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Numerical and experimental investigation of heat transfer in liquid cooling serpentine mini-channel heat sink with different new configuration models

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ABSTRACT

Cooling of electronic chips has become a basic viewpoint in the advancement of electronic devices. Overheating may cause glitch or harm to hardware. A water-cooled mini-channel is a successful cooling innovation for cooling of heat sinks. In this work, geometric optimisation of a 3D serpentine mini-channel heat sink (SMCHS) was investigated. Four configurations of SMCHS were proposed. These configurations were then simulated numerically and tested experimentally. Finite volume method computational fluid dynamics technique is used to model single-phase forced convection for water-cooling laminar flow in a 3D mini-channel heat sink with various channel configurations. Experiments were conducted to analyse the effect of water mass flow rate and heat load on thermal and hydraulic performances of the SMCHS. Experimental results agree well with numerical results. Results indicate that the performance of the proposed device effectively improves when serpentines with two inlets and two outlets are used compared with conventional serpentine with one inlet and one outlet.

1. Introduction

A basic serpentine mini-channel heat sink (SMCHS) has received considerable attention given the high heat transfer coefficient and success of this device in high heat flux applications for electronic devices. Many studies have developed various aspects of engineering applications, including theoretical viewpoints which involve different patterns of investigations and outline strategies, and the practical aspects of these applications. Many recent studies have concentrated on hydrodynamic analysis and enhancement of straight minichannel heat sinks. Several of these studies have focused on the effects of heat flux, Reynolds number, channel dimensions and electric field on enhancing the cooling performances of electronic devices. Xie et al. [1] examined the effects of channel dimensions, fin thickness, bottom thickness and inlet velocity; Kumar and Sehgal [2] considered the effect of channel hydraulic diameter; Naphon and Nakharintr [3] studied the effects of heat flux, fin height and coolant flow rate; Moghanlou et al. [4] tested the effect of an electric field on the laminar flow of a square channel. Ghasemiet et al. [5] studied the effect of the channel diameter of a circular-shaped minichannel heat sink. The other part of studies has focused on the effects of using obstacles, grooves and surface roughness on minichannels. Bi et al. [6] contemplated the effects of dimples and cylindrical grooves; Xiaoqin and Jianlin [7] investigated the effects of non-uniform inlet cross sections; Attalla et al. [8] studied the influences of different degrees of surface roughness; Shen et al. [9] examined the effect of internal vertical bifurcation. Different unconventional flow field configurations have been widely used to enhance heat sink performance. Gongnan and Shian [10] explored two types of chip arrangements, namely, diagonal and parallel; Tang et al. [11] presented a mini-channel heat sink with a double-layer structure that consists of a minichannel and holes; Banda et al. [12] proposed non-conventional patterns for liquid-cooled heat sinks; Kim et al. [13] designed a multistage minichannel heat sink. Numerous studies have handled heat transfer enhancement using nanofluids. Various formulations of nanofluids are used as coolants in serpentine and straight channels that are incorporated in a minichannel and microchannel heat sinks. Ijam et al. [14] tested Al_2O_3–water and TiO_2–water nanofluids for a copper minichannel heat sink; Ho and Chen [15,16] investigated the heat transfer characteristic of Al_2O_3–water nanofluid in a rectangular forced and natural circulation loop; Naphon and Nakharintr [17] tested a mixture of deionised water and nanoscale TiO_2 particles with three different channel heights; Moraveji and Ardehali [18] and Ho et al. [19] investigated the effect of Al_2O_3–water nanofluid in a rectangular minichannel; Mashaei et al. [20] explored the effects of Al_2O_3–water nanofluid in a serpentine microchannel; Sivakumar et al. [21,22] examined the use of water–CuO and Al_2O_3–water that flows through a

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Nomenclature

A	heat transfer area of heat sink ($m^{2)}$)
A_s	surface heat transfer area of channel ($m^{2)}$)
C_p	specific heat at constant pressure (J/kg °C)
D_h	hydraulic diameter (m)
H_{ch}	height of channel (m)
H_b	plate thickness (m)
h_{av}	average convection heat transfer coefficient (W/m^2 °C)
k_s	thermal conductivity of heat sink (W/m °C)
k_f	thermal conductivity of fluid (W/m °C)
L	length of heat sink (m)
L_{ch}	length of one channel (m)
LMTD	Logarithmic arithmetic mean temperature difference (°C)
$\dot{m}$	mass flow rate (kg/s)
n	number of channel
n_t	number of turn bend
Nu	Nusselt number
p	pressure (N/m^2)
q	Heat flux (W/m^2)
Q	heat load (W)
R_t	thermal resistance (°C/W)
R_{cond}	conduction thermal resistance (°C/W)
R_{conv}	convection thermal resistance (°C/W)
R_{fluid}	fluid thermal resistance (°C/W)
R_{ch}	radius of channel (m)
t	thickness (m)
T	temperature (°C)
T_{in}	fluid temperature at inlet (°C)
T_{out}	fluid temperature at outlet (°C)
T_{base}	base temperature of heat sink (°C)
T_{max}	maximum base temperature of heat sink (°C)
T_{min}	minimum temperature of fluid (°C)
T_{mf}	mean fluid temperature (°C)
U	overall heat transfer coefficient (W/m^2 °C)
u	velocity component in the x-direction (m/s)
v	velocity component in the y-direction (m/s)
V	Average velocity (m/s)
w	velocity component in the y-direction (m/s)
W	width of heat sink (m)
W_{ch}	width of channel (m)
x, y, z	Cartesian coordinate (m)
ρ	density (kg/m^3)
μ	dynamic viscosity (N s/m^2)
ν	kinematic viscosity (m^2/s)

