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Improvemet Mixed convection heat transfer of liquid metal in a single channel heat sink under uniform external magnetic field

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Abstract

The most obvious feature of heat sinks is their ability to transfer heat and their cooling properties. In this research, a vertical single-channel active heat sink with Galinstan liquid metal fluid was used and the discretization of Navier Stokes equations was done using the second-order upwind finite volume method. Investigation of Mixed Convection heat transfer with Richardson numbers 0.45, 1 and 10 has been done in both directions of flow from top to bottom and flow direction from bottom to top and the effects of external magnetic field in two directions perpendicular to the flow axis have been investigated. The results showed that the flow direction from bottom to top with a Richardson number of 10 without the presence of a magnetic field improved the Nusselt number by 11.30% compared to the flow direction from top to bottom. With the Richardson number of 1 and the flow direction from bottom to top, the effect of applying the magnetic field in the Z direction (perpendicular to the current axis) with the Hartmann number of 129, 164.5, and 194, respectively, is 11.29, 13.63, and 15.88 percent of the Nusselt number has been improved. With the Richardson number of 1 and the flow direction from the bottom to the top, the effect of applying the magnetic field in the X direction (perpendicular to the flow axis) with the Hartmann number of 64.6, 129 and 194, respectively, is 7.08, 8.28 and 8.76% of the Nusselt number has improved.

Keywords: Microchannel, Mixed convection heat transfer, liquid metal, heat sink, magnetic field.

1. Introduction

Rapid developments in the computer industry have created great challenges in the cooling mechanisms of electronic components. The performance of these mechanisms is largely influenced by the cooling technologies associated with them. In this case, microchannel heat sinks based on liquid metal are suitable options. A microchannel heat sink is a small heat exchanger that can remove a large amount of heat flux from a small surface area. 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 convection heat transfer (natural, forced, combined), the application of magnetic field has different effects on the convection heat transfer coefficient and pressure drop. The mechanism of heat transfer between the fluid and its adjacent surfaces is called convection. In this study, the combined heat transfer includes free and forced heat transfer. Mixed convection will be formed when the effect of forced flow and free flow dominate each other.

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 fluid agent in increasing heat 3- Application. Investigating the magnetic field and investigating the behavior of fluid flow and its effectiveness in the field of combined heat transfer.

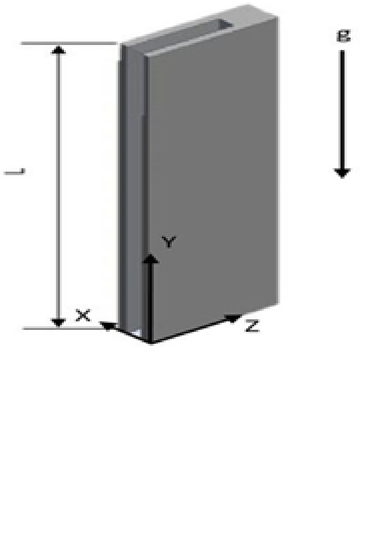
Most of the researches carried out regarding heat sinks in the field of geometrical changes of microchannels (hydraulic diameter, changes in the order of inlet and outlet, changes in fins and blades of heat sinks, changes in metals used, etc.) as well as changes in fluid properties (use of water and 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. Wu et al. [3] using a numerical method, the flow and heat transfer of well heating on the metal body with different types of working fluid, cross-sectional shapes of various microchannels and different inlet velocities are investigated.

Singh and Gohil [4] numerically investigated liquid metal flow and heat transfer in a multi-stage chamber in the presence of a magnetic field. 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 Mixed convection heat transfer of liquid metal under magnetic field.

In this research, Mixed convection heat transfer with galinstan metals under the effect of magnetic field in two directions perpendicular to the flow axis in a microchannel heat sink has been investigated. The external uniform magnetic field in two directions perpendicular to the flow causes a change in the flow which helps to improve the heat transfer. The flow direction in the vertical heat sink (flow direction from top to bottom and vice versa) has also been investigated regarding the improvement of heat transfer by mixed convection.

2. Methodology

A heat sink with a single microchannel similar to the work of Sarovar et al. [10] has been used. The following geometric center is used in the comparison study of two substrates and coolers. Channel height H=5 mm, channel width b-2c=1 mm, channel wall thickness c=b/4 and base thickness W-H=2 mm and size L×W=4 cm×7 mm.



