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The water based Al_2O_3 nanofluid flow and heat transfer in tangential microtube heat sink with multiple inlets

Dorin Lelea *, Ioan Laza

University Politehnica Timisoara, Faculty of Mechanical Engineering, Department of Thermal Machines and Transportation, B-dul Mihai Viteazu nr. 1, 300222 Timisoara, Romania

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ABSTRACT

Micro thermal systems are convenient cooling devices for high heat flux applications. Besides, the nanofluids are used to improve the cooling capabilities. The suspended nanoparticles in the base fluid increase the thermal conductivity, fluid viscosity and fluid density but decrease the effective heat capacity. To analyze the suitability of using the nanofluids for cooling applications, the numerical simulations are made for nanofluid heat transfer and fluid flow in micro-heat sink with straight microtubes and multiple tangential inlet jets. The configurations with five inlet jets is considered and numerical simulations are based on a finite volume method. The Al_2O_3 water based nanofluid was used in simulations. The heat flux spread through the bottom surface of the heat sink was $q = 50\ W/cm^2$. Re from 15 to 100 was considered to simulate the laminar fluid flow. The analysis is based on thermal and hydrodynamic results obtained for nanofluid and compared with results obtained for water. The results are analyzed on a fixed pumping power, Re or mass flow rate basis. It is observed that the conclusions are strongly dependent on the analysis constraint. Moreover the surface temperature difference is not very much improved by using the nanofluid.

1. Introduction

The miniaturization of devices like computers or optoelectronic installation raised the issues regarding the proper thermal management of the high heat fluxes dissipated by them. Since Tuckerman and Pease [1] experiment, the micro-channel heat sink became a very attractive solution for thermal management of the high heat flux devices. It combines two modes of heat transfer: increasing heat transfer coefficient by decreasing the channel diameter and heat conduction through the channel walls. On the other hand liquid based suspensions of nanoparticles (nanofluid) gained interest in the recent years due to their efficient thermal capabilities [2]. The outcome of these tools might be a very effective thermal system.

To optimize micro-channel heat sink performances a large number of the reports were announced, both for single layer [3–7] and double layer or stacked microchannel heat sinks arrangements [8,9]. Xu et al. [10] presented the three-dimensional numerical simulations of conjugate heat transfer in conventional and interrupted microchannel heat sinks. It was observed that the heat transfer was enhanced remarkably for the interrupted microchannel heat sink than for the conventional one. Liu et al. [11] presented the improved design of fractal branching channel net used for cooling of rectangular electronic chip. It is found that the best total branching levels is 7 regardless the mass, pressure drop or the pumping power. If the surface area for cooling is fixed, the optimum ratio of length to width is 1.87. Hung and Yan [12] presented the numerical optimization of the microchannel heat sink with a tapered channel design. It was found that tapered microchannel heat sink has a 37.6% lower thermal resistance than the original parallel channel design. Ma et al. [13] presented the high heat flux cooling solution for the traveling – way – tube circuit based on a microchannel heat sink. It is found that the temperature can be kept in the safe region with the reasonable water flow rate. Raisi et al. [14] reported numerical study on thermal performance of a microchannel, cooled with pure water and Cu–water nanofluid, while considering the effects of both slip and no-slip boundary conditions on the flow field and heat transfer. Boteler et al. [15] performed the fundamental analysis of the manifold microchannel heat sink. It was found that the heat transfer coefficient was increased by 50%. The experimental and numerical research on microchannel heat sink for liquid cooling was reported by Chiu et al. [16] while the new hybrid concept with microchannel impingement cooling was proposed by Sung and Mudawar [17]. Chang and Dhir [18] analyzed the heat transfer in swirl flow induced by tangential fluid injection.

The concept of the tangential microchannel heat sink was introduced by Lelea [19,20] for single inlet jet and Lelea [21] for multiple inlet jets. Tabrizi and Seyf [22] analyzed numerically the water

* Corresponding author. Tel./fax: +40 256 403666.
E-mail addresses: ldorin@mec.upt.ro, ldorin@hotmail.com (D. Lelea).

