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

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Introduction: The energy release during the adsorption process in the cycle of an adsorption heat pump is highly unsteady. A goal in the further development of adsorption heat pumps is to increase the volume specific cooling power through heat transfer intensification in the adsorber. Therefore the heat transfer resistance to the fluid cycle and the thermal mass of the adsorber element (*i.e.* heat exchanger, HX) have to be minimized, while keeping the pressured 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.

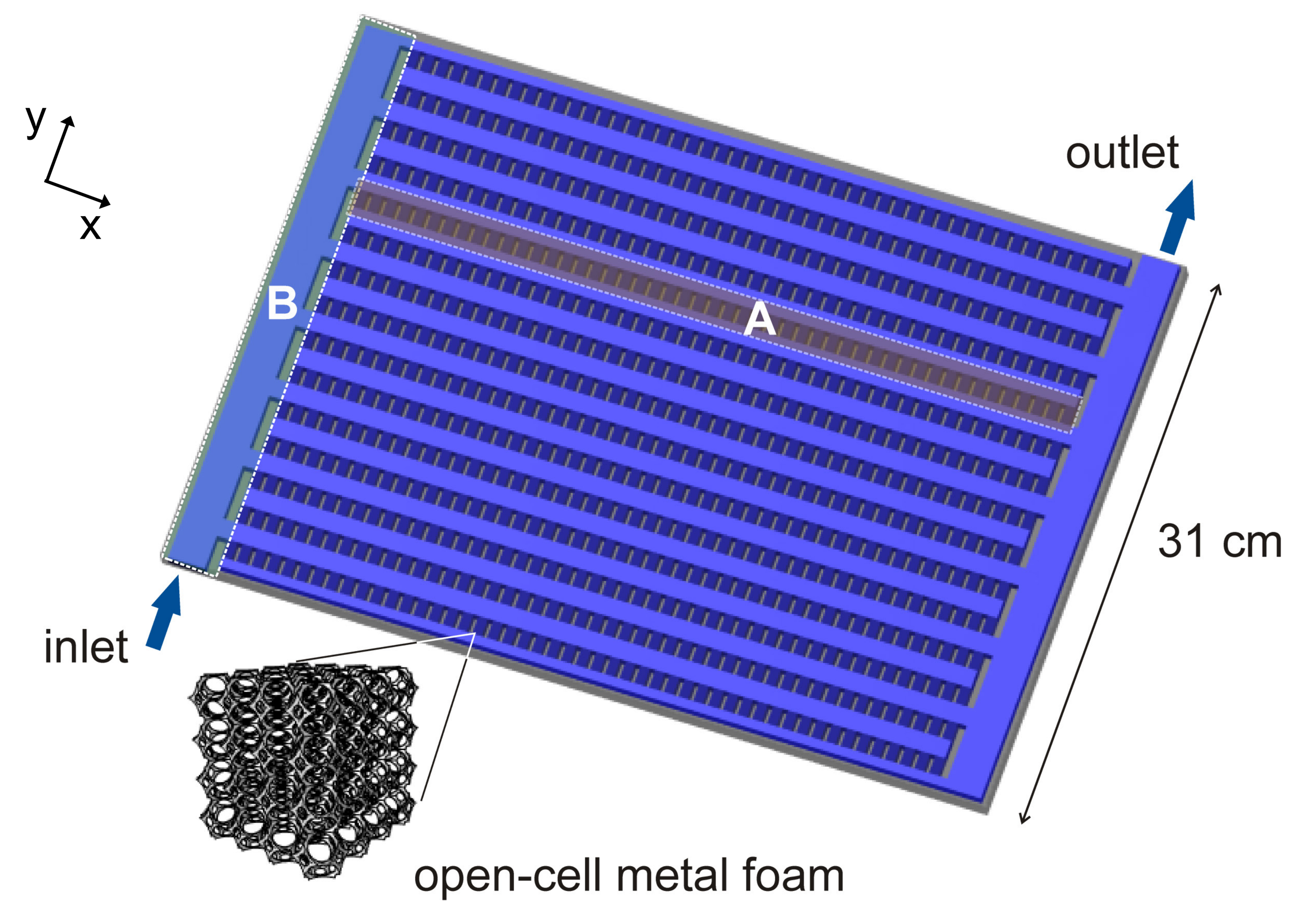

Figure 1. Sketch of the hierarchical heat exchanger.

