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Numerical investigation of hydraulic and thermal performance of a honeycomb heat sink

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ABSTRACT

The thermal and hydraulic performance of a heat sink having aluminum honeycomb fins is numerically investigated by using a finite-volume-based solver. The fin height (*H*), the distance between the fins in the streamwise direction (S_y) and the Reynolds number (*Re*) are selected as design parameters while the thermal resistance of the heat sink (R_{th}) and the pressure drop (ΔP) are regarded as the performance criteria. Each design parameter is examined in three levels and twenty-seven three-dimensional simulations are carried out in total. A computational domain consisting of three parts as the inlet and outlet sections and the test section where the honeycomb heat sink is located is used in the simulations. The CutCell mesh is employed for the test section while hexahedral meshes are used to discretize the inlet and outlet sections. The Reynolds-Averaged Navier-Stokes (RANS) based *Realizable k-ε* turbulence model in combination with the enhanced wall function is employed in the simulations. The effects of each design parameter on the performance criteria are examined in detail.

1. Introduction

Heat sinks are used to provide safe, long life, high performance and reliable electronic devices by dissipating the excessive heat generated due to electrical work. For this purpose, in the literature, various types of heat sinks such as triangular, rectangular, hexagonal, trapezoidal, annular, tapered and diamond etc. are designed to realize the heat transfer mechanism at the most effective way [1–6]. There are also different types of heat sinks in addition to aforementioned conventional ones. Honeycomb heat sinks are one of them. Some structural and thermal properties of honeycombs such as large surface-area-to-volume ratio, low pressure drop and high conductive materials make them a powerful candidate to use in heat exchanger/sink applications [7–11].

A brief literature review related to the heat transfer applications of honeycombs is reported below. Zhang et al. [7] reviewed the extensive usage areas of the bio-inspired honeycombs ranging from architecture and engineering to biomedicine including heat transfer. Dempsey et al. [11] numerically and experimentally investigated the pressure drop through the unidirectional honeycomb channels and the total heat transfer rate of the heat sinks. They concluded that the square cell Linear Cellular Arrays (LCAs) provide high heat transfer rates at relatively low pressure drop. They suggested that it would be interesting to investigate their performance under the turbulent flow regime. Wen et al. [12] examined the heat transfer and pressure drop characteristics of metallic honeycomb structures both experimentally and numerically. They showed that the pressure drop is correlated with the surface area density and the cell shape while the heat transfer rate is related to the surface area density, the cell shape, the ratio of cell and the thermal conductivity of the solid material. They also reported that the metallic honeycombs are an excellent candidate for heat sink applications. Heat transfer properties of a honeycomb core panel at high temperature are investigated numerically and experimentally by Zheng et al. [13]. It is reported that the findings provide an important foundation for the safety design of high-speed aircrafts. They also concluded that the numerical results are consistent with the experimental data. Zhang et al. [14] developed a numerical method by combining the finite element and finite difference methods to examine the forced convection of uniform and graded honeycomb heat exchangers. They tested reliability, accuracy and precision of the proposed method by comparing the results with those obtained from Computational Fluid Dynamics (CFD) simulations. They reported that the precision of the new method is similar to the CFD results while its calculation efficiency is increased 10^2 to 10^4 times of the CFD simulations. However, they also mentioned that the assumption of the proposed model is only suitable for the heat

