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Numerical study of the effect of channel geometry on the performance of Magnetohydrodynamic micro pump

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ABSTRACT

Magnetohydrodynamic micropumps received more attention due to its applications in pumping of biological and chemical specimens, such as blood, DNA, and saline buffers. In this paper the MHD flow in different cross section microchannels has been numerically investigated with different electromagnetic boundary conditions. Square, rectangular, circular and trapezoidal cross section microchannels have been used to explore the effect of channel geometry on the MHD micropump operation. The study covers a selected range of applied electric currents and magnetic flux to show their effects on MHD flow. Thermal characteristics of MHD flow have been also studied by calculation the temperature distribution through MHD micropump region. The results obtained show a considerable effect of channel geometry, the applied electric and magnetic fields on the velocity and flow rate. The circular cross section micropump gave higher velocity and flow rate compared with other cross sections, and there is a slight increase in temperature due to small effect of Joule heating.

1. Introduction

Magnetohydrodynamic is the branch of science that investigates the flow of the electrically conducting fluids subjected to electromagnetic forces. It deals with the mutual interaction between electromagnetic fields and fluid flow. Non-magnetic and electrically conducting fluids must be used, which limit the application of hot ionized gases (plasmas), liquid metals and electrolytes [1]. In the last two decades the application of microfluidic devices has widely used in variety of fields, therefore, it needs extra investigation for affecting parameters such as channel geometry as will be done in this paper. In microfluidic systems the fluid flows in micron size devices which makes biological tests more effective though reduced reagent quantities and shorter reaction time, it can analyze and treat the blood with only about 10 micro liters [2–4]. Microfluidic devices are used in various applications such as reactors, micropumps, pressure flow sensors and mixers. The micropumps are the basic signs of the development of these devices. MHD micropump is one of the most important microfluidic systems that generates continuous flow without moving parts and is suitable for biomedical applications. Now adays, the flow and heat transfer in different shapes of microchannels and exposed to a magnetic field have received more attention of the research [2,5].

Atypical micro pump is a μ-EMS device; it is the actuation source thought which a fluid sample (Drugs and therapeutic agents) is transferred with precision accuracy and reliability from a reservoir to the target. The most useful μ-EMS applications are the laps-on-a-chip (LOC) which is microscale laboratories on a microchip that can perform clinical diagnosis [6,7].

There are many investigations in the previous studies aimed to describe of the velocity profiles and other MHD parameters.

Homsy et al. (2005) [8] carried out the first attempt in using high-current density MHD micropumps which achieved pumping at a high current density of 4000 A/m^2 and minimizing the effect of bubbling. They designed MHD main channel with two channel located on the two longitudinal sides. Electrodes are physically separated from main channel in which flow is generated. So bubble formed in side channel cannot obstruct the flow of main channel. They found that, the maximum reported flow rate was only 0.5 μl/min for a channel of 75 μm.

Luciano P. A. et al. (2013) [1] presented a closed water circuit with square cross-section filled with an electrolyte fluid, their model was derived from the Navier-stokes equations for Newtonian

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Nomenclature

Symbol	*Description (Unit (SI))*
B	Magnetic flux density vector (T)
Cp	Specific heat of fluid (J/kg.K)
E	Electric field (v)
F_L	Lorentz force (N)
J	Current density vector (A/m^2)
K	Thermal conductivity (W/m.K)
Le	Electrode length (m)
p	pressure (N/m^2)
t	Time (s)
T	Temperature (K)
U	Flow velocity (m/s)

Greek symbols

Ø	Electric potential (v)
δ	ectric conductivity (s/m)
μ	Viscosity (Pa-s)
ρ	Fluid density (kg/m^3)

fluid using the k-turbulence model and coupled with the Maxwell's equations. They found that, for the Lorentz force an M shape profile is observed, and the velocity increased with the increasing of the applied voltage and that the M-shaped profile of the velocity is the consequence of the uneven distribution of Lorentz force and the mass conservation condition.

