Journal of Magnetism and Magnetic Materials 401 (2016) 159–168

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

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

Numerical investigation of magnetic field effect on mixed convection heat transfer of nanofluid in a channel with sinusoidal walls

M.M. Rashidi [a,b], Mohammad Nasiri [c,*], Marzieh Khezerloo [c], Najib Laraqi [d]

[a] Shanghai Key Lab of Vehicle Aerodynamics and Vehicle Thermal Management Systems, Shanghai, China
[b] ENN-Tongji Clean Energy Institute of Advanced Studies, Shanghai, China
[c] Faculty of Mechanical Engineering, University of Tabriz, Tabriz, Iran
[d] Universite Paris 10, LTIE, EA 4415, GTE, 50 Rue de Sevres, F92410 Ville d'Avray, France

ARTICLE INFO

Article history:
Received 19 March 2015
Received in revised form
8 June 2015
Accepted 9 October 2015

Keywords:
Nano-fluid
Mixed heat transfer
Sinusoidal channel
Magnetic field
Magneto-hydrodynamics (MHD)

ABSTRACT

In this study, mixed convection heat transfer of nano-fluid flow in vertical channel with sinusoidal walls under magnetic field effect is investigated numerically. The heat transfer and hydrodynamic characteristics have been examined. This study has performed for $500 \leq Re \leq 1000$, $5 \times 104 \leq Gr \leq 1 \times 106$, three amplitude sine wave (0.1, 0.2 and 0.3) and three values of Hartman numbers (0, 5 and 10). Water was utilized as the base fluid and Al2O3 is the considered nano-particle. Flow is assumed two dimensional, laminar, steady and incompressible. As well the thermo-physical properties of nano-fluid are considered constant. The Boussinesq approximation used for calculated the density variations. The average Nusslet number increases by increasing the Grashof number for nano-fluids with different volume fraction. The average Nusselt and Poiseuille number increase as Reynolds number increases. Also, the average Nusselt number and Poiseuille number increases by increasing the Hartman number.

1. Introduction

In many engineering applications, especially in heat exchangers, heat transfer improvement is an important issue. The plate heat exchangers are most important in most industries such as food processing, drug and chemical industries. Use the channel with corrugated walls can be improved the heat transfer rate. For increasing heat transfer production of corrugated channels is easier than the other ways such as embedding pore, producing vortices, etc. Corrugated walls increases the heat transfer rate by increasing bulk flow mixing, or reducing the thickness of the thermal boundary layer. The heat transfer and fluid flow in a channel with corrugated walls have been studied by many researcher using numerical and experimental methods.

Sui et al. [1] numerically studied fluid flow and heat transfer in microchannel with rectangular cross section and wavy side walls. The obtained results showed the heat transfer rate in wavy microchannel is more than straight microchannel. But, with increasing heat efficiency, pressure drop increases. Mohamed et al. [2] numerically investigated the fluid flow and heat transfer in the entrance region of a sinusoidal channel. They observed that the local Nusselt number reduces in the developing region and this decline occurs faster by increasing the Reynolds number and wave amplitude. The fluid flow and heat transfer of nanofluids in a wavy channel was studied numerically by Heidary and Kermani [3]. They found that by adding the nanoparticles to base fluid and using the wavy channel, heat transfer rate increases to 50%. The effects of wavy fins characteristics on heat transfer and pressure drop in smooth wavy fin-and-elliptical tube heat exchanger was analyzed by Lotfi et al. [4]. In another study, Wang and Chen [5] numerically studied fluid flow and heat transfer in wavy-wall channel. It was found that the heat transfer and friction factor increase by increasing the wave amplitude and Reynolds number. The low thermal conductivity of fluids such as water, oil and air, leads that some researchers add the metal particles in the nanometer dimensions to the base fluid, in order to obtain new fluids with higher thermal conductivity. Garoosi et al. [6] conducted a study on natural convection heat transfer in a 2D square cavity using a Buongiorno model. They obtained optimal volume fraction of the nano-particles for maximum heat transfer rate. Rabienataj et al. [7] experimentally investigated the hydrothermal behavior of nano-fluid flow in helical corrugated tube. They found that the friction factor and heat transfer rate increase by increasing nanoparticles volume fraction. Laminar nanofluid flow in a two-dimensional sinusoidal channel was studied numerically by Ahmed et al. [8]. They showed that the heat transfer, local and average

* Corresponding author.
E-mail addresses: mm_rashidi@sawtc.com (M.M. Rashidi), m.nasiri1989@gmail.com (M. Nasiri), m.khezerloo91@ms.tabrizu.ac.ir (M. Khezerloo), najib.laraqi@u-paris10.fr (N. Laraqi).

