Advanced Powder Technology 26 (2015) 83–90

Contents lists available at ScienceDirect

Advanced Powder Technology

journal homepage: www.elsevier.com/locate/apt

Original Research Paper

Investigating the effect of Brownian motion and viscous dissipation on the nanofluid heat transfer in a trapezoidal microchannel heat sink

Behzad Fani [a], Mohammad Kalteh [b,*], Abbas Abbassi [a]

[a] Department of Mechanical Engineering, Amirkabir University of Technology, Hafez Ave., P.O. Box 15916-34311, Tehran, Iran
[b] Department of Mechanical Engineering, University of Guilan, P.O. Box 3756, Rasht, Iran

ARTICLE INFO

Article history:
Received 22 December 2013
Received in revised form 23 June 2014
Accepted 15 August 2014
Available online 27 August 2014

Keywords:
Nanofluid
Two-phase
Eulerian–Eulerian approach
Trapezoidal microchannel-heat-sink
Viscous dissipation
Brownian motion
Aspect factor

ABSTRACT

In the present study, laminar forced convection of copper-oxide nanofluid in a trapezoidal microchannel-heat-sink (MCHS) is studied using the Eulerian–Eulerian two-phase approach. The incompressible, three dimensional and steady state conservation equations are solved using finite volume method. The substrate material is assumed to be silicon, mean diameter of spherical nanoparticles are considered 100 nm and in the 1–4% volume concentration range. The effects of viscous dissipation, Brownian motion and geometry change on thermal performance of MCHS are evaluated. It is observed that the Brownian motion depends on three parameters, namely, nanofluid inlet temperature, nanoparticles diameter and volume fraction. Also, it is found that with the increase in aspect factor at constant Re, average Nusselt number and pressure drop reduce, while at a specified length of MCHS, average Nusselt number decreases. Finally, it is shown that considering the viscous dissipation, pressure drop varies very slowly, while with the increase in nanoparticles volume fraction and therefore increase in viscous dissipation, heat transfer reduces non-linearly.

1. Introduction

From thermal management point of view, heat removal from electronic devices such as chips and transistors has a vital and important effect on the life cycle of these devices [1]. Microchannel heat sink (MCHS) is one of the most important cooling techniques which have attracted attention of many researchers and engineers in the field of thermal sciences. Cooling performance of a MCHS depends on geometry, size and number of the channels and also on type of the carrying fluid. According to this matter, using nanofluid in the MCHS enhances the heat transfer and it can be selected as an appropriate solution to dissipate heat from electronic devices. Numerous studies have been performed which propose microchannel heat sinks and nanofluids for cooling purposes especially for electronic devices [2–9]. Following our last paper [10], this paper investigates the effects of Brownian motion, geometry variation and viscous dissipation on the thermal behavior of water based copper-oxide nanofluid in a trapezoidal MCHS.

Some studies in the last decade have proven that Brownian motion, which creates due to collision between particles, is one of the most important mechanisms in heat transfer enhancement of the nanofluids which also plays significant role in nanofluid thermal conduction [11–17]. Ghazvini and Shokouhmand [18] observed that Brownian motion increases by increasing the bulk temperature and consequently, more heat transfer occurs in the nanofluid. Seyf and Nikaaein [19] reported that by including the Brownian motion, nanofluid temperature distribution is closer to MCHS bottom wall which means higher heat transfer coefficient and consequently lower thermal resistance. Selvakumar and Suresh [20] expressed that augmentation in heat transfer coefficient is related to thermo-physical properties of the carrying fluid and Brownian motion of the suspended particles has major contribution in heat transport. Alvarino et al. [21] utilizing the order of magnitude method concluded that Brownian diffusion effect alters the nanoparticles concentration near the wall region. Nield and Kuznetsov [22] found that combined effect of Brownian motion and thermophoresis reduces the Nusselt number.

Wu and Cheng [23] observed that friction factor depends on the channel cross-sectional shape. Koo and Kleinstreuer [24] proposed that microchannels with higher aspect ratios are better candidates for designing the micro-heat-sinks. Morini et al. [25] argued that Nusselt number is a function of the channel aspect ratio. Lee and Garimella [26] concluded that both average and local Nusselt numbers are functions of aspect ratio and axial distance from the entrance. Mlcak et al. [27] found that thermal resistance is a

* Corresponding author. Tel.: +98 1316690276; fax: +98 1316690273.
E-mail address: mkalteh@guilan.ac.ir (M. Kalteh).

