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Numerical simulation of forced heat transfer of liquid metals in a microchannel heat sink under a magnetic field

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Abstract

Increasing the heat transfer rate in various industries in order to improve the efficiency of equipment, prevent damage to parts and reduce costs is one of the essential discussions in the industry. One of the solutions to increase heat transfer is the use of active heat sink. In the present work, an active heat sink with Galinsten liquid metal fluid was used and the discretization of Navier-stokes equations was done using the second order upstream finite volume method. The effect of applying the magnetic field in the Y direction (perpendicular to the flow axis) to the heat sink has caused the creation of a force against the flow direction called the Lorentz force, which has caused the M-shaped velocity distribution. According to the constant flux boundary condition, increasing the flow velocity in the vicinity of the walls has caused the surface temperature to decrease and the heat transfer to improve. The results showed that the effect of applying a uniform external magnetic field in both Y and X directions with a Hartmann number of 517 improved the Nusselt number by 38% and 13%, respectively, compared to a Hartmann number of zero. The effect of applying a magnetic field in the Y direction to the heat sink with a Hartmann number of 517, 38%, Hartmann number of 258, 22% and Hartmann number of 129, 13% has improved the heat transfer.

Keywords: Forced convection heat transfer, magnetic field, liquid metal, heat sink, microchannel

1. Introduction

Cooling is a major concern in many different industries, for example, electronic devices, chemical vapor devices, solar energy collectors, and many others. To avoid hot spots that reduce the life of mechanical devices or even permanently damage electronic components, the temperature of the components must be reduced; Therefore, an effective cooling technique is necessary to eliminate the thermal load on the system and maintain maximum performance under all conditions. In this case, microchannel heat sink based on liquid metal are suitable options. Liquid metals have a higher thermal conductivity coefficient than normal fluids; Therefore, they are more efficient in terms of increasing heat transfer from the hot source. The effect of applying a magnetic field on the flow of liquid metal causes a change in the flow behavior due to its high electrical conductivity coefficient. According to the type of displacement heat transfer (natural, forced, mixed), the application of magnetic field has different effects on the displacement heat transfer coefficient and pressure drop.

According to the topic of this research, the research done in this field is divided into three general categories: 1- Research in the field of active heat sinks 2- Effectiveness of liquid metals as a working fluid in terms of increasing heat transfer 3- Application of magnetic field and investigation of fluid flow behavior and its effectiveness in the field of free, combined and forced displacement heat transfer.

Most of the researches carried out regarding heat sinks in the field of geometrical changes of microchannels (hydraulic diameter, changes in the order of inlet and outlet, changes in fins and blades of heat sinks, changes in metals used, etc.) as well as changes in fluid properties (use of water and nanofluids and liquid metals, etc.) and changes in flow properties (flow speed) and investigating the application of magnetic fields on conductive fluids. Since the first work by Tuckerman and Pace [1], much research has been done to study the thermal performance and hydraulic characteristics of microchannel heat sinks. Gunnasegaran et al [2] investigated the flow and convective heat transfer characteristics of water in rectangular, trapezoidal and triangular microchannels under different Reynolds numbers. Kumar et al [3] investigated the effect of fluid flow inlet and outlet arrangements on thermal and hydraulic performance. Ho et al. [4] studied forced thermal transfer of water-aluminum oxide nanofluid (experimentally) in a microchannel heat sink. Miner and Ghoshal [5] performed analytical and experimental work on liquid metal flow in a pipe. Their results showed that the heat transfer in both calm and turbulent regimes is increased by using liquid metal coolant. . Zhang et al. [6] showed that liquid metal can enhance convective heat transfer due to its superior thermophysical properties. Wang et al [7] studied the external natural convection heat transfer of liquid metal under the influence of magnetic field. Hajmohammadi et al [8] conducted a numerical study to investigate the effects of a uniform and non-uniform external magnetic field on the optimized geometry and thermal performance of a microchannel heat sink. Wang et al. [9] investigated the combined displacement heat transfer of liquid metal under magnetic field.

In this research, forced displacement heat transfer (Reynolds and Prandtl numbers without significant dimension) of galinstan liquid metal (due to its superior thermophysical properties) under the application of a uniform magnetic field (without magnetic gradients and Kelvin volume force) in two directions perpendicular to the axis The current (maximum effect of the magnetic field) has been discussed.

2. Methodology

A microchannel heat sink similar to the work of Sarovar [10] has been used. The heat sink consists of 20 identical rectangular channels as shown in Figure 1. The following geometrical parameters were used in the comparison study between bed and cooling materials: channel height H=5mm, channel width Wc=1mm, channel wall thickness Ww=1mm and base thickness tb=2mm with dimensions W×L=4cm×4cm.

