Topology Optimization of Thermal Heat Sinks

J. H. K. Haertel[1], K. Engelbrecht[1], B. S. Lazarov[2], O. Sigmund[2]

[1]Technical University of Denmark, Roskilde, Denmark
[2]Technical University of Denmark, Kgs. Lynby, Denmark

Abstract

1. Introduction

The topology optimization method is becoming increasingly popular as a design tool for multiphysics systems [1,2]. Topology optimization of fluid-thermal systems has been presented for example in [3] for forced convective heat transfer and in [4] for natural convection problems. In this work, topology optimization including density filtering and projection is applied to optimize the cooling performance of thermal heat sinks. The coupled fluid-thermal model of a heat sink cooled with forced convection is implemented in COMSOL Multiphysics® software as well as a three-field density-based topology optimization. The optimization objective is to minimize the heat sink's temperature for a prescribed pressure drop and fixed heat generation. Results for optimized 2D heat sinks are presented and the effect of the prescribed pressure drop on different system parameters is analyzed.

2. Use of COMSOL Multiphysics

Within the presented studies, air was used as fluid and copper as heat sink material. A 2D fluid flow is assumed between the heat sink fins to simplify the model.

The studies in this work were conducted at moderate Reynolds numbers of up to 150. Therefore, the COMSOL Laminar Flow physics interface was used to solve the stationary Navier-Stokes and continuity equation. To allow for an interpolation of fluid flow penalization within the design space, an artificial friction term was added to the Navier-Stokes equation. The COMSOL Heat Transfer Module was used to solve the heat transport equation in the fluid and in the solid plate in which the heat generation occurs.

The solid plate average temperature was minimized within the Optimization Module using the GCMMA optimization method. The COMSOL LiveLink™ for MATLAB® was used to automate simulations and to ramp optimization parameters as necessary. A PDE type density filter as described in [5] was implemented within the Coefficient Form PDE physics interface. This was done to introduce a minimum length scale into the design and to solve issues with ill-posedness of the optimization problem. A drawback of density filtering is the inherent introduction of a band with intermediate densities between solid and fluid regions. Therefore, the filtered design variable field is projected with a smoothed Heaviside function as presented in [6]

to obtain a crisp design.

3. Results and Discussion

Exemplary plots of the optimized design variable field, the fluid velocity magnitude, and temperature distribution are depicted in (Figure 1), (Figure 2), and (Figure 3). A parameter study of the optimized heat sink's solid plate temperature plotted against the allowed system pressure drop is shown in (Figure 4).

4. Conclusion

A 2D heat sink model with constant heat production and a density-based topology optimization were implemented in COMSOL. Topology optimization was used to minimize the heat sink's temperature. This work demonstrates that COMSOL Multiphysics offers the possibility to use the topology optimization method including density filtering and projection with relatively little implementation effort. Thus making this approach particularly interesting from an engineering point of view for the design of heat sinks and other fluid-thermal systems.

Reference

1. J.D. Deaton and R.V. Grandhi, A survey of structural and multidisciplinary continuum topology optimization: post 2000, Structural and Multidisciplinary Optimization, 49, 1-38 (2014)
2. E.M. Dede et. al., Multiphysics Simulation, Springer (2014)
3. G.H. Yoon, Topological design of heat dissipating structure with forced convective heat transfer, Journal of Mechanical Science and Technology, 24, 1225-1233 (2010)
4. J. Alexandersen et al., Topology optimisation for natural convection problems, International Journal for Numerical Methods in Fluids, 76, 699-721 (2014)
5. B.S. Lazarov and O. Sigmund, Filters in topology optimization based on Helmholtz-type differential equations, International Journal for Numerical Methods in Engineering, 86, 765-781 (2011)
6. F. Wang et al., On projection methods, convergence and robust formulations in topology optimization, Structural and Multidisciplinary Optimization, 43, 767-784 (2011)

