Numerical study of the heat transfer performance of heat sinks with different microchannel structures

Heng Ren

***Abstract*—In this paper, the effect of microchannels with different structures on the cooling capacity of heat sinks is investigated. Three different geometries were designed, including square, circular and triangular microchannels. The results showed that the heat sink with square sink has less thermal resistance compared with the other two geometries. The temperature distribution of the heat sinks and pressure drop of the channels are presented. It is found that the reverting microchannels remarkably reduced the maximum temperature of heat sink and the temperature distribution of the heat sink is more uniform.**

***Index Terms*— Heat sink, microchannel, temperature distribution, thermal resistance.**

[1] INTRODUCTION

The use of small channels and utilization of nanoscale sizes are approaches for improving heat transfer rate in channels that has been received great attentions in recent years. The use of forced flow inside microchannels is a method suggested for cooling electronic parts generating high temperatures. This idea was first put forward when Tuckerman et al. [1] stated that the use of small-diameter channels is useful for cooling electronic circuits. They stated that as diameter decreases heat transfer coefficient increases. They showed that it is possible to increase heat transfer coefficient of microchannels by 40 times compared the conventional heat exchangers.

Technological advances have introduced higher heat transfer capability as an important factor in designing micro-scaled systems. The configuration of microchannels has a tangible effect on the heat transfer rate. Pan et al. [2] experimentally studied and optimized different structures of microchannels used in methanol steam reactor. They studied the effects of both cross-section and configuration and concluded that reactor efficiency depends on configuration more than cross-section. Based on the constructal theory, wechsatel et al. [3] developed convectional tree networks for cooling of heat generating disk-shaped parts. The aim of optimized designing of the structures was to achieve tree-like configuration with the minimum possible resistance against flow on the one hand and the minimum possible thermal resistance on the other hand. They showed, however, that the addition of bifurcations in several stages decreases the thermal resistance more than radial distribution. Ramiar et al. [4] numerically solved the conjugate heat transfer of a nanofluid in a 2D microchannel and investigated the effect of Reynolds number, nanoparticle conductivity. In another work, Bello-Ochende et al. [5] studied the geometric optimization of a 3D heat sink numerically using the finite element method. In their study, microchannel had a variable cross-sectional area. The numerical results revealed that the degree of freedom has higher effect on the maximum temperature. In this way, optimum geometric properties were obtained.

In this study the effect of reverting channels inside a heat sink on increasing the cooling rate and the effect of different configurations of microchannels on maximum temperature and pressure drop was investigated.

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[2] NUMERICAL METHOD

Conservation of mass and conservation of momentum equations are stated as follows

$$\nabla \cdot \bar{U} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (1)$$

$$(\bar{U} \cdot \nabla \bar{U}) = -\nabla P + \mu \nabla^2 \bar{U} \quad (2)$$

Conservation of energy equation for the fluid phase is defined as

$$\rho_f C_{p,f} (\vec{U}.\nabla T) = k_f \nabla^2 T \quad (3)$$

While the equation of heat transfer for solid phase is defined as

$$k_s \nabla^2 T = 0 \Rightarrow \nabla^2 T = 0 \quad (4)$$

Standard no-slip condition is applied on channel walls. Constant mass flow rate boundary condition is applied in the inlet of the channel. Outlet pressure and inlet temperature were considered as $P_{out} = 1bar$ and $T_{in} = 300K$ for simplification purposes. Thermal flux imposed from the bottom side is derived from the following equation

$$k_s \frac{\partial T}{\partial y} = -q'' \quad (5)$$

Regarding the continuum of temperature and heat flux in fluid and solid interface, we have

$$-k_s \frac{\partial T_s}{\partial n}\bigg|_{\Omega} = -k_f \frac{\partial T_f}{\partial n}\bigg|_{\Omega} \quad (6a)$$

$$T_s = T_f \quad (6b)$$

Where k_f and k_s are fluid and solid thermal conductivity coefficients, respectively. Ω is the normal vector of fluid

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and solid interface.

[3] Computation Model

As illustrated in Fig. 1, fluid distribution channels are located in 3D heat sinks. This study assesses the configuration of microchannels and their optimization as well as the geometric optimization of the studied heat sink under heat flux in order to achieve the maximum heat transfer rate. Three cross sections of heat sink (i.e. circular, triangular and square) were studied for the geometric optimization purposes. The constant volume of the heat sink and the ducts embedded inside were considered as the constraints of the studied geometries. Heat is transferred to the bottom heat absorbing surface through the heat generating surfaces and is then directed through silicon-made solid surfaces with a high coefficient of conductivity. Then, it is dissipated by coolant fluid flowing through microchannels. According to Fig. 1, microchannels can be distributed along the diameters or along the mid-side of triangular and square heat sinks.

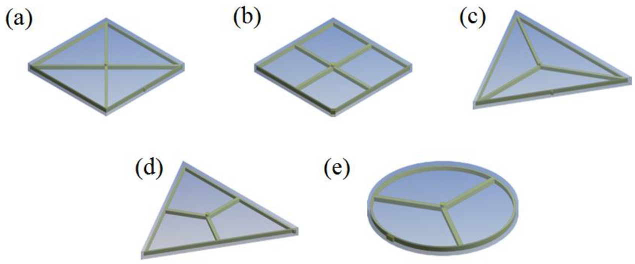

Fig. 1. Distribution of microchannels inside the heat sink. (a) case 1, (b) case 2, (c) case 3, (d) case 4, (e) case 5.

