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Research Paper

Design of bifurcating microchannels with/without loops for cooling of square-shaped electronic components

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HIGHLIGHTS

- Constructal theory was used to design reverting channels for cooling a square piece.
- Effect of bifurcating loops and their place on cooling performance was studied.
- The increased number of branches, reduces temperature and pressure drop.

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ABSTRACT

This study investigates the using of microchannels with/without loops for cooling process of a square electronic component with internal heat generation via convection using the constructal theory. The collection problem of the cooling fluid flowing through the microchannels of a square electronic piece is examined and a solution to overcome this problem is suggested by designing reverting microchannels with/without loops. The proposed microchannel network facilitates the collection of the fluid flowed in radial and bifurcated ducts embedded in the body. This research investigates uniform temperature distribution and maximum temperature reduction to recognize the effect of branching on thermal resistance. The goal is to develop a system configuration that minimizes thermal resistance. The results indicate that increasing the number of branches reduces both temperature and pressure drop. In the test results, the maximum dimensionless temperature is reduced by 10% and 20%, while the maximum dimensionless pressure drop is decreased by 25% and 33% for one and two branch reverting microchannels, in comparison with the case without a branch. Path length ratio, width ratio of channels in each branch of the tree network, and finding the optimal split point are among the parameters investigated in this study.

1. Introduction

The growth and development of science in manufacturing small-sized components necessitates the investigation of cooling small-sized components. Microchannels are best for obtaining small geometries for use in industrial applications. For instance, microchannels are used in heat exchangers, micro electro-mechanic systems, medical technologies, and nuclear reactors. They are also used to decrease not only pernicious materials in the environment, such as the ozone layer, but also air pollution in the manufacturing of industrial devices. It is proved today that the functional speed of computer circuits, electromechanical systems and the like is directly related to their temperature, and thus keeping them at an appropriate temperature is very important. Several methods were proposed for improving the cooling process of electronic systems with high heat flux and compact size. Among these methods, the heat absorbing microchannels have attracted much attention for their high heat transfer coefficient. This movement started in 1981 when Tuckerman and Peace [1] produced a publication that outlined the benefits of using small-diameter channels for cooling electrical circuits. They noted that as the hydraulic diameter of a channel decreases, the heat transfer coefficient increases. They also showed the capability of increasing the heat transfer coefficient by 40 times via microchannels, compared to common heat exchangers.

A numerical investigation by Gou et al. [2] analyzed the effect of viscous dissipation on a curved square microchannel in laminar flow of the fluid. They studied entropy production for two scenarios, one with the fluid getting cold and the other, hot. The results showed that the entropy generation number in the heat exchanger

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Nomenclature

Be	dimensionless pressure drop
H	height of the heat sink
h	height of microchannel
k	thermal conductivity
L	length
$\dot{m}$	mass flow rate
P	pressure
ΔP	pressure drop
q''	heat flux
Sv	sveltness
T	temperature
Pr	Prandtl number
Greek symbols	
μ	dynamic viscosity
ν	kinematic viscosity
ρ	density
ϕ	volume ratio
Subscripts	
ave	average
f	fluid
in	inlet
out	outlet
s	solid
Superscripts	
$\sim$	dimensionless

increases at higher Reynolds numbers. Lee et al. [3] numerically investigated the effect of sectional oblique fins, in contrast to continuous fins for modulating flow in the microchannel heat sink. They showed that oblique sections reduced the thickness of the boundary layer. In this case, the flow remained in a developing state at all times, and the heat transfer was ultimately improved.

Nature provides effective solutions to many major problems. In recent years, there has been a growing effort to achieve designs with a more natural pattern. The constructal theory, introduced by Bejan, clarifies the structures of various natural and engineering systems, and deals with the morphing flow shapes through time [4]. This theory predicts tree shape configurations using the optimization procedure. The application of the constructal theory can optimize the geometric features of microchannels.