Figures used in the abstract

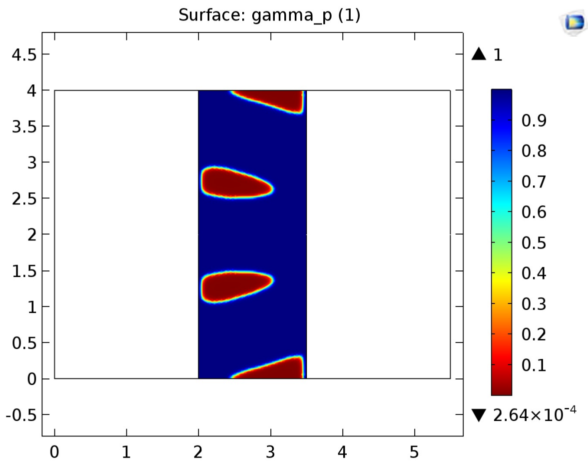

Figure 1: Figure 1. Design variable field of optimized heat sink. A density of 0 indicates solid material and 1 indicates flow passages.

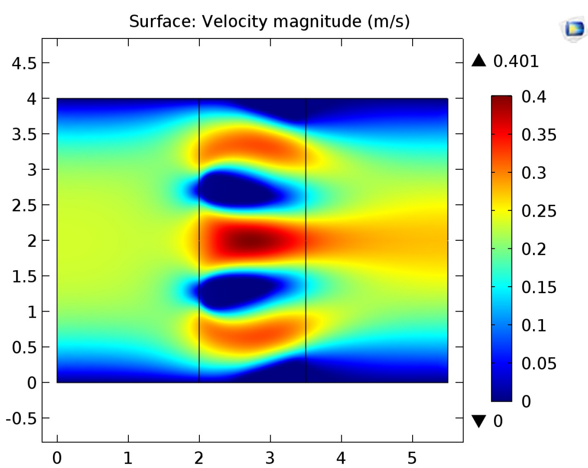

Figure 2: Figure 2. Fluid velocity magnitude field of optimized heat sink.

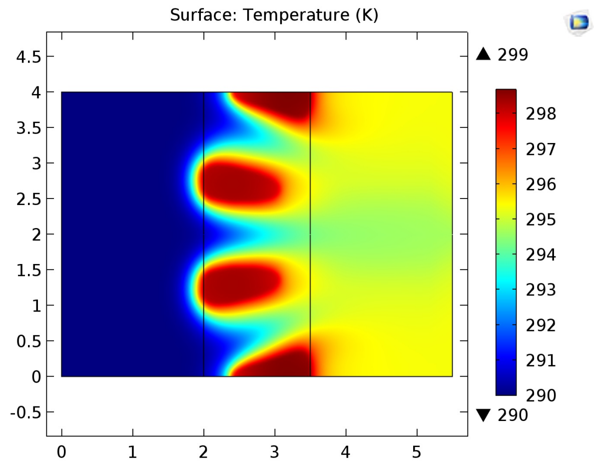

Figure 3: Figure 3. Temperature distribution for optimized heat sink.

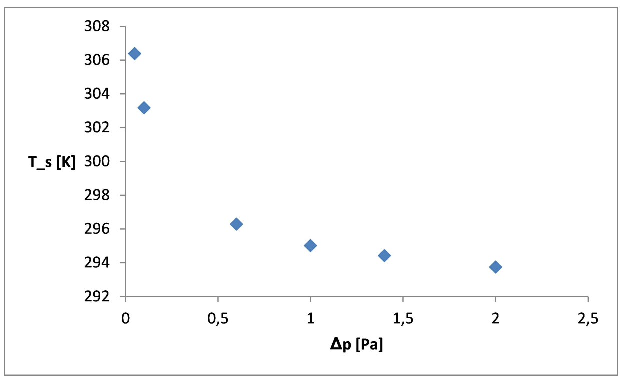

Figure 4: Figure 4. Solid plate temperature of optimized heat sink plotted against prescribed system pressure drop.