EngOpt2018 - 6th International Conference on Engineering Optimization
Instituto Superior Técnico, Lisbon Portugal • 17-19 September, 2018
Editors: H.C. Rodrigues, J. Herskovits, C.M. Mota Soares, et al.

Abstract ID 1104

A MACRO-SCALE TOPOLOGY OPTIMIZATION METHOD FOR FLOWS THROUGH SOLID STRUCTURE ARRAYS

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Keywords: topology optimization; micro-size flow device; macro-scale modeling

Abstract: Periodic arrays of solid structures such as pin fins are being included in more and more micro-size fluid flow and heat transfer devices. Such arrays are beneficial towards device performance since, in comparison to microchannel devices, they are able to further reduce the pressure drop and increase the heat transfer rate between a flow and solid. In recent years, mathematical optimization strategies such as topology optimization are increasingly being applied to microchannel flow devices in order to pursue innovative designs with superior performance. These techniques optimize the material placement of either solid wall or void channel in the entire design domain. Current topology optimization methods require direct numerical simulation (DNS) of the flow and conjugate heat transfer for proper resolution of the physics, which for large problems can become computationally very costly. From a manufacturing point of view, devices containing periodic solid structure arrays are more easily fabricated than optimized microchannel design topologies. However, at present no comparable optimization methodologies exist to optimize the size or placement of solid structure arrays in flow devices, with the aim of improving performance. In this research, we present a macro-scale topology optimization method for flow systems consisting of an array of solid structures with fixed position and shape, but varying size. The hydraulic performance of these devices is maximized by optimizing the size of each individual solid structure. Since DNS of microscale features in a flow device is computationally infeasible, the presented macro-scale method relies on solving the spatially filtered Navier-Stokes flow equations. This allows us to capture the average flow features without solving all of the detailed flow phenomena. To this end, the effect of the solid structures is modeled via an interfacial force. The results of our method are compared to traditional cases of topology optimization of fluid flow problems, and DNS is used to validate our designs and verify the accuracy of the assumption of the interfacial force replacing the actual microstructures.