http://dx.doi.org/10.1016/j.jmmm.2015.10.034
0304-8853/

Nomenclature

x, y	Cartesian coordinate axes
u, v	Velocity component in x and y directions, respectively
V	Velocity vector
$\vec{r}$	Acceleration vector
k	Thermal conductivity
C_p	Specific heat capacity
k_B	Boltzmann constant
g	Gravity acceleration
T	Temperature
h	Convection heat transfer coefficient
q''	Heat flux
w	Channel width at inlet section
a	Wave amplitude
A	Dimensionless wave amplitude
D_h	Hydraulic diameter
L	Channel length
L_s	Channel entrance length
L_w	Wavelength
S	Sine wave profile
f_{drag}	Drag coefficient
ρ	Density
μ	Dynamic viscosity
V_m	Mean velocity
V_{dr}	Drift velocity
V_{pf}	Slip velocity
Re	Reynolds number
Gr	Grashof number
Pr	Prandtl number
Nu	Nusselt number
Po	Poiseuille number
Ha	Hartman number
$\vec{E}$	Electrical field
$\vec{B}$	Magnetic field

Greek symbols

ν	Kinematic viscosity
β	Thermal expansion coefficient
λ	Mean free path
φ	Particle volume fraction
σ	Electrical conductivity

Subscripts

p	Particle
bf	Base fluid
eff	Effective
ave	Average
$wall$	Wall
b	Bulk

friction coefficient increase by increasing the amplitude of channel wave, Reynolds number and the volume fraction of nanoparticles. Yang et al. [9] optimized the heat transfer parameter of nanofluid flow in a wavy channel using genetic algorithm method. Nitiapiruket al. [10] experimentally investigated laminar water–TiO_2 flow in a wavy channel and compared results with the different numerical models. Cho et al. [11] numerically investigated mixed convection heat transfer of nano-fluid in a lid-driven cavity with wavy surface. They optimized wavy surface parameters for average Nusselt number. Pelevic and Meer [12] proposed an equation for effective thermal conductivity of nano-fluids by using the lattice Boltzmann model. This equation has good agreement with both the experimental and the theoretical results. Khedkar et al. [13] experimentally studied the nano-fluid flow heat transfer in a concentric tube heat exchanger. They observed that the heat transfer coefficient of 3% volume fraction nano-particles increases 16% respect pure water. Aminfar and Motallebzadeh [14] investigated effect of nanoparticle diameter on the velocity distribution and concentration using Euleian–Lagrangian approximation. They showed that the nanoparticle distribution is non-uniform and particles concentrations in the center are more than the near wall. Rashidi et al. [15] studied a two-dimensional magnetohydrodynamic fluid flow over a vertical stretching sheet using by homotopy analysis method. Beck [16] studied the magnetic and electric fields effects on the laminar electrically conductive fluid flow between two parallel plates. They showed that the development length increased due to decreasing Joule heating. Makinde and Chinyoka [17] numerically investigated the unsteady heat transfer slip flow between two parallel plates with temperature dependent viscosity, electrical conductivity fluid and uniform magnetic field. They showed that the velocity profile becomes more uniform by increasing Hartmann number, but the temperature profile does not change. Heidary et al. [18] studied the hydrothermal behavior of nano-fluid flow by applying magnetic field on a straight duct. Aminfar et al. [19] numerically investigated effect of non-uniform magnetic field on the hydrodynamic and thermal behavior of ferrofluids in vertical pipe using two-phase mixture model. They found that the velocity profile becomes more uniform and heat transfer coefficient increases when the magnetic field gradient is negative. Freidoonimehr et al. [20] investigated the unsteady MHD laminar free convection nano-fluid flow. They observed that by decreasing the nano-particle volume fraction, the magnetic parameter, suction parameter and the skin friction coefficient decrease. Muthuraj and Srinivas [21] investigated effects of magnetic field on mixed convection in vertical wavy channel with porous medium. They found that the effect of Hartmann number on the main flow velocity is quite opposite to that of porosity parameter. More analytical simulations of nanofluids can be found in [26–28]

In this study, magnetic field effect on mixed convection heat transfer of nanofluids flow in a wavy channel is studied using mixture model. The effects of nano-particle volume fraction, sine wave amplitude, Reynolds number, Grashof number and Hartman number on fluid flow and heat transfer characteristics are studied in details.

2. Theoretical formulation

2.1. Governing equations

Using a quite multiphase model for numerical simulation is very difficult, particularly for wide distribution of particle. The mixture model is a suitable and very accurate approximation in more application of multiphase flows. In this study, flow is assumed laminar, steady state and incompressible with constant thermo-physical properties. The effects of dissipation and body forces are negligible. As well, the Boussinesq approximation is used for calculating the density variations due to buoyancy force. The governing equations including continuity, momentum, energy