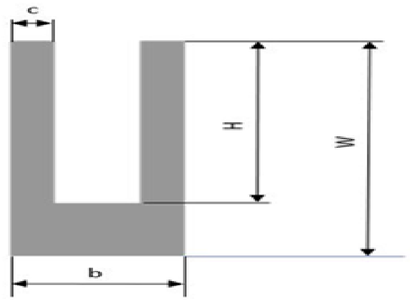


Figure 1. Full 3D view and single microchannel

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

Mixed convection will be formed where forced flow and free flow dominate the composition. In this research, a vertical heat sink is used, which is done in two ways: 1- Flow direction from bottom to top (y+) 2- Flow direction from top to bottom (y-) has been carried out to investigate the environment of free movement.

Figure 2 shows the changes of Nusselt number in two directions of flow from bottom to top and vice versa without the presence of magnetic field. With the increase of Richardson's number in the range of 0.45 to 10, the effects of free convection on the improvement of heat transfer have increased. With the flow direction from bottom to top and Richardson number 0.45, 1 and 10 respectively, Nusselt number has been improved by 2.8, 4.4 and 11.30% compared to top to bottom flow direction. The increase of Nusselt number with the direction of flow from bottom to top is because forced and free convection have strengthened each other's effects. If they weaken each other's effects with the flow direction from top to bottom. The increase in Richardson's number increases the effects of buoyancy force, which improves heat transfer.

Figure 3 shows the changes in the speed distribution under the application of the magnetic field in the Z direction with the increase of the Hartmann number in the section y=0.02 m. The effect of the application of the magnetic field in the Z direction (perpendicular to the flow axis) has caused the creation of a force opposite to the flow direction, called the Lorentz force, which has caused the M-shaped velocity distribution. This type of velocity distribution has caused an increase in the flow velocity in the vicinity of the walls and a decrease in the flow velocity in the central line of the microchannel.

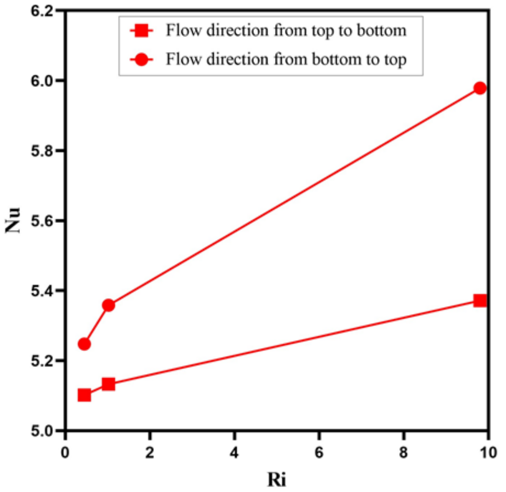


Figure 2. Investigating the Nusselt number by increasing the Richardson number in two states of flow direction from bottom to top and vice versa

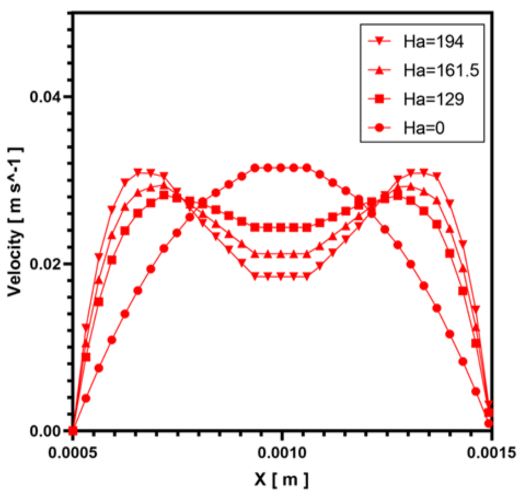


Figure 3. Changes of velocity distribution under application of magnetic field in Z direction with increasing Hartmann number, section y=2 cm

Figure 4 shows the flow velocity contour with increasing Hartmann number for the flow direction from bottom to top. With the increase of the Hartmann number, the thickness of the hydrodynamic boundary layer has decreased and has increased the flow velocity near the walls.

