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Research Paper

Multi-objective optimization of cooling of a stack of vertical minichannels and conventional channels subjected to natural convection

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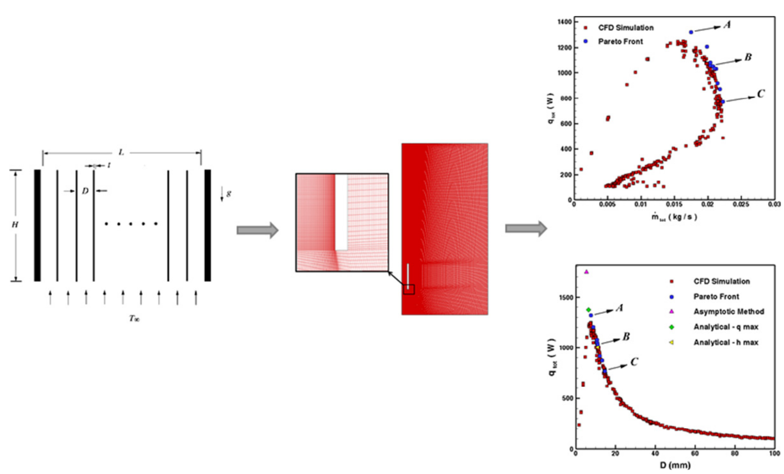
HIGHLIGHTS

- Cooling of a stack of channels subjected to natural convection is multi-objectively optimized.
- The MOO is performed using the combination of CFD and NSGA II algorithm.
- The objectives are maximizing the cooling flow rate and heat transfer from the stack of channels.
- The investigated channels can be classified between minichannels and conventional channels.
- From among the optimal points, those with special characteristics have been analyzed.

GRAPHICAL ABSTRACT



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ABSTRACT

In this paper, by employing the Computational Fluid Dynamics (CFD) and applying the NSGA II algorithm, cooling of a stack of vertical parallel plates subjected to natural convective heat transfer is multi-objectively optimized. In the optimization process, the plates spacing is changed so as to simultaneously maximize the flow rate of the fluid sucked through the stack of plates (cooling flow rate) and the amount of heat transfer between the plates and ambient air. The plates spacing varies from 200 μm to 100 mm; and thus, the investigated channels can be classified between minichannels and conventional channels. In Section 3, the Pareto front, which simultaneously displays the variations of the cooling suction flow rate and the heat transfer from plates, will be presented, and it will be demonstrated that the Pareto front conveys very important results for the thermal designing of a stack of parallel channels subjected to natural convective heat transfer. At the end, the multi-objective optimization results obtained in this paper will be compared with the related results of the asymptotic method and the analytical approach, which are single-objective optimization methods and aimed at increasing the amount of heat transfer from the plates; and very useful and valuable conclusions will be obtained.

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1. Introduction

Heat sinks that are cooled by natural convection and forced convection have been used in different industries and applications, like in the cooling of electronic parts, solar energy, etc. Numerous investigations have been conducted in recent years on the numerical modeling, geometrical optimization and the governing conditions of heat sinks [1–6]. Bejan and Sciubba [1] applied the asymptotic method to determine the optimum geometry of a stack of parallel plates cooled by forced fluid flow. They demonstrated that the thermal conditions of channel walls, with the temperature or flux being constant, do not make much of a difference in the final results. They used a single-objective optimization, and their goal was to increase the amount of heat transfer in the stack of plates. By applying the genetic algorithms, Wei and Joshi [2] minimized the thermal resistance of a micro-channel heat sink. The design variables in their research consisted of some geometrical parameters including the blade thickness, ratio of channel width to blade thickness, etc. They performed their single-objective optimization process by considering two constraints: maximum permitted pressure loss, and maximum permitted inlet flow rate. By combining numerical, analytical and experimental studies and employing the asymptotic analysis method, Bejan et al. [3] optimized the natural convective flow around a stack of horizontal cylinders. They used a single-objective optimization approach, and the design variable in their research was the cylinders spacing, and the constraint they had in mind was the constant volume of the region under investigation. Finally, they presented an equation for the optimal cylinders spacing and the maximum degree of heat transfer, which was a function of geometrical variables and the non-dimensional Rayleigh number. Goshayeshi and Ampofo [4] numerically investigated the performance of heat sinks, placed horizontally and vertically and subjected to natural convective flow. They concluded that the vertical heat sinks have the best performance. Bar-Cohen and Rohsenow [5] used the analytical equations to calculate the optimum channel width for the maximum amount of heat transfer in a stack of vertical channels subjected to natural convection, for two boundary conditions of constant temperature and constant flux at channel walls. Using numerical modeling, Buonomo and Manca [6] explored the flow of air in vertical microchannels subjected to free convection. They investigated the slipping fluid flow, and the wall boundary condition was the constant flux at the walls.

