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Nanofluid heat transfer analysis in a microchannel heat sink (MCHS) under the effect of magnetic field by means of KKL model

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ABSTRACT

The present study investigates heat transfer of nanofluid flow in micro channel heat sink (MCHS) in the presence of a magnetic field. Al_2O_3-water nanofluid is chosen the best among other nanolfluid and is used as a coolant fluid in solution. The KKL correlation is utilized for calculation of the effective thermal conductivity and viscosity of nanofluid. Modified Darcy equation is applied for porous medium and the two-equation model with thermal dispersion is employed for heat transfer between fluid and solid sections. Since the coupled heat transfer equations of nanofluid and solid phase are nonlinear, the analytical Collocation method (CM) is employed to solve this problem. Effects of the Hartmann number, nanoparticles volume fraction, nanoparticle diameter, porosity, channel aspect ratio on temperature distribution, velocity and Nusselt number are investigated deliberately. Results show that Nusselt number has direct relationship with applying a magnetic field on MCHS.

1. Introduction

Progress of technology and changing the size of electronic components to a smaller scale, have always made cooling challenges in this field. Hence, employing techniques such as using fin and uneven surfaces to increase heat transfer interface or heat transfer coefficient is prevalent. One of the main ways of enhancing heat transfer in small components is plying Micro Channel Heat Sinks which improves heat transfer process via extending heat transfer interface. Since heat conduction in fluids is weak, which leads into heat transfer limitations, small volume fraction of some metals with high thermal conductivity is added to it, to noticeably enhance the heat transfer rate. This type of fluids, which was first invented by [1],is called Nanofluids. Since then, researchers attention in the field of nanofluid behavior in heat transfer is paid to: a) increment of the thermal conductivity of nanofluids proportional to the base-fluid; b) increase the viscosity of nanofluids in comparison with the base-fluid [2]; and c) enhancement of the single-phase heat transfer coefficient of nanofluids relative to the base fluid [3].

Buongiorno [4] asserted that the Brownian diffusion and thermophoresis are the vital slip mechanisms in nanofluids and the other slip mechanisms can be neglected. Subsequently, many researchers studied convective heat transfer in nanofluids, by taking Buongiorno's model into consideration in different geometries [5,6]. There are many models being employed to calculate viscosity and thermal conductivity of the nanofluid that one of them is KKL (Koo-Kleinstreuer-Li) model, which is utilized in many researches [7,8]. The comprehensive reviews on heat transfer characteristics of nanofluids have been carried out by Salman et al. [9], Sheikholeslami et al. [10]. Recent improvements in nanotechnology show that the nanofluid is an effective coolant for electronic devices, hence some research have been done recently in the field of micro channel heat sink [11,12]. Wang et al. [13] optimized the geometric structure of MCHS using water and nanofluids as a coolant employing a three-dimensional heat sink model with the simplified conjugate-gradient method. Then, Koh and Colony [14] considered the microchannel as a porous medium by using Darcy's equation to describe the flow. Ghazvini and Shokouhmand [15] studied the effect of different aspect ratios on heat transfer rate for porous medium models and fin approach for cu-water nanofluid. Also, an optimum aspect ratio is found to minimize the friction factor in different Reynolds numbers. Although most of the researches in this field employed Darcy model in their works, there are other studies which used Non-Darcy model, such as [16,17].

However, one of the ways of controlling the fluid flow and heat transfer characteristics of nanofluids which is ideal for a wide range of thermal equipment, is applying a magnetic field. Li et al. [18] showed that direction and power of the magnetic field are two parameters influencing the fluid flow and heat transfer. The study on MHD to examine the impact of a uniform magnetic field was first conducted by Hartman [19] on a laminar flow of an electrically conductive fluid.

Two phase nanofluid double diffusion convection in presence of induced magnetic field is analyzed by Sheikholeslami et al. [20]. Their results revealed that Nanofluid motion reduces with the rise of Schmidt and Hartmann numbers, however, it enhances when Buoyancy ratio

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Nomenclature

A_{pe}	wetted area per volume (m^{-1})
C	thermal conductivity ratio
C_p	specific heat in constant pressure ($Jkg^{-1}K^{-1}$)
Da	Darcy number
D_h	hydraulic diameter of microchannel (m)
d_p	nanoparticles diameter (m)
q''_w	wall heat flux ($W\,m^{-2}$)
h	convection heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
L	Length of heat sink (m)
K	Permeability (m^2)
k	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
N	number of channel
Nu	Nusselt number
p	pressure
P	Dimensionless pressure gradient
R_{tot}	Total thermal resistance of MCHS
T	Temperature (K)
U	dimensionless nanofluid velocity
u	nanofluid velocity ($m\,s^{-1}$)
u_m	mean nanofluid velocity ($m\,s^{-1}$)
Ha	Hartmann number
σ	Electrical conductivity
W_{fin}	Width of the heat sink (m)
W_{ch}	Width of channel (m)
x	horizontal axes coordinate
y	dimensionless vertical coordinate
X	dimensionless horizontal coordinate
Y	dimensionless vertical coordinate
Greek letters	
ϕ	nanoparticles volume fraction
θ	dimensionless temperature
ρ	Density($kg\,m^{-3}$)
ε	porosity
μ	dynamic viscosity($N\,s\,m^{-2}$)
$\propto_s$	aspect ratio of the microchannel
Subscripts	
ch	channel
f	fluid
nf	nanofluid
p	particle
hs	heat sink
s	solid
w_1	of bottom wall
w_2	of top wall