serpentine microchannel; Sohel et al. [23] studied the use of Al_2O_3–H_2O nanofluid instead of pure water in a minichannel heat sink; Ghasemi et al. [24] tested the effect of using alumina–water (Al_2O_3–H_2O) nanofluid as a coolant on the performance of a triangle-shaped minichannel heat sink; Saeed and Kim [25] tested the Al_2O_3–H_2O nanofluid as a coolant in minichannel heat sinks with three channel configurations. Kazuhisa and Koichi [26] experimentally investigated the heat transfer characteristics of the mini-channel heat sink. Copper mini-channel-finned heat sinks are examined under constant heat flux conditions of over 200 W/cm^2 to elucidate their relevance as a single-phase flow cooling device for next-generation power devices. The effects of fin thickness and channel width are assessed in detail. Xuekang et al. [27] investigated the significance and advancement of the channel geometry of a serpentine channel heat sink that utilises a multi-objective genetic algorithm. A straightforward network model for thermal resistance is created to explore the total thermal characteristics performance of the serpentine channel heat sink. Inlet velocity, channel height, channel width, and fin width are parameters that must be enhanced in accordance with the requirements of fixed width and length of the heat sink. The investigation shows that a decrease in pressure drop and thermal resistance can be efficient by streamlining channel design and inlet velocity. The issue of a uniform flow distribution has received an increasing consideration for heat sink outline. Chen et al. [28] exhibited a multi-objective basic plan of a serpentine channel heat sink. The effects of channel height, channel width, inlet velocity, and number of channels are studied as the outline factors. The structural modelling of a serpentine channel heat sink with one inlet and one outlet is the 3D model of this heat sink. In this demonstration, the two variables are considered to represent the performance of the heat sink, that is, total thermal resistance and pressure drop of a serpentine channel. Numerical outcomes and experimental data have determined that the deterioration in thermal resistance and pressure drop can be accomplished by ensuring channel configuration and inlet velocity, thereby resulting in the desired thermal performance of the heat sink. Xiaohong et al. [29] developed an orthogonal trial plane technique that uses a multi-objective improvement design to enhance the heat transfer capacity and flow consistency of a U-type heat sink. Thus, a computational fluid dynamics (CFD) model is established, and then the temperature and flow fields are explored. The results demonstrate that the dispersion of liquid in each parallel channel is not only a component of the flow conditions in the header but also affected by the geometric size of the header and parallel channels; moreover, the optimum U-sort heat sink through orthogonal experiment outline technique can provide a uniform distribution flow. Saad et al. [30] explored tentatively a water-cooled mini-channel heat sink that is used to simulate a high heat-generating microchip. The effect of sink geometry on water is investigated along with five heat sinks. The five heat sinks have a fin spacing of 0.2, 0.5, 1.0 and 1.5 mm with a flat plate heat sink. The base temperature and thermal resistance of the heat sinks are reduced by decreasing the fin spacing and expanding a volumetric flow rate of water that circulates through the heat sink. Xiao et al. [31] proposed a straightforward thermal resistance model to simulate the thermal characteristics of serpentine channel heat sinks. The model involves an advancement of thermal resistance units associated with stream systems which show the pressure and temperature distribution among the units. The fluid Reynolds number, pressure and temperature results of a 10-channel serpentine heat sink are acquired by fluctuating the channel aspect ratio and thus contrasted with a full 3D CFD modelling. The results exhibit that the model can anticipate characteristics of the heat transfer for serpentine channels with high precision and in a general senseless enlisting time. Hao et al. [32] proposed an analytical model to research the pressure drop and thermal resistance in heat sinks with serpentine channels of 180° bends. The aggregate thermal resistance is obtained by utilizing a network model for thermal resistance given an equivalent thermal circuit strategy. Pressure drop is determined considering a straight channel by bend loss because the bends disrupt the hydrodynamic boundary occasionally. The model is experimentally approved by measuring the pressure and temperature characteristics of heat sinks with geometric parameters of a diver and various Reynolds numbers. Tong et al. [33] numerically examined the temperature uniformity in a water-cooled mini-channel heat sink under high-heating flux with various flow field configurations. A network model for thermal resistance is established, and the channels of variable height were proposed to enhance the uniformity of temperature on the heating surface. The effect of flow field configurations on uniformity flow distribution is firstly examined, and a circular turning constructal distributor is selected because of its optimal uniformity flow distribution and cooling performance. Waleed et al. [34] conducted experimental and numerical studies of the attributes of fluid flow and heat transfer in a square cross section wavy serpentine microchannel with insulated

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