Numerical Model: The flows of interest in the heat exchanger are within the laminar regime (Re < 10). The model equation for both levels of the HX (A & B) is the 3D Navier-Stokes equation with Darcy-Brinkman extension

$$\frac{\rho_f}{\varepsilon^2}\langle u_j\rangle\left(\frac{\partial\langle u_i\rangle}{\partial x_j}\right) = -\frac{\partial\langle p\rangle}{\partial x_i} + \frac{\mu}{\varepsilon}\frac{\partial}{\partial x_j}\left(\frac{\partial\langle u_i\rangle}{\partial x_j}\right) - \frac{\mu}{K}\langle u_i\rangle - \frac{\rho_f C_E}{\sqrt{K}}|\vec{U}|\langle u_i\rangle$$

with the porosity of the micoporous structure $\varepsilon = 0.7$ and the permeability $K = 7\cdot 10^{-10} m^2$.

Optimization: One main goal of the optimization of a hierarchical structure is the *uniformity of the flow distribution to the channels* $\dot{V}_{ch}$ in the heat exchanger plane. The shape optimizations of the manifolds on both hierarchy levels (A & B) have been performed. The optimization is based on the Genetic Algorithm (GA) implemented in MATLAB.

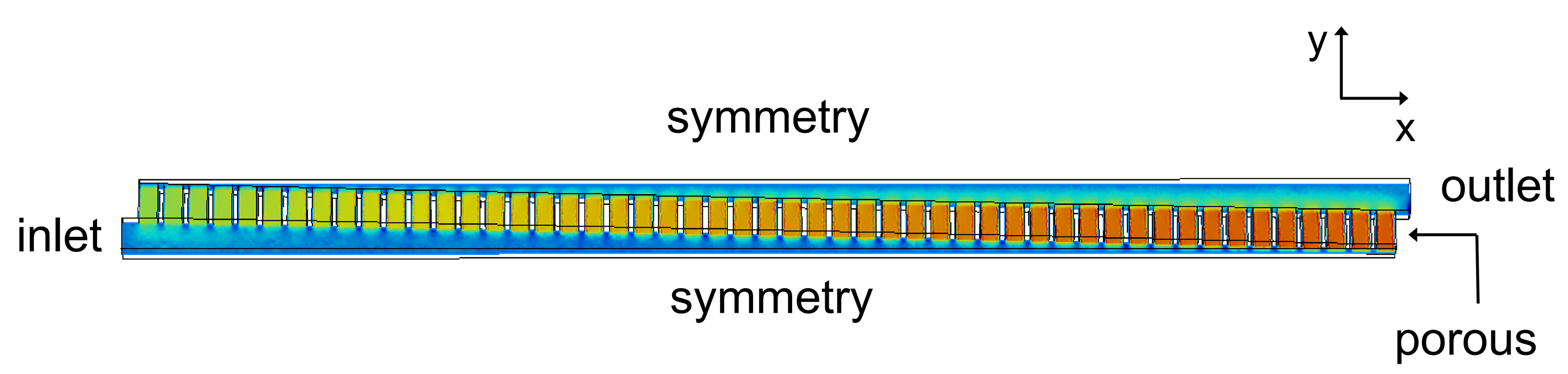

Figure 2. Velocity component v_y in optimized geometry of hierarchy level A.

