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Research Paper

Experimental study on cooling performance of sinusoidal–wavy minichannel heat sink

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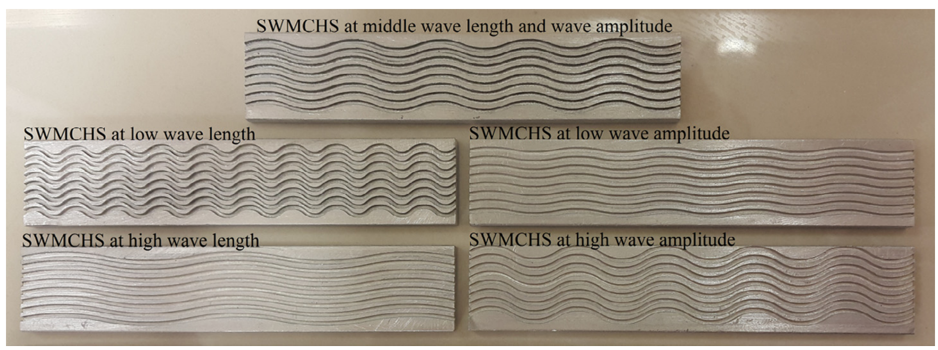
HIGHLIGHTS

- Cooling performance of SWMCHSs is studied experimentally.
- Effects of geometrical parameters and working fluid are examined.
- Decreasing wave length and increasing wave amplitude augment thermal performance.
- Q/P_P ratio increases with decreasing the weight fraction of ethylene glycol.

GRAPHICAL ABSTRACT



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ABSTRACT

The cooling performance of the sinusoidal–wavy minichannel heat sink (SWMCHS) having square cross section is experimentally investigated. The effects of specific geometrical parameters of the SWMCHS, i.e. wave length (l = 10, 20, and 40 mm) and wave amplitude (a = 0.5, 1.0, and 2.0 mm), are examined. Each SWMCHS is made of aluminum and contains eight minichannels in parallel. The water–ethylene glycol mixtures (100:0, 75:25 and 50:50 by mass) are selected as working fluids to investigate the effect of coolant. This study covers Reynolds number in the range of 60–4000, covering both the laminar and the transition flow regimes based on the applied working fluid. Heat transfer and fluid flow characteristics of the SWMCHSs are obtained and the results are compared with a straight MCHS. The results show that the thermal performance of the SWMCHSs is much better than the straight MCHS. Both the heat transfer coefficient and the pressure drop inside the SWMCHSs increase proportionally, as the wave length decreases and the wave amplitude increases. It is found that in the studied range, the water–ethylene glycol mixture of 100:0 shows the greatest values of the heat transfer rate to pumping power ratio. Also, there is an optimum geometry for the SWMCHS (a = 40 mm and l = 10 mm), which has the maximum values of the heat transfer rate to pumping power ratio. Finally, correlations are developed for the SWMCHSs as function of Reynolds number, Prandtl number, and geometrical parameters.

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1. Introduction

Today, reducing energy resources is the main reason for the energy conservation and management. Therefore, heat transfer enhancement (HTE) techniques can help save and manage the energy. Also, the miniaturization of heat exchange devices, as a passive HTE technique, has the potential to provide energy efficient systems. The concept of micro/mini-channels was firstly proposed in heat sinks by Tuckerman and Pease [1] at 1981. The micro/mini-channels are different from the conventional channels in terms of the channel hydraulic diameters. Based on the classification of Kandlikar and Grande [2], a mini-channel heat sink (MCHS) is typically defined as a number of parallel mini-size channels with the hydraulic diameter between 200 μm and 3 mm. The HTE in the MCHSs is an active area of study followed by many researchers.