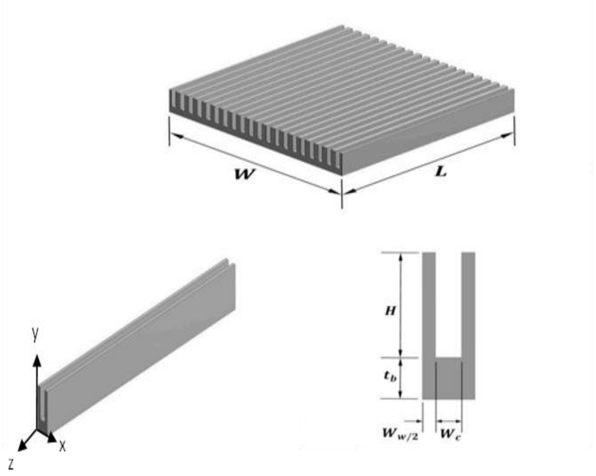

Figure 1. Full 3D view and single microchannel

In the simulation, for boundary conditions, a constant heat flux will be applied to the bottom of the heat sink, and the walls around the heat sink are considered insulated, and the fluid enters the microchannel with temperature T_f and velocity U_f. For the output, the boundary condition of the output pressure and applying the magnetic field, all the walls of the heat sink are considered conductive. Ansys Fluent software has been used for simulation, which is done according to the incompressibility of the flow, the pressure-based solver and the SIMPLEC solution algorithm and the governing equations using the finite volume method with second-order discretization. Magnetohydrodynamics refers to the interaction between a generated electromagnetic field and an electrically conductive fluid. The magnetohydrodynamic model in AnsysFluent analyzes the behavior of electrically conductive fluid flow under the influence of constant or fluctuating electromagnetic fields. The magnetohydrodynamic model is activated by selecting Fluent's internal simple functions as an add-on module in Ansys Fluent software.

3. Discussion and Results

First, the effects of a uniform external magnetic field in three different directions on the flow field and temperature have been investigated. The displacement heat transfer of liquid metals in microchannels depends on the thermal properties of liquid metals. According to the displacement heat transfer theory, Nusselt number is related to Reynolds number (Re) and prandtl number (Pr). The thermal properties of liquid metals, including thermal conductivity and specific heat capacity and viscosity, lead to different Reynolds and prandtl numbers.

Figures 2 and 3 show the flow velocity distribution in the section Z=0.02 m with inlet velocity of 0.3 and 1 m/s under the application of magnetic field in three directions X, Y and Z with Hartmann number 517. The effect of applying the magnetic field in the Y direction has caused an M-shaped velocity distribution, and the effect of applying the magnetic field in the X direction has caused the velocity distribution to change from uniform to flat.

By applying the magnetic field in the Z direction, there is no change in the fluid velocity distribution, because the effect of applying the magnetic field is parallel to the direction of the fluid flow, and it has caused the Lorentz force to become zero, and in fact, the expression of the volume magnetic force from Navier-stokes equations It has been deleted. Applying the magnetic field in two directions X and Y (perpendicular to the flow axis) due to the 90-degree angle between the magnetic field vector and the fluid flow axis has caused the maximum application of the Lorentz force.

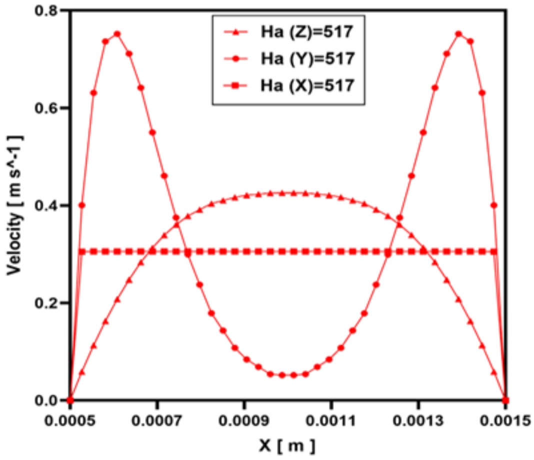

Figure 2. Investigation of the flow field by applying the magnetic field in three different directions to the heat sink at the section Z=0.02 m with the inlet velocity of 0.3 m/s.

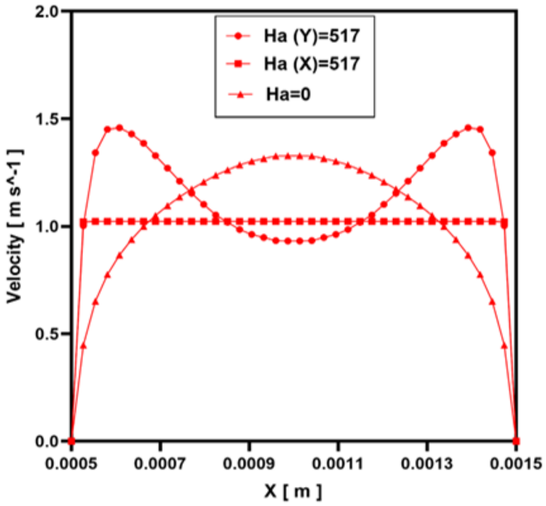

Figure 3. Investigation of the flow field by applying a magnetic field perpendicular to the flow axis and zero Hartmann number, section Z=0.02 m with an inlet velocity of 1 m/s

Figure 4 shows the speed contour by applying the magnetic field in the Y direction with increasing Hartmann number. With the increase of Hartmann number, the flow velocity near the walls has increased compared to the center line of the microchannel.
Figure 5 shows the temperature change diagram due to the application of magnetic field in three directions X, Y and Z with the input flow speed of 0.3 m/s. The effect of applying the magnetic field in the Y and X direction has caused a decrease in the temperature of the surface of the heat sink. Therefore, the highest efficiency in reducing the temperature of the heat sink surfaces will be formed when the magnetic field is applied to the heat sink in the Y direction.

