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Entropy generation analysis of graphene–alumina hybrid nanofluid in multiport minichannel heat exchanger coupled with thermoelectric cooler

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ABSTRACT

Entropy generation analysis of hybrid nanofluid in a two pass multiport minichannel heat exchanger coupled with a thermoelectric cooler is experimentally investigated. Alumina (Al_2O_3, 50 nm), graphene (5 nm) and the hybrid of these two in equal portions with 0.1% volume concentrations is separately dispersed in to the base fluid and tested. The hydraulic diameter and aspect ratio of the channel are 1.184 mm and 0.689 respectively. The heat flux is varied from 6250 W/m^2 to 25,000 W/m^2 and the flow regime is considered to be laminar with the Reynolds number varying from 200 to 1000. The results showed an enhancement of 17.32% in cooling capacity and coefficient of performance (COP) with the use of pure graphene–water nanofluid when compared with that of the other tested combinations of nanofluids. Total entropy generation decreased from 0.0361 W/K to 0.0184 W/K with increase in Reynolds number from 200 to 1000 for the maximum applied heat flux of 25,000 W/m^2. Similarly an enhancement of 88.62% in the convective heat transfer coefficient and a reduction of 4.7 °C in the device temperature are achieved when pure graphene–water nanofluid is used as the coolant. Among the tested nanofluids, graphene–water nanofluid shows better performance in terms of heat transfer, thermodynamic and exergic analysis.

1. Introduction

The latest advancements in electronics, mostly the miniaturization and integration of modern electronic devices demand for effective cooling for improved efficiency, reliability and long term operation. Even the latest available thermal management techniques are not enough to cater the cooling demands from the modern electronic devices. This motivates the heat transfer engineers to go for new advancement techniques in the field of electronic cooling and its applications.

The air cooling and liquid cooling are the main available cooling methods presently used in all devices. Though the air cooling method is the most common and relevant one, it is not adequate in the current scenario. The main issues with the air cooling methods are (i) large heat sink and fan are required for higher heat flux, (ii) efficiency is less at higher ambient temperatures, (iii) heat carrying capacity of air decreases with increase in temperature of ambient, (iv) the temperature of the device cannot be lowered below ambient, (v) low thermal conductivity, (iv) noisy and occupies more space. The liquid cooling methods are more effective than the air cooling methods. However, the main issues with the liquid cooling methods are (i) poor thermal conductivity of the working fluid, and (ii) lower convective heat transfer characteristics. Hence, it is necessary to go for an advanced heat transfer fluid with relatively higher thermal conductivity, and enhanced heat transfer capabilities.

Enhancing the thermal conductivity of the working fluid is the main challenge in the advancement of liquid cooling. The thermal conductivity of the conventional working fluids is enhanced by dispersing nanometre sized solid particles with higher thermal conductivity. A variety of particles including metals (Cu, Al, Ag, Au, etc.,), metal oxides (CuO, Al_2O_3, ZnO, TiO_2, etc.,), non metals (CNT, etc.,) and ceramics (graphite, graphene, etc.,) are used by many researchers as nanoparticles with size varying from 1 nm to 100 nm [1–3]. An appreciable enhancement of 30% in thermal conductivity of nanofluids is reported by most of the researchers [4–9].

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Nomenclature

A	area of cross section (m^2)
Be	Bejan number
c	number of passes
C_p	specific heat (kJ/kg K)
D_h	hydraulic diameter (m)
f	friction factor
Ex	exergy (W)
h	convective heat transfer coefficient (W/m^2 K)
H	height of the channel (m)
I	current (A)
K	thermal conductance of thermoelectric elements (W/K)
k	thermal conductivity (W/m K)
L	length (m)
$\dot{m}$	mass flow rate (kg/s)
m	module
n	number of channels per pass
N	number of pellets
Nu	Nusselt number
Pr	Prandtl number
Q	heat absorbed (W)
q''	heat flux (W/m^2)
R	electrical resistance of thermoelectric elements (Ω)
Re	Reynolds number
S	entropy (W/K)
$\dot{V}$	volume flow rate (m^3/s)
T	temperature (°C)
TEM	thermoelectric module
V	voltage (V)
v_m	mean velocity (m/s)
W	width of the channel (m)
x	section of the minichannel (m)
ΔP	pressure drop (Pa)
ΔT	thermoelectric temperature difference (°C)