Mehdi Kiyasatfar et al. (2014) [9] studied Magnetohydrodynamic flow model in rectangular channel to explore the characteristics of Magnetohydrodynamic pumps for prediction of pumping performance in a Magnetohydrodynamic flow. The non-linear governing equations of motion and energy including viscous and Joule dissipation are solved numerically for velocity and temperature distribution. They develop a finite difference approximation based code to solve the equations. They also investigate the effects of magnetic flux density, applied electric current and channel size on flow velocity field as well as thermal behavior in various working medium with different physical properties. Their results show that at small Hartman numbers, the temperature and velocity profiles which parabolic and increase in Hartman number lead to reduction in velocity and temperature and so their profiles get flat.

Kosuke Ito et al. (2014) [10] studied experimentally and numerically the fluid behavior in an MHD-micro pump by using a permanent magnet. Their experimental and numerical results show that Hartman flow is not observed in the channel because the MHD interaction is very weak, so that poiseuille flow is maintained in the channel. Their numerical study also examines the influences of the channel height and the strength of applied magnetic flux density on the fluid temperature in the channel.

Mohsen Sheikholeslami (2015) [11] studied numerically the effect of thermal radiation on MHD nanofluid between two horizontal rotating plates. They included the effects of Brownian motion and thermo phoresis in the model of nanofluid. They solved the governing equations numerically using the fourth-order Runge–Kutta method. They investigated the effects of Reynolds number, Brownian parameter, magnetic parameter, rotation parameter, Schmidt number, thermo phoretic parameter, and radiation parameter on heat and mass characteristics. They found that Nusselt number has direct relationship with radiation parameter and Reynolds number while it has reverse relationship with other active parameters. Also they found that concentration boundary layer thickness decreases with the increase of radiation parameter.

Arash K. and Masoud A. (2016) [12] studied numerically the forced convection of water Cu nanofluid in a two-dimensional microchannel. They assume that, whole of microchannel is under the influence of a magnetic field with uniform strength and used a slip velocity and temperature jump along the microchannel walls for different values of slip coefficient. They developed computer code in FORTRAN to solve Navier–Stokes equations. They investigated the effect of magnetic field on slip velocity and temperature jump. They found that, Larger Hartmann number, Reynolds number, and volume fraction correspond to more heat transfer rate; however, the effects of Ha and volume fraction are more significant at higher Re.

M. Sheikholeslami et al. (2016) [13] investigated the effect of magnetic field dependent (MFD) viscosity on the free convection heat transfer of nanofluid in an enclosure. They utilized Single phase nanofluid model considering Brownian motion with bottom wall has constant flux heating element. Control volume based finite element method is applied to simulate this problem. They examined the effects of viscosity parameter, Hartmann number and Rayleigh number on hydrothermal behavior. They found that, Nusselt number is an increasing function of Rayleigh number and volume fraction of nanoparticle while it is a decreasing function of viscosity parameter and Hartmann number. Also they found that, reduction of Nusselt number due to MFD viscosity effect is more sensible for high Rayleigh number and low Hartmann number.

The reviewed literature shows that, there is no comprehensive research on the effect of channel geometry on the flow and heat transfer of the MHD micro pump. In this paper the MHD flow in microchannel will be studied numerically and the effects of microchannel geometries will be studied with different values of applied electric and magnetic fields boundary conditions to overcome the lag of research in this field.

2. Problem description

In the MHD micro pump, the pumping action is generated by the electromagnetic Lorentz Force generated from the applied magnetic field and electric current. The basic principle based on applying an electric current and orthogonal magnetic field across a channel filled with electrically conducting fluid [10,14]. Fig. 1 shows the description of the studied MHD micro pump where the electrical field is applied in the horizontal direction by two parallel electrodes and the magnetic field is applied in the vertical direction by two parallel magnets. As shown in Fig. 1, the direction of flow is perpendicular on both of the electrical and magnetic fields created by the Lorentz force generated by the interaction of electrical and magnetic fields. The formulation of MHD steady state model is derived from Maxwell equations coupled with Navier-stokes equations. Therefore the phenomena are described by the electro magnetism and the fluid dynamics equations [1,15]. A phosphate buffered saline (PBS) solution is used as a working fluid. The thermo physical properties of PBS solutions are summarized in Table 1 [10]. A microchannel with square, rectangular, circular and trapezoidal cross section area used to measure the effect of channel shape on the MHD micropump operation. Two cases for trapezoidal channels are investigated as will be discuses later.

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