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Effect of channel angle of pin-fin heat sink on heat transfer performance using water based graphene nanoplatelets nanofluids

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ABSTRACT

This study reports an experimental work to examine the angle effect of pin fin heat sink channel in terms of convective heat transfer coefficient, log mean temperature difference and thermal resistance using water based graphene nanoplatelets (GNPs) nanofluids in a flow rate range of 0.25–0.75 LPM. Three heat sinks having channel angles, measured from positive *x*-axis, 22.5 degree, 45 degree and 90 degree are used. The volumetric concentration of GNPs particles is 9.5% and these particles consist of overlapped two-dimensional graphene layers. All heat sinks are fabricated with copper substrate, which is maintained at uniform heat flux during experimentation. Heat sink with 22.5 degree channel angle shows better thermal performance as compared to other tested heat sinks. For the same flow rate, 22.5 degree heat sink shows lowest convective thermal resistance as compared to other tested heat sinks.

1. Introduction

Due to ever increasing heat generation by electronics products, different cooling techniques are being adopted for safety consideration. With technological development, heat flux generated by electronic chips has reached to more than 100 W/cm^2 [1]. As a result, failure risk of electronic devices has also increased. Consequently, there was a need of an ideal cooling method to remove this excessive heat for proper functioning of electronic products. Air cooling methods have become insufficient for high heat removal aptitude. Due to air cooling methods limitations, researcher's attention was moved to ideal liquid cooling techniques. At the beginning, water was used as coolant. Although, water gave better results; however, it showed limitations of heat removal. Hence, there was a need of a liquid that has better thermal properties than water. Nanofluids, containing dispersed nanoparticles, have recently showed promising results for thermal applications. These nanoparticles have size in the range of 1–100 nm.

The other popular approach adopted by researchers was the modification of the heat sink geometry with a perspective to achieve a better fluid-geometry interaction. Subsequently, minichannels and ultimately microchannels which has hydraulic diameter ranging 10–1000 μm were introduced. Recently, research on micro level has attracted interest due to rapid growth in electronics industry, which needs higher heat transfer rates through a compacted area.

First time in 1981, Tuckerman and Pease [2] used microchannels for thermal management of microprocessor, where higher surface area was available for heat transfer. They investigated performance of silicon made microchannels using water as coolant. Although heat transfer performance was increased with higher surface area, however, a great increase in pressure drop by using microchannels was also reported. Their investigation gave new direction to researchers. Particularly, after the discovery of nanofluids by Choi and Eastman [3] in 1995, the applications of microchannels further increased. After this innovation, Kandlikar and co-workers performed series of investigation on microchannels using liquid as coolant. They found 4–10-fold increase in heat transfer enhancement using liquid as compared to heat transfer enhancement by air. They reported possibility of heat removal up to 1000 W/cm^2 with enhanced microchannels [4–6].

Sohel et al. [7] experimentally showed that by the increase of volumetric concentration of Al_2O_3/H_2O nanofluids from 0.1% to 0.25%, thermal effectiveness increased at all flow rates. However, they found that thermal effectiveness was not necessarily increased with the increase of flow rate. They found 18% convective heat transfer coefficient enhancement by using 0.25% concentrated Al_2O_3/H_2O nanofluids as compared to distilled water.

Liquid impingement cooling is also very useful technique in terms of heat transfer enhancement. Naphon and Wongwises [8] used this technique to lower the base temperature, and found significant temperature reduction than conventional cooling systems. They observed that the velocity was one of the dominant factors in heat transfer rate. Heat transfer enhancement was increased with a decrease in inlet diameter of the nozzle.

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Nomenclature

A	area, m^2
C_p	specific heat, J/kg °C
d	diameter, m
D_1, D_2, D_3, D_4	distance b/w thermocouples, m
d_h	hydraulic diameter, m
dh	channel clearance, m
$GNPs$	Graphene nanoplatelets
h	convective heat transfer coefficient, W/m^2 °C
h_b	thickness of heat sink base, m
h_c	channel height, m
h_f	fin height, m
H_w	distance b/w thermocouple and wall, m
k	thermal conductivity, W/m °C
L_1	total length of fin area, m
L_2	total length of active area, m
$LMTD$	log mean temperature difference, °C
$\dot{m}$	mass flow rate, kg/s
n	empirical shape factor
Nu_{avg}	Nusselt number
P	perimeter, m
Pr	Prandtl number
Q	heat flow rate, W
Q_f	flow rate, m^3/s
Re	Reynolds number
R_{th}	thermal resistance of heat sink, °C/W
S_L	distance between pin fin along longitudinal axis (center to center), m
S_t	distance between pin fin along transverse axis (center to center), m
t	total number of pins
T	temperature, °C
T_1, T_2, T_3, T_4	thermocouples
v_{max}	maximum velocity, m/s
W_1	total width of fin area, m
W_2	total width of heat sink, m
w	weight fraction
w_c	channel width, m
w_f	fin width, m