Lorenzini et al. [5] used this theory to find the optimal configurations of X-shaped high-conductivity inserts embedded within a square-shaped heat-generating body of low-conductivity material. Feng et al. [6] optimized tree-shaped fluid networks in a disk shaped area by taking total pressure drop as the optimization function. In this study, both laminar and turbulent regimes were considered. They also found the optimal aspect ratio of the elemental sector in the radial-pattern disk [7]. Rocha et al. [8] investigated the creation of dendritic architectures for a circular body with natural heat convection, cooled with a heat sink, and compared them accordingly. Xia et al. [9] investigated the flow field in the current complex corrugation microchannel heat sink using experimental and numerical methods. They evaluated performance by the total thermal resistance and thermal enhancement factor. In comparison to the rectangle microchannel, results indicated a decrease in both average temperature and maximum temperature, and temperature distribution had become more uniform.

Wechsatol et al. [10] used constructal theory to develop tree-shaped convection networks for cooling disk-shaped components with heat generation. The aim in optimal design of these structures is to develop tree-shaped configurations with minimum flow and thermal resistance. In addition, they showed that when the number of branching stages is increased, the ratio of thermal resistance to radial spacing is far lower. da Silva et al. [11] investigated the cooling of disk-shaped components with natural convection. In this study, the configuration of the fins, which were located inside the disk and attached to its wall, was investigated. In addition, the optimal geometric parameters and thermal resistance were diagrammed as a function of the ratio of the heat transfer coefficient, volume ratio, and the number of sectors.

Using the constructal theory, Salimpour and Menbari [12] analytically optimized a dendritic path flow structure carved in a ring-shaped body, to minimize the overall flow and thermal resistances. Results indicated that the mass flow rate had the most effect on thermal resistance, while its effect on flow resistance was insignificant.

In another work, they performed an analytical study to find the best architecture of the cooling pathways on a ring-shaped body [13]. The purpose of the design was to obtain suitable tree networks for cooling electronic parts, which would minimize the system's overall flow resistance. Salimpour and Menbari [13] investigated the influence of ducts that reach the points on the internal circle, number of branching, internal radius of body disk and mass flow rate. The best performance was achieved when the number of branches was increased.

Gosselin and Bejan [14] addressed the cooling of a 2D square component with a pointed heat sink, placed on a corner of the component. They first proposed an equation for depicting the effect of size coefficient on the thermal conductivity coefficient of the blades, and then used the principles of constructal theory to obtain high-order optimal constructs by optimizing minor elements and putting them together. Rocha et al. [15] investigated the optimization of tree- and cyclic-shaped constructs for cooling a disk with internal heat generation via a numerical solution. Wang et al. [16] documented laminar convective heat transfer in constructal microchannel networks with loops. They validated their results with those of Senn and Poulikakos [17]. Based on the constructal theory concepts, Hajmohammadi et al. [18] numerically determined the optimal design of heat flux elements mounted on the outer walls of a rectangular duct in order to minimize the maximum temperatures (hot spots) of the device. They studied the influence of Graetz number and the number of unequal heat flux elements on temperature reduction. Results showed that the hot spot temperature decreased by about 25% in the case of four unequal heat flux elements, relative to the uniform heat flux.

Ghaedamini et al. [19] used radial microchannels to investigate the convection cooling of a circular disk. In the proposed microchannel network, a fluid collection network is used to increase heat transfer. The current paper thoroughly investigates the effects of the number of branches on pressure drop and heat transfer, and illustrates the effect of latitudinal cross-section on thermal resistance. Results were obtained for two dimensionless heights. Temperature distribution becomes more uniform as the number of branches increase, but its gradient decreases proportional to the number of branches. It may thus be inferred that maximum complexity does not necessarily equate with maximum performance. Azad and Amidpour [20] used the constructal theory to design and optimize a tubular shell exchanger by maximizing the total heat transfer coefficient (shell and tube). They initially decreased the thermal transfer level to reduce construction expenditures, and then reduced the energy required by the pump to