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Numerical study on thermal hydraulic performance of water cooled mini-channel heat sinks

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ABSTRACT

This paper presents a numerical investigation on the thermal hydraulic performance of mini-channel heat sinks with different fin configurations. Results in terms of pressure drop, base temperature, thermal resistance, and overall heat transfer coefficient were compared for different geometrical configurations modeled by variation of fin spacing, fin thickness and fin height of the heat sink. In comparison to un-finned geometry, a reduction of 44.84% in base temperature was observed with the minimum temperature value of 33.7 °C for the heat sink with fin spacing and fin thickness of 0.2 mm and 0.4 mm respectively. In association with the previous studies, pressure drop and thermal resistance were reduced by 46.5% and 30.4% respectively. The heat sink geometry with the best thermal performance was also simulated for higher heat fluxes within the same operating limits. Results were validated using available correlations and experimental data. Flow maldistribution, pressure drop and local heat transfer coefficient in the header are also reported.

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Étude numérique de la performance thermo-hydraulique des puits de chaleur à minicanaux refroidis à l'eau

Mots clés : Minicanal ; Puits de chaleur ; Transfert de chaleur conjugué ; Refroidissement de processeur central (CPU) ; Refroidissement électronique

1. Introduction

Heat sinks are the components that elude the damage of electronic equipment caused by overheating, by continuously removing heat. A semiconductor junction is the most critical part of an electronic device whose temperature cannot exceed a temperature set by the manufacturer. The drive toward the more powerful, efficient and compact electronic devices such as cell phones, tablets and computers has set the engineers to design effective yet very compact heat sinks. To some extent, the absence of effective heat removing components has limited the advancement toward more powerful and compact electronic devices. Heat removing methods using air as a coolant have already touched their maximum limit and have been studied to death. In the last decade, liquids as coolants have received a lot of attention due to their higher value of heat transfer coefficient. Microchannel (Bello-Ochende et al., 2007; Gong et al., 2011; Li and Peterson, 2007; Wang et al., 2011) and minichannel (Caney et al., 2007; Hu et al., In Press; Jajja et al.,

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Nomenclature

A_i	interfacial area between fluid and solid domain [mm^2]
A_b	area of base plate [mm^2]
A_p	area of base protrusion [mm^2]
d	hydraulic diameter [mm]
h_b	height of sink base plate [mm]
h_f	height of fin [mm]
h_p	height of protrusion [mm]
k_s	thermal conductivity of solid [$W \cdot m^{-1} \cdot K^{-1}$]
k_f	thermal conductivity of fluid [$W \cdot m^{-1} \cdot K^{-1}$]
l_f	length of fin [mm]
l_s	length of sink [mm]
l_u	unfinned length of heat sink [mm]
N	total number of fins
Nu	Nusselt number
p	pressure [Pa]
Δp	pressure drop across heat sink [Pa]
Δp_c	pressure drop across channels only [Pa]
R_e	Reynolds number
R_{therm}	thermal resistance [$K\ W^{-1}$]
s_f	fin spacing [mm]
t_f	thickness of fin [mm]
T	temperature [°C]
T_b	base temperature (average)/operating temperature [°C]
$T_{b,max}$	temperature of base maximum [°C]
T_{in}	temperature at inlet [°C]
T_{out}	temperature at outlet [°C]
u	velocity [ms^{-1}]
u_m	mean channel velocity [ms^{-1}]
$\dot{V}$	volume flow rate [m^3s^{-1}]
w_s	sink width [mm]
α_c	fin aspect ratio
μ	dynamic velocity [kg m s]
ρ	density [kgm^{-3}]