Greek symbols

μ	viscosity, kg/m/s
$\varnothing$	volume fraction
ρ	density, kg/m^3
Ψ	particle sphericity

Subscripts

bf	base fluid
c	channel
c_c	cross section of channel
c_f	cross section of fin
e	effective
f	fin
hs	heat sink
in	inlet
m	mean
min	minimum
nf	nanofluid
np	nanoparticle
out	outlet
r	room temperature
tc	thermocouple
w	wall

Singh et al. [9] tested three volumetric concentrations of 0.25%, 0.5% and 1.0% in base fluid of water and ethylene glycol. They used two different particle sizes of 45 nm and 150 nm along with microchannels having hydraulic diameters of 130 μm, 211 μm and 300 μm. They found that transition phenomenon from laminar to turbulence occurred quickly for 211 μm and 300 μm due to higher surface roughness.

Anoop et al. [10] used three different weight concentrations of 0.2%, 0.5%, 1% of SiO_2/H_2O nanofluids to find heat transfer rate flowing through poly di-methyl siloxane microchannels in a Reynolds number range of 4–22. They found that nanofluids were more effective in term of heat transfer at lower Reynolds number as compared to higher Reynolds number.

Nazari et al. [11] performed experimental investigation on CPU cooling using water based carbon nanotubes (CNT) and alumina nanofluids. They also tested ethylene glycol with 30% and 50% concentrations in water as a base fluid and compared results of all tested fluids with water. They found 13% enhancement in convective heat transfer coefficient by 0.25% vol. and 6% enhancement by 0.5% vol. CNT nanofluids. Results of their investigation also showed that 30% ethylene glycol/water was more efficient as compared to 50% ethylene glycol/water.

Ho et al. [12] assessed Al_2O_3/H_2O nanofluids forced convection heat transfer. They observed 1% vol. nanofluid was more efficient than 2% vol. nanofluid due to more variation occurrence in dynamic viscosity with temperature. Using 1% vol. concentrated Al_2O_3/H_2O nanofluids, 70% enhancement was found in convective heat transfer coefficient.

Thermal performance is highly dependent on heat sink material and its surface roughness. Tullius and Bayazitoglu [13] observed effects of 0.01% vol. concentrated alumina/water nanofluids on pure, along with 6 × 12 fin array and fully grown multi wall carbon nano tube (MWCNTs) silicon minichannels. They found, 58%, 84% and 136% more heat flux could be applied using pure, fully MWNCTs grown and 6 × 12 fin array minichannels respectively, while keeping base temperature constant. Further, Vanapalli and Brake [14] revealed that heat transfer capabilities of nanofluids were highly dependent on heat sink geometry and flow conditions. They also derived a correlation relating heat transfer potential with viscosity, specific heat and thermal conductivity.

Ray et al. [15] compiled a correlation for thermal/dynamic performances, accounting particle size and volumetric concentration of nano-particles. Experimentally, they used three different water based nanofluids; alumina, silicon dioxide and copper oxide with 1% volumetric concentration on minichannels and compared them with HFE-7000 coolant. All fluids showed better performance as compared to base fluid.

Ferrouillat et al. [16] studied shape factor effects of two different nanofluids, SiO_2/H_2O and ZnO/H_2O with two different morphologies. They found small enhancement in Nusselt number of nanofluids with respect to base fluid. However, they found better performance of ZnO nanofluids with a shaper factor larger than 3.

Chein and Chuang [17] experimentally measured the thermal superiority of $CuO–H_2O$ nanofluids against base fluid. They used silicon mini channel heat sink (MCHS) with four different concentrations of $CuO–H_2O$ nanofluids and found that nanofluids at low flow rates were more effective and well correlated with analytical model. They also noticed particle agglomeration reduction at high mean temperature. Further, Chein and Huang [18] used Cu/H_2O nanofluids with different concentrations on two different micro channels. They found that, no extra pressure drop occurred due to

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