and thermophoretic parameters go up. Also, in another research [21] they studied the influence of external magnetic source on heat transfer in a cavity with circular hot cylinder and showed that the rise of Lorentz forces cause the nanofluid velocity to decline and increase the thermal boundary layer thickness, causing heat transfer to improve.

Sheikholeslami [22] investigated the nanofluid natural convection in a porous enclosure in existence of Lorentz forces. Results indicated that temperature gradient decrease with increase of Lorentz forces. Also, the effect of nanoparticle on thermal conductivity was achieved to be more sensible for higher values of *Ha*. Sheikholeslami and Rashidi [23] studied the effect of space dependent magnetic field on free convection heat transfer of Fe3O4–water nanofluid. They indicated that the Nusselt number increases as Rayleigh number, Magnetic number and nanoparticle volume fraction increase. Then, many of other researches such as Rahman SU et al. [24] and Sheikholeslami et al. [25,26] showed that by applying magnetic field on nanofluid, heat transfer process improves.

Since the majority of engineering problems, especially those that govern the equations of fluid motion and heat transfer, are nonlinear, they do not have an exact and unique solution; therefore, a strong analytical method along with numerical techniques are required for them. With the rapid development of nonlinear science, many Different methods were proposed to solve various boundary value problems (BVP), while some other methods called Weighted Residuals Methods (WRMs) exist, which first used by Ozisik [27] to solve heat transfer problems. Collocation method (CM), which is one of WRMs, is employed here, and is utilized in solving the wide range of non-linear heat transfer problems [28].

In this article, thermal analysis of MCHS in the presence of MHD is carried out, and Al_2O_3-water nanofluid is considered as a coolant medium and KKL method is employed to calculate viscosity and thermal conductivity. Forchhiemer-Brikman model, which is actually an extended form of the Darcy equation, is applied to describe the fluid flow and porous medium. In addition, a two-equation model with thermal dispersion is considered for the heat transfer. Nonlinear equations the fluid flow and energy are solved using CM and 4th order Runge-kutta methods. Dimensionless temperature profile for the solid part and liquid phase is represented, and Nusselt number variations, temperature distribution contour in the channel and optimized nanoparticle diameter have been investigated.

2. Problem description and governing equations

The microchannel examined in this study generally includes N channels, each channel with length L_{hs}, width W_{ch}, height h_{ch} and thickness of the channel plate is W_{fin} as shown in Fig. 1. Since this type of microchannel is used for cooling microprocessors and electronic chips, a constant heat flux boundary condition is applied on its underside ($y = 0$). The upside of MCHS ($y = H$) is also covered by an insulated layer with the thickness of t_g. Table 1 shows the list of MCHS specifications and dimensions. The process of the heat transfer in the microchannel includes conduction in the solid part and convection between the solid part and the coolant fluid passing through. Porous media approach is used to scrutinize the performance of microchannel heat sinks under different conditions. Since nanoparticles put a great impact on the heat transfer coefficient, a water-based nanofluid is used as the coolant fluid. To simplify the analysis, the flow is assumed to be laminar and both hydrodynamically and thermally fully developed. First, Brinkman [29] extended Darcy equation for the fluid flow, which by adding magnetic field relation leads into:

$$-\frac{d}{dx}\langle p\rangle_{nf} + \mu_{nf}\frac{d^2}{dy^2}\langle u\rangle_{nf} - \frac{\mu_{nf}}{K}\varepsilon\langle u\rangle_{nf} - \sigma B^2\langle u\rangle_{nf} = 0 \qquad (1)$$

The porosity (ε), permeability (K) and Darcy number (Da) are given as:

$$\varepsilon = \frac{W_{ch}}{W_{ch} + W_{fin}} \quad K = \frac{\varepsilon W_{ch}^{2}}{12} \quad Da = \frac{K}{L_{ch}^{2}} \quad \propto_s = \frac{L_{ch}}{W_{ch}} \qquad (2)$$

Dimensionless parameters to make Eq. (1) dimensionless are defined as follows:

$$Y = \frac{y}{L_{ch}} \qquad U = \frac{\langle u\rangle_{nf}}{u_m} \qquad P = \frac{K}{\varepsilon\mu_{nf}u_m}\frac{d}{dx}\langle p\rangle_{nf} \qquad (3)$$

By applying dimensionless parameters, Eq. (1) turns into:

$$U = A_1\frac{d^2U}{dy^2} - P - Ha^2U \qquad (4)$$