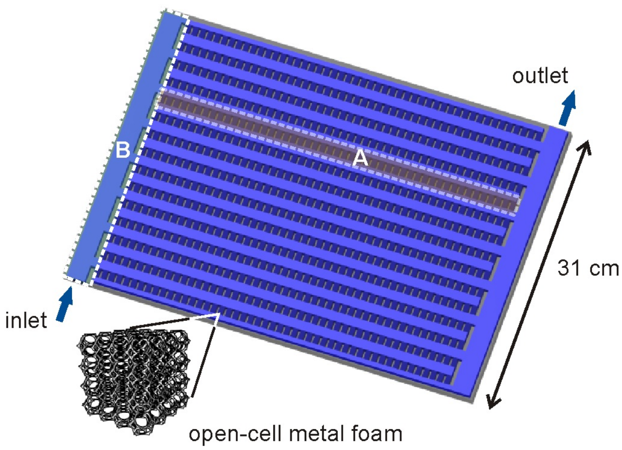

Figure 1: Sketch of the hierarchical heat exchanger with the optimized hierarchy levels A (flow distribution to the micro-porous channels) and B (manifold). The channels of hierarchy level A are connected with micro-porous channels.

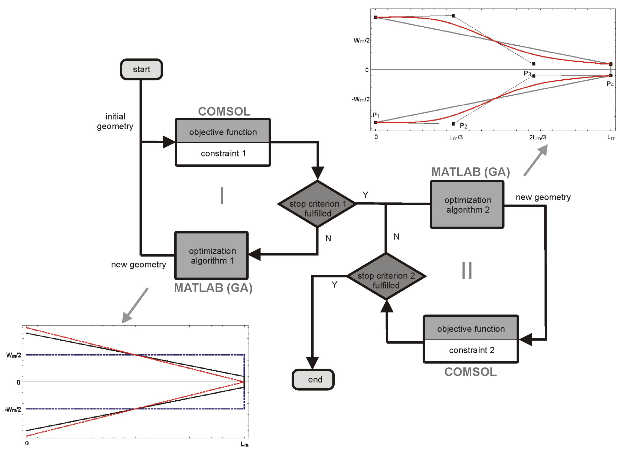

Figure 2: Flow-chart of the two-step optimization. (fig. left bottom) Optimized linear polynomial-shape (gray curve) in opt. step I; (fig. right top) optimized cubic polynomial-shape (red curve) in opt. step II.

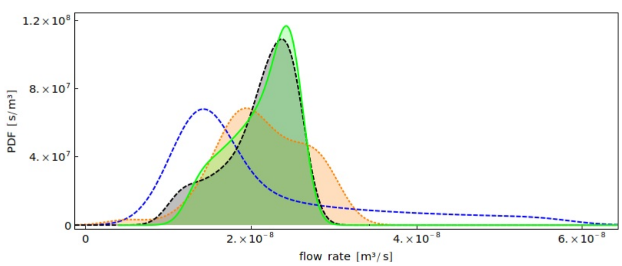

Figure 3: Flow distribution to the micro-porous parallel channel network of hierarchy level A characterized by PDF. (blue) Rectangular limiting shape; (black) optimized linear polynomial-shape (opt. step I); (green) optimized cubic polynomial-shape (opt. step II). (orange) Optimal shape for the approximation of laminar, fully developed flows.

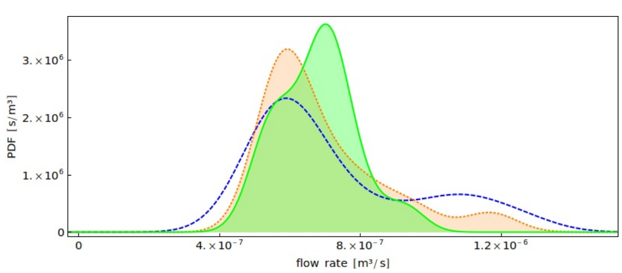

Figure 4: Flow distribution to the parallel channel network of hierarchy level B characterized by PDF. (blue) rectangular limiting shape; (green) optimized cubic polynomial-shape (opt. step II). (orange) Optimal shape for the approximation of laminar, fully developed flows.