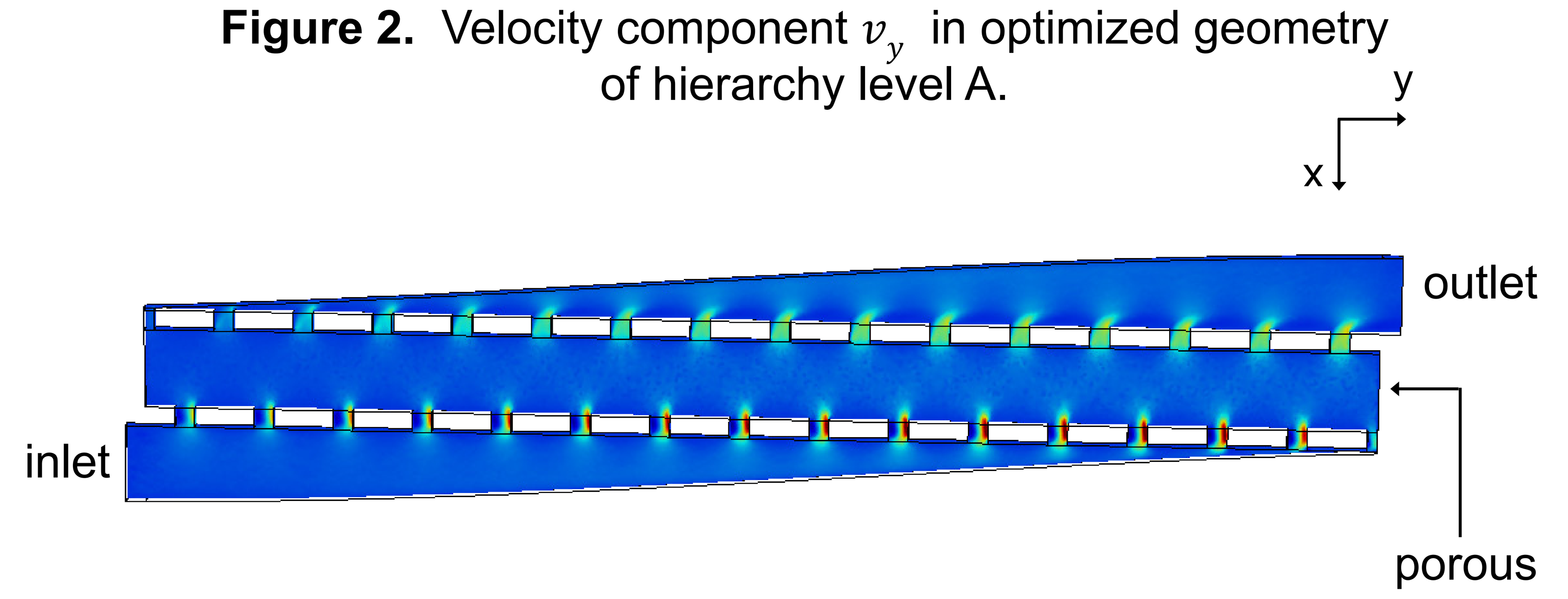

Figure 3. Velocity component v_x in optimized geometry of hierarchy level B.

Optimization Problem: $\underset{a_{min,i}\leq a_i \leq a_{max,i}}{\text{Min}} \{Var[\dot{V}_{ch}(\boldsymbol{a})]\}$

The optimized shape functions are cubic Bézier curves

$$y(t;\boldsymbol{a}) = (1-t)^3\cdot P_1(a_1) + 3(1-t)^2 t\cdot P_2(a_2) + 3t^2(1-t)\cdot P_3(a_3) + t^3\cdot P_4(a_4)$$

where the parameters a_1 and a_4 are determined in the optimization step I. The parameters a_2 and a_3 are determined in optimization step II. This two-step optimization allows a notable improvement of the optimization performance.