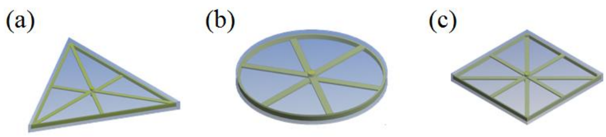

Fig. 2. Distribution of reverting microchannels inside the heat sink. (a) case 6, (b) case 7, (c) case 8.

Fig. 2 shows the second configuration in which reverting channels located beneath the inlet channel. In this case, fluid enters from the center of top surface, flows through microchannels and leaves the heat sink from the bottom surface through reverting channels. In order to compare the effect of different configurations on the dimensionless maximum temperature, the same boundary conditions were applied in all cases. The ratio of volume taken up by the microchannels to the remaining volume of disk was introduced as the volume ratio shown by ϕ . As a constraining condition, ϕ has the same value in all cases and equals to 0.05.

[4] Results and discussion

For cases 1-5, fluid tends to flow through a path with the minimum pressure drop. Therefore, less fluid flows through the path with the maximum length and there will be a higher mass flow rate in the paths closer to the outlet. In addition to the distributed pressure drop, there is a local pressure drop due to the elbows in fluid path line. In general, pressure drop inside a microchannel, which includes both local and distributed pressure drops, is derived from relationship (7) as follows

$$\Delta P = \Delta P_{distributed} + \Delta P_{local} \qquad (7)$$

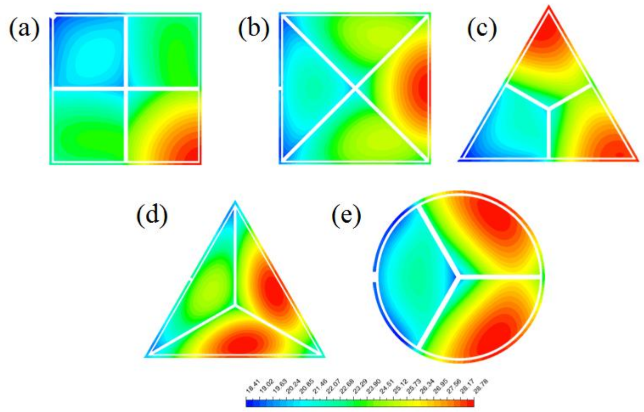

Fig. 3. Contour of temperature distribution for case 1 to case 5.

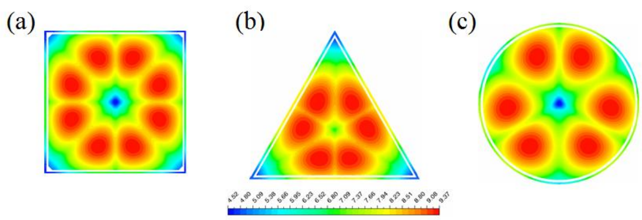

Fig. 4. Contour of temperature distribution for case 6 to case 8.

From figure 3, it is seen that the use of collecting ring in the square heat sink not only did not decrease dimensionless maximum temperature but also increased it. The reason is that between two known points (inlet and outlet points) fluid tends to flow through a route with a minimum pressure drop. Therefore, in a route with a higher pressure drop, the fluid velocity decreases and it flows in a very small amount. This increases temperature in regions that are closer to the microchannels.

Table 1 S/V ratios of microchannels for case 1 to case 5

Case	Case 1	Case 2	Case 3	Case 4	Case 5
s/v	0.1936	0.2108	0.1892	0.2158	0.1775

According to table 1, the higher S/V ratio, the higher the rate of heat transferred to coolant fluid and the lower the maximum temperature inside the heat sink.

A notable conclusion that can be derived from above obtained results is that temperature has an asymmetric distribution in the mentioned configurations. When we speak about the best thermal design, both maximum temperature and uniform temperature distribution factors should be studied at the same time. In fact, the optimal design of a heat sink is the case in which whole the heat sink works at the same temperature, or in other words, there is a uniform temperature distribution. To achieve a more uniform temperature distribution, the distributed fluid can be reused for cooling purposes. Reverting channels embedded beneath the inlet channel can be used for this purpose. In the studied cases, the S/V ratio was 0.2532, 0.2256 and 0.2358 for square,

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circular and triangular heat sinks respectively. According to the temperature contours (Fig. 4), in case of using microchannel for cooling purposes, a more uniform temperature distribution is obtained compared with previous cases. This figure indicates the superiority of center collection approach because in this case, the maximum dimensionless temperature of the heat sink decreases significantly as compared to the side and corner collection approach showed in figure 3.

The difference between average temperature of heat sink and the maximum temperature can be considered a proper measure for uniform temperature distribution. The best design for fluid distribution is the case in which the average temperature in the heat sink approaches the maximum temperature. The use of collecting ring results in a more uniform temperature distribution across the heat sink. However, an increased flow rate significantly increases the pressure drop while temperature gradient decreases with a low speed. This means that any increase in flow rate does not necessarily an economical.

[5] CONCLUSION

To improve the thermal performance of a silicone made heat sink, different configurations of microchannels with different geometries were studied. Hereby, three geometries were numerically studied at a constant volume of microchannels. According to the results, in different configurations the use of reverting channel network as well as distributing fluid along diameter has a considerable effect on the dimensionless maximum temperature and uniform temperature distribution due to higher S/V ratio. However, numerical results suggested that square geometry shows the least thermal resistance. Another conclusion was that the use of reverting microchannels reduced the maximum temperature and increased the pressure drop. Reverting channels shifted the maximum temperature zone from sides to the surface center. In addition to a remarkable decrease in the dimensionless maximum temperature, the addition of reverting microchannels resulted in more uniform temperature distribution.

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