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Introducing a ψ-shaped cavity for cooling a heat generating medium

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ABSTRACT

Reducing the excess temperature in the heat generating pieces such as electronic devices is becoming a formidable challenge. The competition for introducing more efficient tools to cool down the hot pieces still continues. In this paper, a new configuration of an inverted fin ('cavity'), penetrated into a heat generating medium, is proposed, evolved and optimized. On account of its particular shape, the new configuration is called the 'ψ-shaped' cavity. A big picture of how this flow configuration evolves to become better, is provided. To accomplish this, a numerical optimization based on a finite element code and exhaustive search algorithm is performed to seek for the best geometric structure of the ψ-shaped cavity. The optimization objective is to minimize the excess (hot spot) temperature of the heat generating piece subjected to a fixed volume of the cavity constraint. It is convincingly indicated that the ψ-shaped cavity with optimum geometrical structure performs dramatically superior among the single-cavity structures investigated in the literature. For example, the lowest hot spot temperature obtained in the ψ-shaped cavity is found about 25% lower than that obtained in the best cavity investigated in the literature when the cavity occupies 10% of the heat generating body.

1. Introduction

According to constructal design [1], geometry endows the flow pattern with the ability to morph (change) as free as possible such that it eventually gains its purpose [2,3,4]. Nowadays, constructal design and geometric optimization are frequently applied in a variety of engineering systems such as furnaces [5], heat exchangers [6], reactors [7] and electronics cooling [8,9]. For a bird's eye view of the evolutionary design field, authors are recommended to study the most recent paper of Bejan [10].

One of the greatest concerns of miniaturization in electronics cooling technology, is that the working temperature of the heated medium exceeds beyond an allowable limit. This, results in mechanical and electrical failure of the device. As the lifespan of the equipment has an inverse relationship with its temperature, it is crucial to reduce its (maximum) temperature. With the help of constructal design, highly conductive inserts [8,11], fins [12,13], and inverted fins (cavities) [14–26] are optimized and are introduced to reduce the excess temperature of heat generating devices.

As depicted in Fig. 1, cavities are actually regarded as 'inverted', 'negative' solid fins or high-conductivity inserts [27]. They are also considered as the regions formed between nearby fins. As well as the fins, cavities are applied in practice where high-density cooling and heat transfer is needed. Therefore, cavity protrusions are the vital promoters of nucleate boiling and condensation (considering the vapotron effect [28]). In electronic cooling, cavities are applied when the excess space occupied by the regular (positive) fins is a great concern. Instead, inverted (negative) fins penetrate *inside* the heat generating pieces.

Several configurations of the cavities are introduced and geometrically optimized in the literature [14–26]. Biserni et al. [14], for example, introduced and optimized a simple cavity called 'C-shaped' or 'I-shaped' cavity. They indicated that there exists an optimum geometrical structure of the I-shaped cavity that reduces the hot spot temperature to a minimum level. Better cavities (like the better high-conductivity inserts) look more like natural trees [29]. In this manner, T-shaped cavity was also introduced by Biserni et al. [14]. T-shaped cavity was found to be more efficient than the I-shaped cavity under the same volume fraction of the cavity. Later, the H-shaped cavity was suggested by Biserni et al. [15]. They indicated that the H-shaped cavity performs better than I-shaped and T-shaped cavities. The Y-shaped cavity investigated by Lorenzini et al. [18,19] was proved to reduce the excess temperature around 35% greater than the I-shaped cavity. The double optimization with respect to the two degrees of freedom was performed to indicate that the global thermal resistance is reduced by an increment in the volume fraction occupied by the rectangle defined

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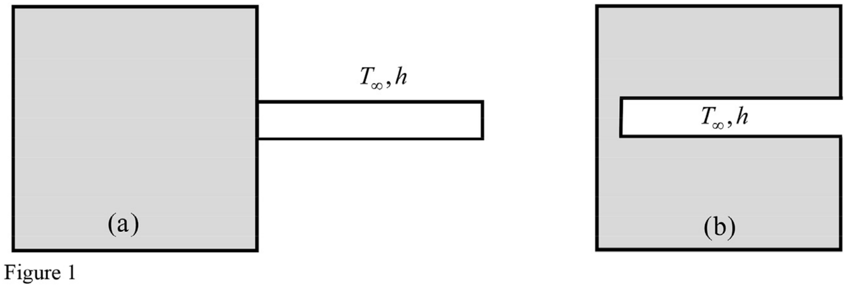

Fig. 1. (a) A schematic of a positive (regular) fin and (b) a negative (inverted) fin called as a 'cavity'.