The single phase flow of the water through a MCHS at constant heat flux was analyzed by Xie et al. [3]. The effects of different geometrical parameters and inlet velocity on the pressure drop, thermal resistance, and maximum allowable heat flux were studied. The performance of a MCHS was investigated under a high heat flux density by Zhou et al. [4]. The temperature rise of both the heated surface and the cooling water were measured. The results depicted that the temperature rise of the heated top surface enhanced quickly at the startup period of heating and then increased slowly. Ijam et al. [5] studied the nanofluid flow across a MCHS. It was found that using the Al_2O_3–water and TiO_2–water nanofluids instead of the water improved the cooling performance of the MCHS about 17%. The entropy generation of the nanofluid turbulent flow through a MCHS with circular cross section was studied by Sohel et al. [6]. It was detected that a smaller diameter showed less entropy generation in case of all nanofluids, and the fluid friction entropy generation rate decreased by increasing of nanofluid concentration. The forced convective heat transfer performance of using the nanofluid as the coolant in a MCHS was also investigated by Ho and Chen [7]. It was explained that the nanofluid cooled heat sink has significantly higher average heat transfer coefficients compared with the results for the pure water. In the other work [8], they focused on the evaluations of the hydraulic and thermal performance of the water-based microencapsulated phase change material particles in a MCHS. The measured results shown that the thermal performance can be enhanced by addition of the MEPCM particles in the water. The thermal–hydraulic performance for enhanced offset and diamond MCHSs was studied by Dixit and Ghosh [9]. It was detected that the pressure drop penalty in the diamond MCHS (with smaller hydraulic diameter) was relatively higher as compared to the offset one (with larger hydraulic diameter). Two-phase heat transfer characteristics in the MCHSs with pin and strip fins under non-uniform heating were investigated by Yoon et al. [10]. Overall, the pin fin MCHS exhibited a superior performance compared to the strip fin MCHS. The effect of the channel spacing on the performance of a MCHS was examined by Jajja et al. [11]. It was concluded that geometrically enhanced MCHSs by using with freely available fluid, i.e. water, still have a lot of potential to cool the high heat generating microprocessors (more than 300 W). Fan et al. [12] proposed a novel cylindrical oblique fin MCHS for cooling heat source with cylindrical surfaces. The thermal performance of a MCHS was investigated for cooling of electronics using nanofluid coolant by Sohel et al. [13]. The experimental results illustrated the higher improvement of the thermal performance using nanofluid instead of the pure water. The heat transfer coefficient was found to be enhanced up to 18% successfully. Naphon and Nakharintr [14] simulated the nanofluid flow inside a MCHS using homogeneous (single phase) and two phase models (mixture and VOF). It was shown that the two phase models were more appropriate than the homogeneous model. Recently, most studies on nanofluids as the heat transfer media were carried out for the microchannel heat sinks [15,16]. Details about the mentioned literature such as applied method/working fluid/geometry and studied parameters/range are tabulated in Table 1.

Based on the above literature, it is found that there are very limited studies about the MCHSs. Although the mentioned investigations examined characteristics of the fluid flow and heat transfer in the rectangular or circular straight MCHSs, to the best of the authors' knowledge, the number of experimental studies conducted on the MCHSs with indirect passes is very scarce. This is the main motivation behind this experimental study. This study tries to analyze the cooling performance of the sinusoidal–wavy minichannel heat sink (SWMCHS) by using the water–ethylene glycol mixtures as working fluid. It is anticipated that this enhanced MCHS can be a great choice in cryogenic heat transfer applications. The studied parameters are the geometrical parameters (wave length and wave amplitude), working fluid compositions (100:0, 75:25, and 50:50 by mass), and mass flow rate (0.003–0.024 kg/s). The SWMCHS samples are made of aluminum in five geometries. Also, the performance of SWMCHSs is compared with a straight MCHS at the same conditions.

Table 1
Investigations on fluid flow and heat transfer of MCHSs.

Source and year	Method	Working fluid	Geometry	Studied parameters	Regime
1. Xie et al. [3] (2009)	Numerically	Water	Rectangular straight	Channel height/width, heat sink thickness/width and inlet velocity	Laminar
2. Zhou et al. [4] (2010)	Experimentally	Water	Rectangular straight	Heat flux density and inlet velocity	Transient
3. Ijam et al. [5] (2012)	Numerically	Al_2O_3/TiO_2–water nanofluids	Rectangular straight	Volume fraction of nanoparticles, heat flux and mass flow rate	Laminar
4. Sohel et al. [6] (2013)	Analytically	Cu/Al_2O_3–water/ethylene glycol nanofluids	Circular straight	Volume fraction of nanoparticles and diameter of channel	Turbulent
5. Ho and Chen [7] (2013)	Experimentally	Al_2O_3–water nanofluid	Rectangular straight	Volume fraction of nanoparticles and volumetric flow rate	Laminar
6. Ho et al. [8] (2013)	Experimentally	MEPCM particles–water	Rectangular straight	Latent–sensible heat ratio and Reynolds number	Laminar
7. Dixit and Ghosh [9] (2013)	Experimentally	Water	Straight, offset, and diamond	Geometrical parameters and Reynolds number	Laminar
8. Yoon et al. [10] (2014)	Experimentally	R245fa	Pin fin and strip fin	Heat flux density and mass flow rate	Laminar
9. Jajja et al. [11] (2014)	Experimentally	Water	Rectangular straight	Channel spacing and Reynolds number	Laminar
10. Fan et al. [12] (2014)	Numerically	Water	Circular straight	Oblique angle, secondary channel gap and Reynolds number	Laminar
11. Sohel et al. [13] (2014)	Experimentally	Al_2O_3–water nanofluid	Rectangular straight	Volume fraction of nanoparticles and flow rate	Laminar
12. Naphon and Nakharintr [14] (2015)	Numerically	TiO_2–water nanofluid	Rectangular straight	Fin height and Reynolds number	Laminar