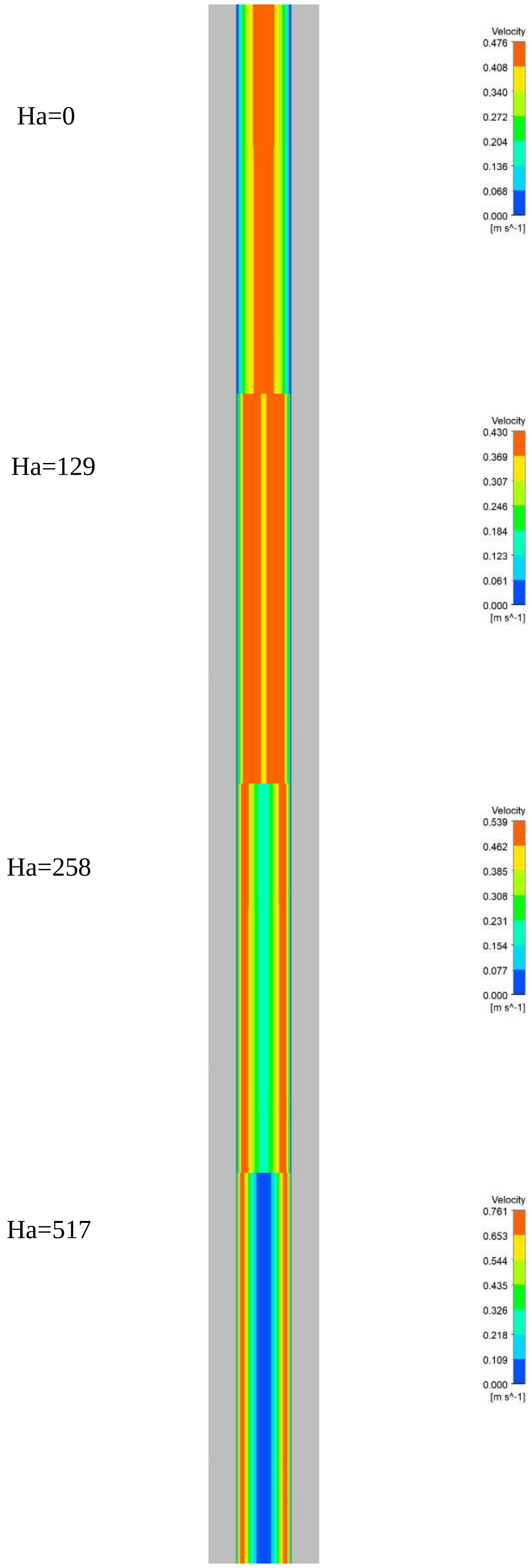

Figure 4. Velocity contour with increasing Hartmann number, applying magnetic field in Y direction

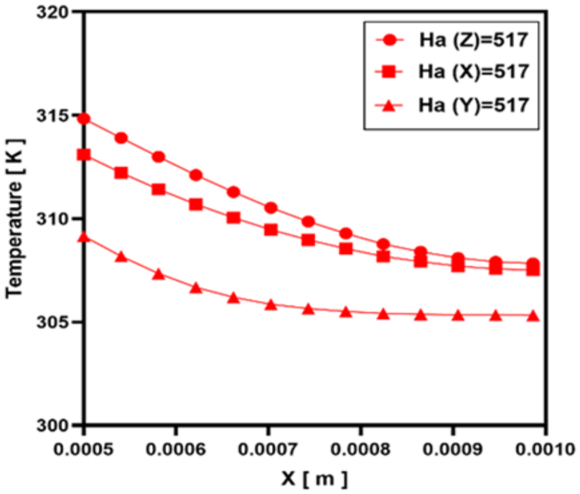

Figure 5. Graph of temperature changes by applying a magnetic field in three different directions with a speed of 0.3 m/s in the section Z=0.02 m

4. Conclusions

The obtained results can be categorized as follows:

1- Specified with an inlet velocity of 0.3 m on the magnetic ground in the Y direction with a Hartmann number of 517, the displacement heat transfer coefficient is 38%, and with an increase in the fluid inlet velocity to 1 m/s, the displacement heat transfer coefficient is 25% higher than the Hartmann number. It has been found that this reduction of magnetic force is at higher speeds.
2- By applying the magnetic field in the Y direction to the heat sink and increasing the Hartmann number, the flow velocity increased near the walls and decreased in the center line of the microchannel, causing the boundary layer area to shrink.
3- The effect of applying a magnetic field in the Y direction to a heat sink with a Hartmann number of 517, 38%, a Hartmann number of 258, 22% and a Hartmann number of 129, 13% has improved the Nusselt number compared to zero Hartmann number.

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