Greek symbols

α	Seebeck coefficient (V/K)
ϕ	volume fraction (%)
μ	dynamic viscosity (mN s/m^2)
ρ	density (kg/m^3)
η	second law efficiency
δ	uncertainty

Subscript

c	cold side
ch	channel
d	destruction
f	base fluid, frictional
g	generation
h	hot side, hydraulic
H	heater
hyb	hybrid
i	node
II	second law
in	inlet
L	liquid
m	module or cooler
nf	nanofluid
out	outlet
P	input power
p	nanoparticle
1, 2	particle type
r	ratio
therm	thermal
t	total
w	wall
∞	ambient

Ghozatloo et al. [10] investigated the performance of graphene–water nanofluids in a conventional circular tube of inner diameter 10.7 mm and length of 1 m in a laminar flow regime. The weight concentrations of graphene used were 0.05%, 0.075% and 0.1%. An enhancement of 23.7% is obtained for a weight concentration of 0.1% at a temperature of 38 °C. The graphene nanofluids are also efficiently tested for electronic cooling applications by other researchers [11,12]. Godson et al. [13] experimentally investigated the heat transfer performance of silver-water nanofluids in a conventional size shell and tube heat exchanger in turbulent flow regime. The volume concentrations of particles used are 0.01%, 0.03% and 0.04% and Reynolds number is varied from 5000 to 25,000. The enhancement in the heat transfer coefficient of 12.4% was observed for a volume concentration of 0.04%. Fotukian et al. [14] experimentally studied the heat transfer characteristics of Al_2O_3-water nanofluids in a small tube of inner diameter 5 mm and length of 1 m in turbulent flow regime. The volume concentrations of nanoparticles used are 0.03%, 0.054%, 0.067%, and 0.135% and Reynolds number is varied from 6000 to 31,000. The maximum enhancement in the value of heat transfer coefficient is 48% for 0.054% volume concentration at a Reynolds number of 10,000 when compared with that of the base fluid.

Wu et al. [15] performed experimental investigations on the flow and heat transfer characteristics of a silicon based trapezoidal microchannel with a hydraulic diameter of 194 μm. The Al_2O_3-water nanofluids with particle volume concentrations of 0.15% and 0.26% are used as working fluid. The results clearly showed that Nusselt number increased with increase in the Reynolds number and nanoparticle volume concentrations. Ho et al. [16] conducted experimental investigations on the cooling performance of laminar flow of Al_2O_3-water nanofluid in the copper microchannel heat sink with a cross-sectional area of 283 μm in width by 800 μm in height and 50 mm length for each microchannel. An enhancement of 70% in the value of heat transfer coefficient was obtained for largest flow rate tested when compared with that of water. The reduction in the wall temperature was about 25%.

Liu et al. [17] experimentally investigated the fluid flow behavior of Al_2O_3-water nanofluids in a circular minichannel in the range of Re varying between 600 and 4500. The volume concentration used was up to 5%. The results showed that the particle–fluid interaction in the fluid flow is significant. It was observed that the heat transfer enhancement was higher at higher Re. Sohel et al. [18] experimentally investigated the thermal performance of the copper minichannel heat sink using Al_2O_3-water nanofluids with volume concentrations of 0.1–0.25% in the laminar regime. The results showed an enhancement in heat transfer coefficient up to 18%. It also showed significant reduction in the thermal resistance (15.72%) and base temperature (2.7 °C) of the heat sink. Ahammed et al. [19] experimentally investigated the heat transfer and fluid flow characterization of Al_2O_3-water nanofluids with 0.1 and 0.2 volume concentrations in a multiport minichannel heat exchanger. The hydraulic diameter and aspect ratio of the channel are 1.184 mm and 0.689. An enhancement of 23.92% in local Nusselt