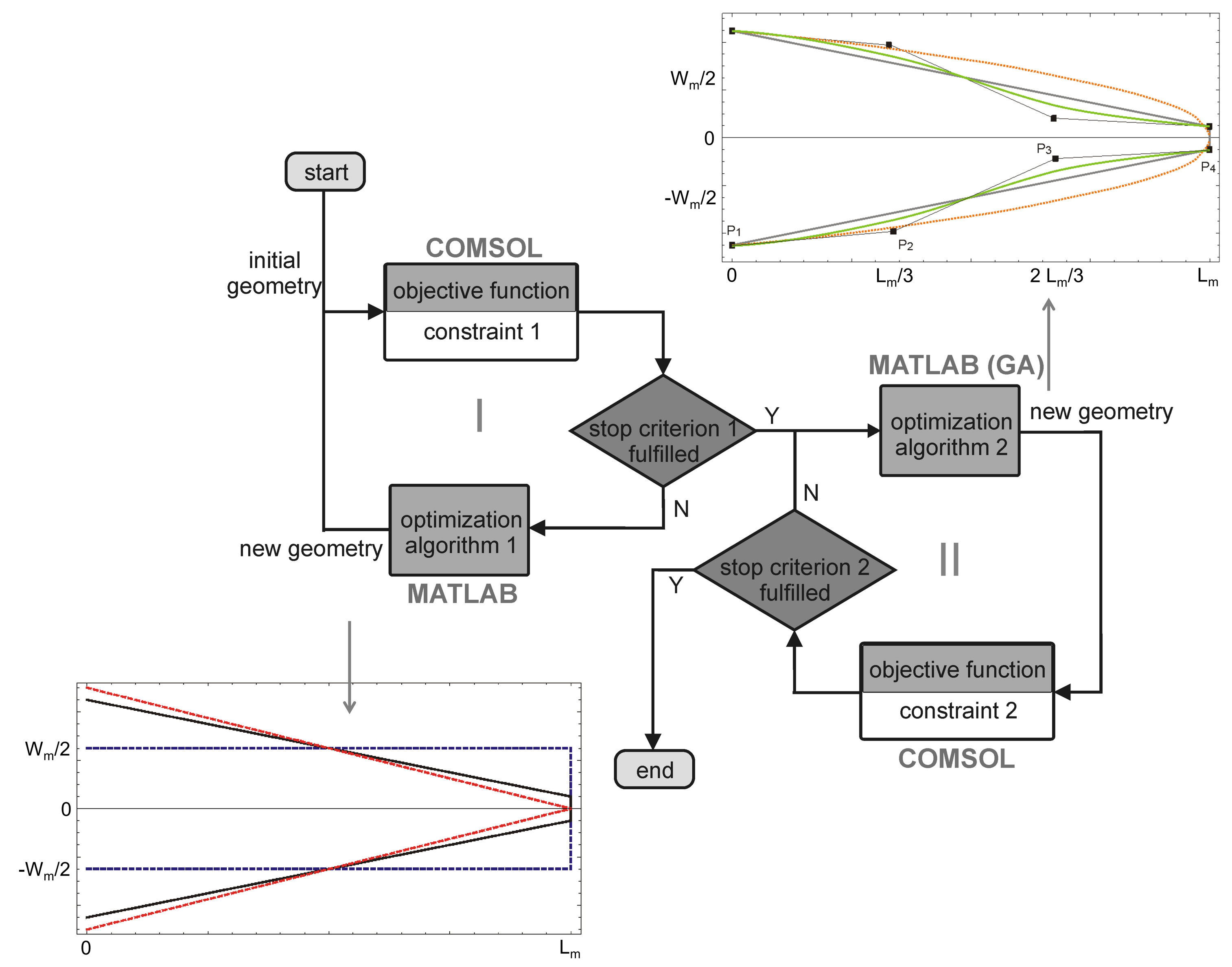

Figure 4. Optimization procedure: I) linear geometry optimization; II) polynomial geometry optimization.

Results: The optimization results are shown for a total flow rate $\dot{V}_{tot} = 1\ l/min$. The uniformity of the flow distribution is shown with the probability density functions (PDFs).