2014; Naphon and Wongwises, 2010; Naphon et al., 2009; Panão et al., 2012; Rafati et al., 2012; Roberts and Walker, 2010; Tullius et al., 2012; Whelan et al., 2012; Xie et al., 2009) heat sinks with liquid as a coolant are considered effective heat removal devices. With the availability of computational resource and reliable commercial CFD packages, a lot of effort has been focused on to optimize the micro and minichannel heat sink geometries. Li and Peterson (2007) optimized numerically the parameters of a microchannel heat sink by keeping the pumping power constant. They reported $100\ \mu m$, $60\ \mu m$ and $70\ \mu m$ as optimized values of channel pitch, width and depth respectively. Later on, they tested the optimized geometry for thermal resistance with different pumping power and showed 20% enhancement in comparison to previous work. Bello-Ochende et al. (2007) also optimized the microchannel geometry numerically by varying the cross-sectional aspect ratio and solid volume fraction by keeping channel length constant. They showed the pressure drop (Δp) increase with the increase of optimal aspect ratio $\left(\frac{Height}{Width}\right)_{optimal}$. Gong et al. (2011) optimized the microchannel geometry with wavy walls by varying wavelength and amplitude of the wavy pattern for Reynolds number range of 50–150. They showed wavy microchannels performed better by 55% in comparison with straight wall microchannels. Wang et al. (2011) employed inverse process method to minimize the thermal resistance of microchannels.

Although micro channel heat sinks have high heat transfer coefficient due to the large area available for heat transfer, the requirement of high pumping power to circulate the coolant through the microchannels is a major hurdle toward its application in slim and compact computers (Naphon et al., 2009). On the other hand, heat removal capabilities of macrochannel heat sinks are not sufficient for such application as well. So minichannel heat sinks, with hydraulic diameter 0.2–3 mm, are good candidates considering high heat flux and low pressure head requirements. Caney et al. (2007) experimentally studied the laminar regime of single phase flow to calculate frictional losses and heat transfer in mini channels. Xie et al. (2009) numerically studied the effect of channel wall thickness, bottom wall thickness and inlet velocity on the pressure drop. They concluded that pressure drop being an essential parameter for minichannel heat sinks is sturdily dependent on the channel geometry. They showed that pressure drop and heat transfer both increase by narrowing the channels and increasing the depth of channels. Naphon et al. (2009) studied heat transfer characteristics and pressure drop for mini-channels numerically for the first time under a real condition of PC. Tullius et al. (2012) optimized the short pin fins mini-channel against fin shapes, height, width, spacing and material. They also devised correlations for Nusselt number and friction factor. Hu et al. (In Press) performed an experimental study to investigate the effect of air velocity on the heat exchanger and mass flow rate of water through heat sink on CPU cooling under harsh conditions.

Many researchers particularly worked on the improvement of commercial minichannel heat sinks used for cooling of the microprocessor. Whelan et al. (2012) designed and tested a liquid cooled system for Intel® Pentium® 4 processor that was able to remove heat generated by microprocessor at a rate of 200 W with a surface area of $8.24\ cm^2$. The new design involved low cost molding techniques reducing the overall cost of the system. At the same time, new design reduced the thermal resistance from 0.25 to 0.18 K/W. Heat removing ability of mini-channel heat sinks was enhanced by Naphon and Wongwises (2010) via introduction of liquid impingement technique. Liquid jet cooling was further enhanced by Panão et al. (2012) with the introduction of an intermediate jet spray system. Along with pure fluids, nanofluids are also being studied to enhance the thermal performance of commercial mini channels. Roberts and Walker (2010) reported 20% enhancement in the thermal performance of minichannel by using Al_2O_3–water nanofluids instead of pure water. Rafati et al. (2012) used a mixture containing 75% water and 25% ethylene as a base fluid in a commercial cooling kit (3D Galaxy II by Gigabyte). They studied the effect of different concentrations of TiO_2, SiO_2 and Al_2O_3 nanoparticles on the operating temperature of quad-core processor having thermal design power of 125 W. The lowest operating temperature achieved was 43.9 °C using 1% volume fraction of Al_2O_3 in the base fluid corresponding to volumetric flow rate of 1.0 LPM. On

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