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Nomenclature

B	micro-heat sink width (m)
b_{ch}	inlet channel width (m)
c_p	specific heat (J/kg K)
D_i	inner diameter (m)
D_h	hydraulic diameter (m)
d_p	particle's diameter (nm)
D_{bf}	molecular diameter of the base fluid (nm)
h_{ch}	inlet channel height (m)
H	micro-heat sink height (m)
k	thermal conductivity (W/m K)
k_b	Boltzmann constant (J/K)
L	length (m)
l	mean free path (m)
L_{ch}	inlet channel length (m)
L	micro-heat sink length (m)
M	mass flow rate of a single micro-tube (kg/s)
N_t	number of the tubes
N_{in}	number of the inlet channels
Δp	pressure drop (Pa)
Pr	Prandtl number
Q	heat transfer rate (W)
q	heat flux (W/cm^2)
Re	Reynolds number
T	temperature (K)
ΔT	temperature difference (K)
u, v, w	velocity components (m/s)
w_m	module width (m)
x, y, z	coordinate (m)

Greek symbols

α	thermal diffusivity (m^2/s)
ϕ	particle's volume fraction (%)
μ	viscosity (Pa s)
ρ	density (kg/m^3)
Π	pumping power (W)

Subscripts

max	maximum
min	minimum
f	fluid
s	solid
b	bulk
bf	base fluid
eff	effective
f	fluid
in	inlet
m	average
nf	nanofluid
out	outlet
p	particle
s	solid
w	wall

based Al_2O_3 nanofluid flow and heat transfer in the tangential microchannel heat sink with the single inlet. It was found that nanofluids can lower the heat transfer entropy generation.

Hung et al. [23] performed the numerical analysis on heat transfer enhancement in microchannel heat sink by using the various types of nanofluids considering different volume fractions or substrate material based on a fixed pumping power. It has to be mentioned that the relation for dynamic viscosity is based only on a volume fraction without considering the particle diameter. It was found that the best thermal performances were observed for water based Al_2O_3 nanofluid.

The experimental research on heat transfer of Al_2O_3/propanol nanofluid was made by Sommers and Yerkes [24]. The heat transfer coefficient enhancement was observed for $Re_D < 3000$ with the pressure drop increasing from 400% to 600% for the 1 wt% Al_2O_3/propanol nanofluid.

Lee and Mudawar [25] analyzed experimentally the effectiveness of the nanofluids for single-phase and two-phase heat transfer in micro-channels. Higher heat transfer coefficients were achieved in the entrance region of micro-channels proving that nanoparticles have an appreciable effect on thermal boundary layer development.

Developing heat transfer of Al_2O_3/water nanofluids in annulus was studied numerically in Izadi et al. [26] with single phase approach adopted for nanofluid modeling. It was concluded that the effect of nanoparticle concentration on the nanofluid bulk temperature is significant.

The experimental research on heat transfer of Al_2O_3/water nanofluid in tubes was analyzed by Wen and Ding [27] and Anoop et al. [28]. The results showed considerable enhancement of convective heat transfer using the nanofluids, particularly significant in the entrance region. Salaman et al. [29] and Abbassi and Aghanajafi [30] analyzed numerically heat transfer augmentation of the nanofluid flow in microtube and microchannel heat sink respectively.

The comparative analysis of different single and two phase models used for simulate the nanofluid flow and heat transfer was made by Akbari et al. [31]. It is found that the single phase model has a better prediction of the thermal results than a two phase models if the appropriate relations for effective thermal properties are used. Moreover the influence on thermal properties on performances of the microtube heat sinks was investigated by Sohel et al. [32] while the thermal analysis of the microchannel heat sink with various types of nanofluids was reported by Ebrahimi et al. [33] and Farsad et al. [34]. Minea [35] investigated numerically the turbulent water based Al2O3 nanofluid flow and heat transfer in the straight tubes. The heat transfer coefficients were developed based on a tube length and volume fraction of the nanofluid.

Koo and Kleinstreuer [36] analyzed numerically steady laminar liquid nanofluid flow in microchannels considering two types of nanofluids, CuO particles at low volume concentrations in water or ethylene glycol. It was concluded that nanoparticles of high thermal conductivity are advantageous and a channel with high aspect ratio is desirable.

Rea et al. [37] analyzed experimentally the laminar convective heat transfer of alumina–water and zirconia–water nanofluids. The data expressed in form of dimensionless numbers (Nu and x+), show good agreement with the predictions of the traditional models/correlations for laminar flow. This suggests that the nanofluids behave as homogeneous mixtures.

Ghasemi et al. [38] analyzed natural convection heat transfer in an inclined enclosure filled with a CuO/water nanofluid. The results indicate that adding nanoparticles into pure water improves its heat transfer performance.

The correlations for temperature dependent effective conductivity of water based nanofluids were developed by Mintsa et al. [39] and Chon et al. [40]. Also a new model for assessment of the effective viscosity of water based nanofluids was developed by Masoumi et al. [41]. The experimentally obtained set of data for temperature and particle size dependent effective viscosity was presented by Nguyen et al. [42]. Zhoua et al. [43] performed measurements of