In the heat sinks cooled by natural convection, it would be ideal for a sink to exchange a lot of heat with the cooling air, while it sucks a large volume of air. In other words, an ideal heat sink must have a maximum suction flow rate and maximum heat transfer capacity. In certain ranges of channel widths in heat sinks, the suction flow rate and the amount of heat transfer conflict each other; meaning that the heat transfer capacity diminishes with the increase of flow rate, and increases with the reduction of flow rate. So to achieve the optimal thermal behaviors in these channels, a multi-objective optimization (MOO) approach should be used to discover the best possible design points with appropriate heat transfer and cooling capacities. NSGA II algorithm is one of the best and most complete multi-objective optimization algorithms, which will be used in this paper as well. This algorithm was first proposed by Deb et al. [7], and it has been used in recent years in various engineering-related applications [8–11].

Based on our information, so far, no multi-objective optimization of heat sinks cooled by natural convection has been performed, with the goal of increasing both the suction flow rate and the amount of heat transfer. In this paper, by employing the Computational Fluid Dynamics (CFD) and applying the NSGA II algorithm, the cooling of a stack of vertical parallel plates subjected to natural convective heat transfer is multi-objectively optimized. In the optimization process, the plates spacing is changed so as to simultaneously maximize the flow rate of the fluid sucked through the stack of plates (cooling flow rate) and the amount of heat transfer between the plates and ambient air. The plates spacing varies from 200 μm to 100 mm; and thus, the investigated channels can be classified between minichannels and conventional channels. In Section 3, the Pareto front, which simultaneously displays the variations of the cooling suction flow rate and the heat transfer from plates, will be presented, and it will be demonstrated that the Pareto front conveys very important results for the thermal designing of a stack of parallel channels subjected to natural convective heat transfer.

2. Mathematical modeling

The data needed for performing the multi-objective optimization in this paper have been obtained by means of numerical modeling. The details of this procedure will be described in this section.

2.1. Geometry

The geometry investigated in this paper has been schematically illustrated in Fig. 1. As is shown in this figure, a number of parallel plates have been placed next to each other and formed a stack of parallel channels. Since, in this stack, the fluid flow field in each channel is the same, the governing equations have been numerically solved for one channel of width D and length H; and finally, the flow rate of the passing fluid and the amount of heat transfer from the plates have been multiplied by the number of channels to get the total values. The total flow rate and heat transfer for the set of channels are computed as follows:

$$q_{tot} = nq_1 \tag{1}$$

$$\dot{m}_{tot} = n\dot{m}_1 \tag{2}$$

$$n \approx \frac{L}{D} \tag{3}$$

The relative thickness of the plates with respect to plates spacing has been ignored in the computations ($\frac{t}{D} \approx 0$). Also, due to the symmetry of the flow field in each channel, half of a channel has been considered for the computations. Hence with the computation of the flow rate and heat transfer values for one symmetric channel

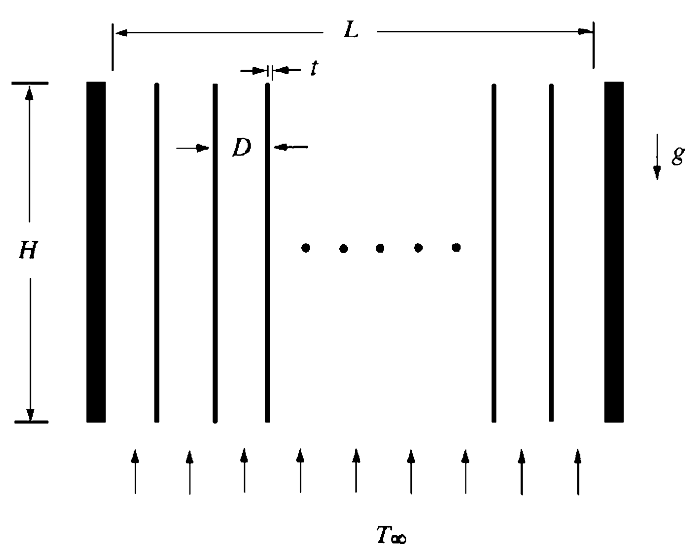

Fig. 1. Schematic of vertical stack of plates cooled by natural convection.