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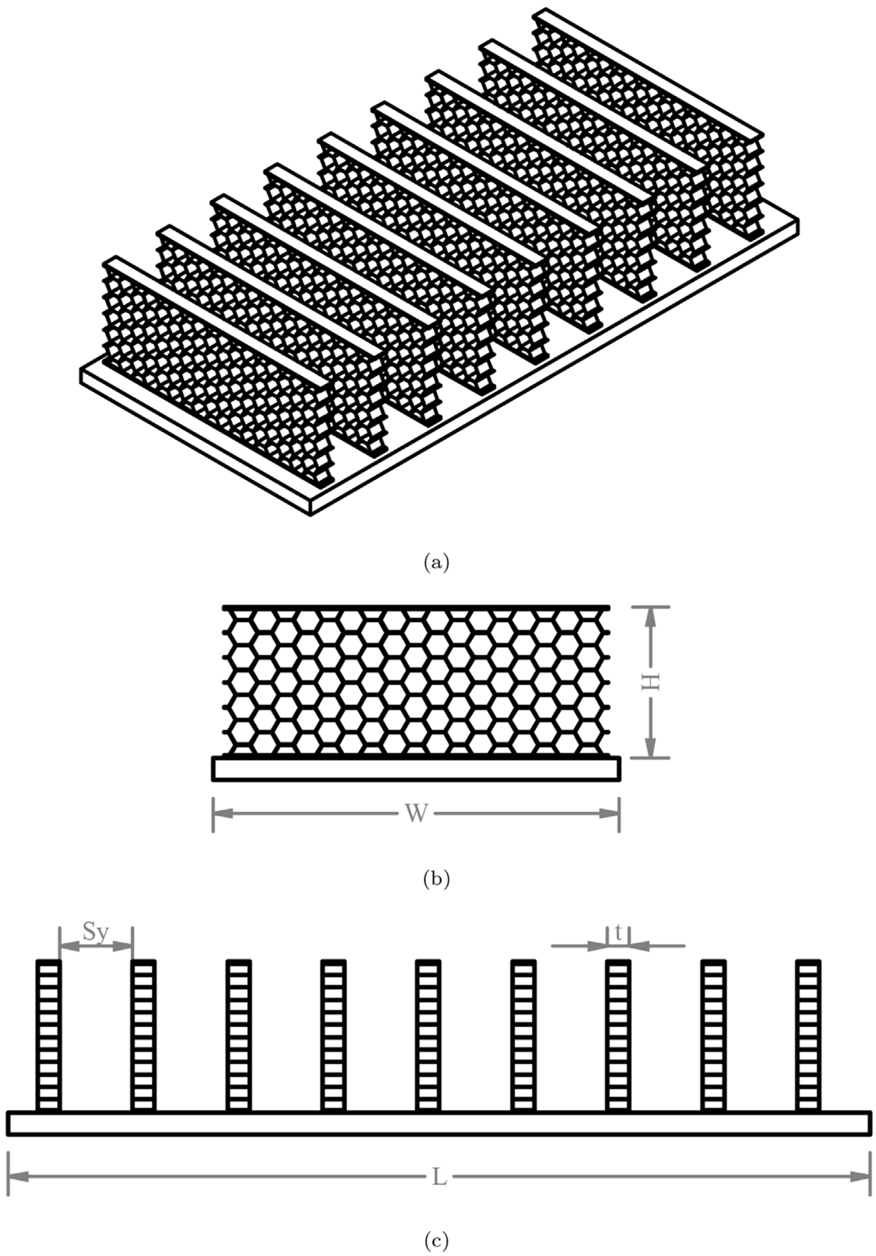

Fig. 1. (A) Isometric (b) front and (c) side view of a honeycomb heat sink. Note that figures are not scaled.

transfer analysis of uniform honeycombs. Liu et al. [15] proposed an analytical model for the heat transfer performance of a heat exchanger filled with the metallic honeycomb under forced convection conditions using the two-equation method. They determined the accuracy of their analytical model by comparing the results with the numerical results. They examined the effects of various parameters such as fluid-to-solid thermal conductivity ratio, cell wall length and relative thickness of the heat exchanger on the hydraulic and thermal performance of the heat exchanger in order to determine the optimal values of the design parameters. They concluded that a considerable heat transfer enhancement with a low pressure drop can be obtained by using the metallic honeycombs in the compact heat exchangers. You et al. [16] numerically studied the performance of a square-celled ceramic honeycomb refrigerator through three-dimensional, unsteady and laminar simulations and investigated the effect of various parameters on the heat transfer mechanism. They checked the accuracy and validity of their numerical results by comparing them with the numerical and experimental data available in the literature. They concluded that their three-dimensional simulations giving error around 1.6% in the temperature efficiency in comparison with the available experimental data reveal a better performance when compared to its two-dimensional counterpart found in the literature whose error is around −3.8%. Additionally, CFD simulations are used in various applications due to its simplicity and low cost when compared to the experimental studies. Design and development of a heat sink is just one example of these applications. Aslam-Bhutta et al. [17] reviewed the applications of CFD simulations in various heat exchangers/sinks. They reported that the k-ε turbulence model is widely used among the other models and also pointed out that CFD is an important part of design process of heat exchangers/sinks especially the eliminating the need of prototyping. Yang and Peng [18] conducted a numerical study on the performance of pin fins for heat transfer enhancement of the plate fin heat sink. They revealed that the plate circular pin fin heat sink has better performance than the plate fin heat sink. Ayli et al. [19] experimentally and numerically examined the effects of the geometrical parameters of a rectangular-type heat sink placed on a square-sectioned duct on the steady-