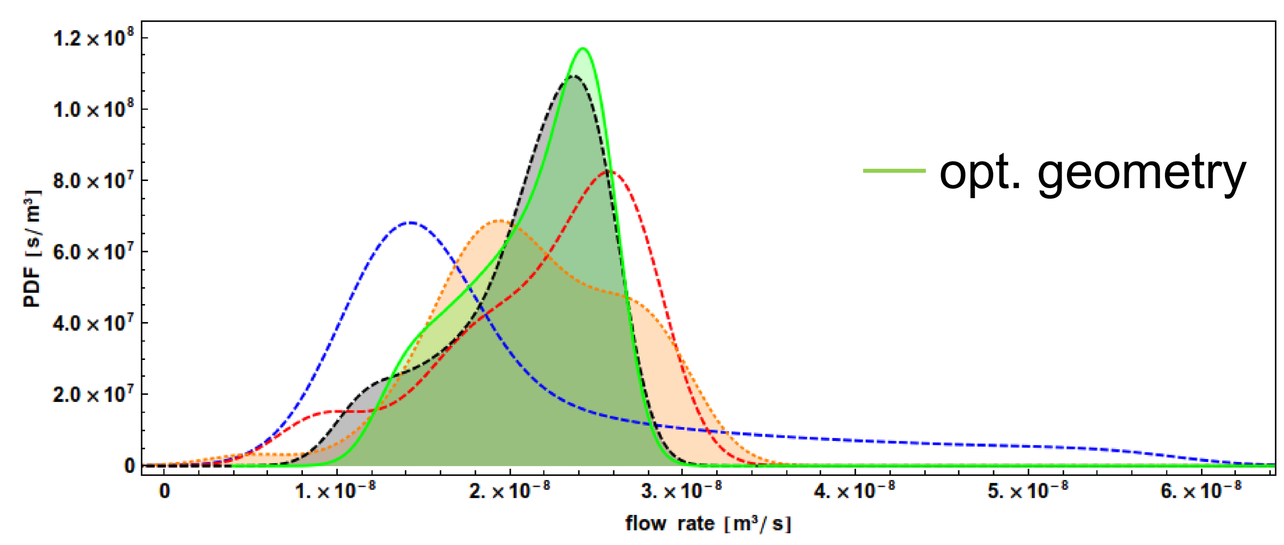

Figure 5. PDFs of the flow distribution of hierarchy level A.

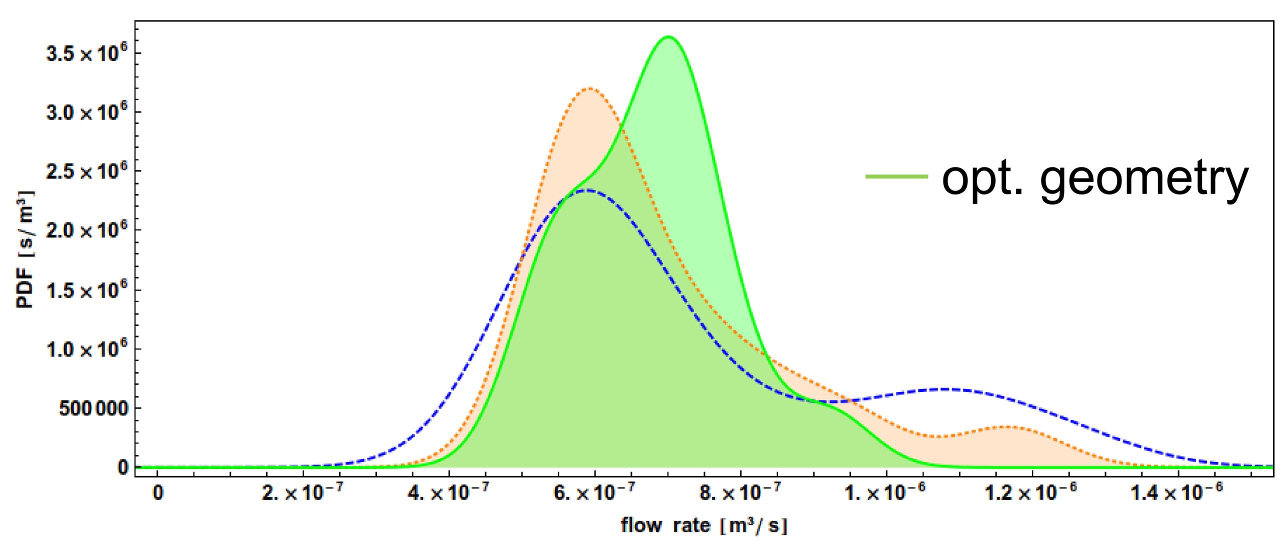

Figure 6. PDFs of the flow distribution of hierarchy level B.

Conclusion:

- With the shape optimization a significant improvement of the flow distribution can be achieved.
- The optimal shape differs from the parabolic shape (orange lines) which results from developed laminar flow approximation.

DBU Deutsche Bundesstiftung Umwelt