http://dx.doi.org/10.1016/j.apt.2014.08.009
0921-8831/

Nomenclature

A	larger base of trapezoidal MCHS (m)
A	cross-section area of MCHS (m^2)
$A.F.$	aspect factor
$A.R.$	aspect ratio
B	smaller base of trapezoidal MCHS (m)
C	cord of MCHS (m)
C_C	Cunningham slip correction factor
C_D	drag coefficient
d_p	nanoparticles diameter (m)
D_B	Brownian diffusivity, K (m^{-1} Pa^{-1} s^{-1})
D_d	interphase drag
D_h	hydraulic diameter of microchannel (m)
e_{pp}	restitution coefficient of nanoparticles
g_0	radial distribution function
H	height of MCHS, m convection coefficient (W m^{-1} K^{-1})
h_v	volumetric heat transfer coefficient (W m^{-2} K^{-1})
k_b	Boltzmann constant
k_{eff}	effective thermal conductivity (W m^{-1} K^{-1})
k_s	substrate thermal conductivity (W m^{-1} K^{-1})
K_Θ	diffusion coefficient
K_{pp}	solid–solid exchange coefficient defined in Eq. (19)
L	MCHS length (m)
Nu	Nusselt number
P	pressure (Pa)
p_{wet}	wetted perimeter (m)
P	pumping power (W)
Q	volume flow (m^3 s^{-1})
q''	heat flux (W m^{-2})
Re	inlet Reynolds number
T	MCHS thickness (m)
T	temperature (K)
w	MCHS width (m)
x	axial coordinate (m)
y	vertical coordinate (m)
z	normal coordinate (m)
Z	non-dimensional normal coordinate

Greek symbols

α	thermal diffusivity (m^2 s^{-1})
β	interphase drag coefficient (Pa s m^{-1})
γ	bulk viscosity (Pa s)
ϕ	viscous dissipation (m^2 s^{-2})
φ	volume fraction
λ	mean free path (m)
μ	dynamic viscosity (Pa s)
θ_p	granular temperature
ρ	density (kg m^{-3})
τ	shear stress (Pa)
Γ_θ	defined in Eq. (17)
ψ_{pp}	defined in Eq. (18)

Subscripts

col	related to collision of particles
d	dispersed phase
f	related to base fluid
in	inlet
kin	related to kinetic energy
nf	related to nanofluid
p	related to particle phase
pw	pure water
s	related to solid substrate

decreasing function for aspect ratios less than 0.10, while for values larger than 0.5, both thermal resistance and friction coefficient are insensitive to the aspect ratio. McHale and Garimella [28] confirmed Lee and Garimella [20] results, although they stated that fully developed Nusselt number and thermal developing length are the main parameters which alter with aspect ratio. Hung et al. [29] showed that optimal thermal resistance for a double-layered microchannel heat sink decreases with pumping power and then tends to a constant value. Hung and Yan [30] revealed that minimum thermal resistance depends on the aspect ratio. Obtained results by Hashemi et al. [31] demonstrated that after a certain value, the effect of aspect ratio on the heat transfer coefficient becomes inconspicuous. Wang et al. [32] optimized a nanofluid-cooled microchannel heat sink with constant pumping power criteria. They considered the effects of channel number, channel aspect ratio and channel width ratio to pitch in the optimization procedure. Wang et al. [33]presented that for channel numbers lower than a specific value, with the increase in aspect ratio, at fixed pumping power and volume flow rate, thermal resistance first decreases and then increases. But, at fixed pressure drop, by increasing the aspect ratio, thermal resistance remains constant.

Koo and Kleinstreuer [34] concluded that the viscous dissipation effects increase with coolant viscosity and channel aspect ratio, while decrease with specific heat capacity and fluid temperature. Morini and Spiga [35] demonstrated that for very narrow micro-channels, viscous dissipation effects become dominant and reduces the heat transfer amount. Hung [36]concluded that ignoring the viscous dissipation effect, the Nusselt number and subsequently, thermal performance is overestimated. Lelea and Nisulescu [37] found that due to the viscous heating, the heat transfer augmentation in the microchannel constantly increases with the axial distance. Mah et al. [38] argued that by considering the viscous dissipation effect in laminar forced convection of nanofluid, thermal performance decreases with an increase in nanoparticle volume fraction.

In the present paper, laminar flow and conjugate heat transfer of copper-oxide nanofluid in the trapezoidal MCHS is studied using the Eulerian–Eulerian two-phase approach. According to the literature, most of the papers have considered the Brownian motion in the nanofluid thermal conductivity models which in turn is substituted in the homogeneous flow equations. But, in the present paper, we aim to consider the Brownian motion by adding the Brownian diffusion term in the continuity equation of the two-fluid model. Moreover, the effects of the viscous dissipation and channel geometry on the nanofluid forced convection are studied.

2. Mathematical description of the problem

Front view of the trapezoidal MCHS, which coordinate origin is placed at the bottom base center of the trapezoidal microchannel, is displayed in Fig. 1. In this study, the value of q'' is considered 430 kW/m^2. Geometrical dimensions of the MCHS are shown in Table 1.

The considered assumptions for solving the conservation equations are incompressible, steady state, three dimensional, laminar flow and conjugate heat transfer. Thermo-physical properties of the nanoparticles, base fluid and substrate are assumed constant and independent of the temperature. In two-phase Eulerian approach, governing equations are described as follows [39]:

Volumetric conservation equation:

$$\varphi_p + \varphi_f = 1 \tag{1}$$