by the 'stem' intrusion. The shape optimization of the Y-shaped cavity was carried out by varying the angle between the tributary branch and the horizontal axis. A hybrid cavity from T- and Y-shaped cavities was studied and optimized by Lorenzini and Rocha [16] who called it a T-Y-shaped cavity. The two cases of isothermal cavity and a cavity with constant convection heat transfer coefficient were considered. They claimed that the T-Y-shaped cavity is superior than T- and Y-shaped cavities under the same thermal conditions and the volume fraction of the cavity. A new configuration proposes by Lorenzini et al. [24,25] included an isothermal X-shaped cavity intruding a square-shaped heat generating pieces. Their results revealed that the increase of the complexity in the geometric construct of the cavity improves the cavities efficiency. They indicated that the excess temperature reduction by X-shaped cavity is 53% greater than the Y-shaped cavity, 68% better than the I-shaped cavity while 22% lower than H-shaped cavity. Several configurations of the cavities are schematically depicted in Fig. 2. In the research papers regarding the design of cavities with different configurations, the heat generating piece is assumed to be rectangular-shaped [14–16,18–20,22–26] trapezoidal-shaped [17,22], or a cylindrical heat generating body [21]. The heat current is extracted to a single-cavity structure or a multiple-cavity structure (e.g., T-Y-shaped cavities with two additional lateral intrusions [20] and N-branch cavities [22]). The cavities are assumed isothermal or with constant convection heat transfer coefficient. Moreover, several algorithms are applied in the optimization procedure pertinent to the confines of this field. Instances are exhaustive search [14–22,24–26] genetic algorithm [23] and simulated annealing [30].

The preceding literature review suggests that the optimal design of the cavities is becoming a challenging competition. One of the most significant reasons may lie within the rapid progress in electronics cooling miniaturization. In synthesis, the following objectives are addressed in the present work,

- A new configuration of cavities with constant temperature/constant heat transfer coefficient is present. On account of its particular shape, the new configuration is called the 'ψ-shaped' cavity.
- A numerical solution is presented to deliver the temperature field within the heat generating body and to evaluate the performance of the proposed cavity.

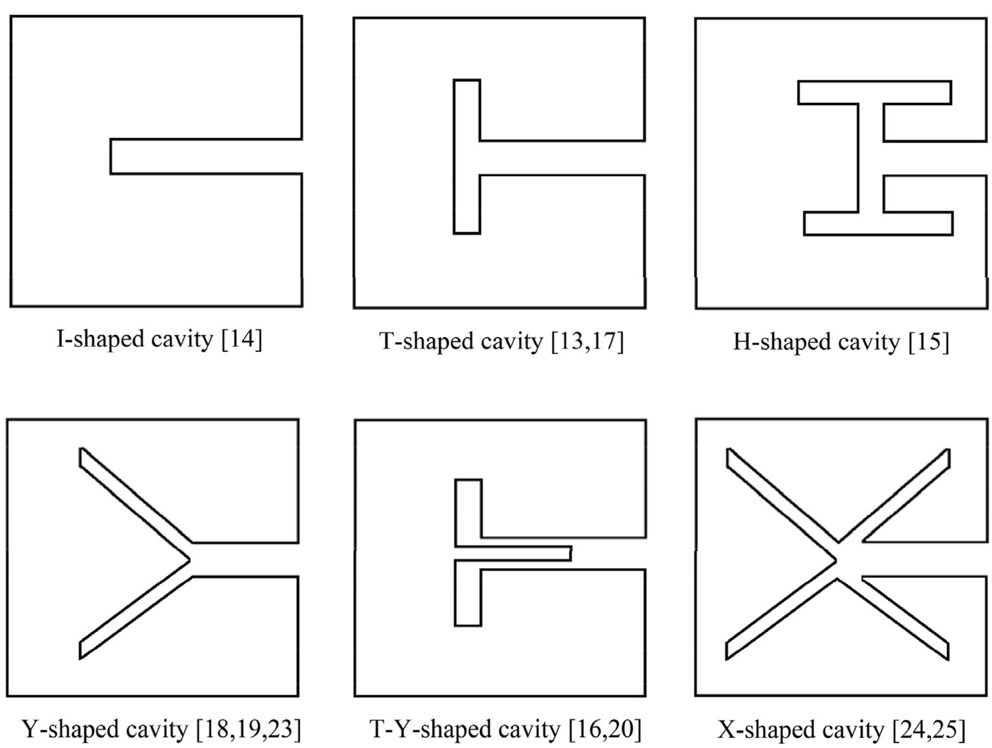

Fig. 2. Several cavity structures investigated in the literature.