Figure 5 shows the speed change diagram in three different states: 1- Flow direction from bottom to top 2- Flow direction from top to bottom without presence of magnetic field 3- Flow direction from bottom to top with presence of magnetic field and Hartmann number 129. The results show that the flow speed in the bottom-up direction increased due to the effect of the buoyancy force compared to the up-down flow direction near the hot walls, and by applying the magnetic field, the flow speed in the vicinity of the walls increased compared to the center line of the microchannel.

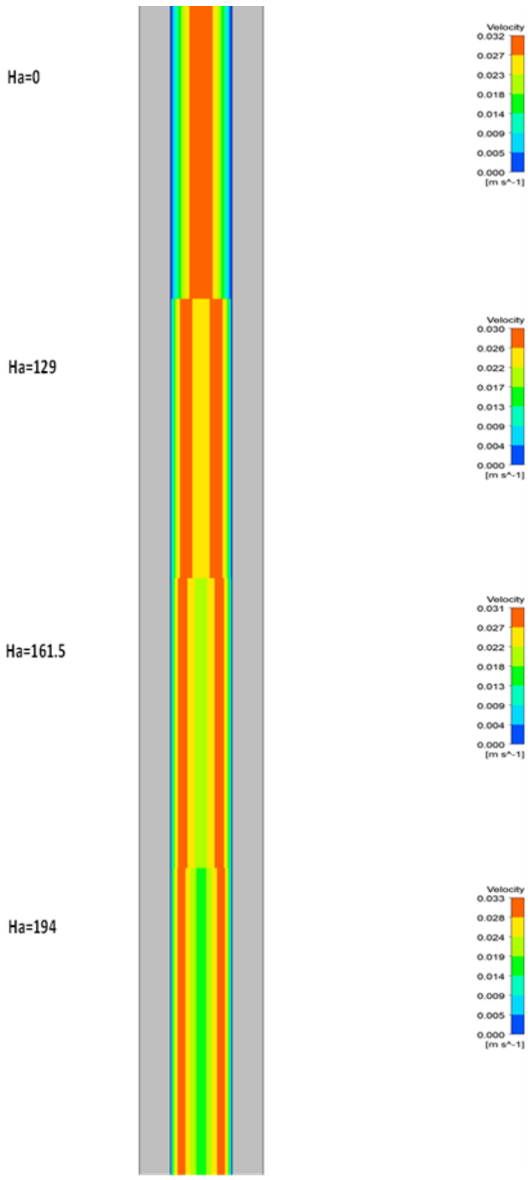


Figure 4. Velocity contour with increasing Hartmann number, downward-upward flow direction, application of Z magnetic field

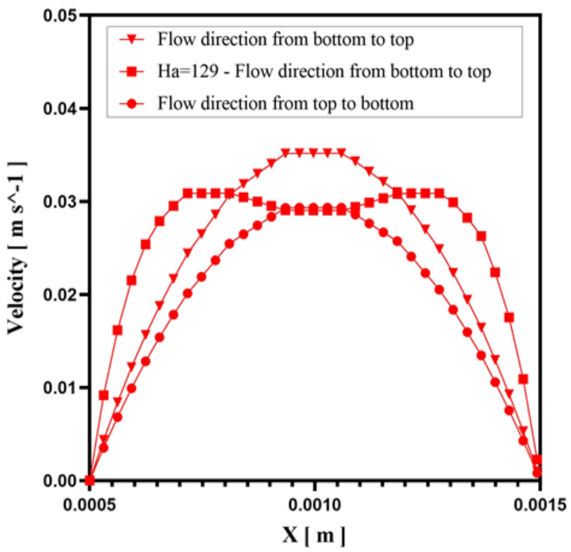


Figure 5. Speed changes in three states: 1) flow direction from bottom to top 2) flow direction from top to bottom 3) flow direction from bottom to top in the presence of a magnetic field with Hartmann number 129, section Z=3.5 mm

Figure 6 shows the graph of velocity changes with the application of magnetic field in the Z direction in the boundary layer region from the entrance to the center of the microchannel (-0.04<y<-0.02). With the increase of the Hartmann number, the thickness of the velocity (hydrodynamic) boundary layer has decreased and the flow velocity has increased in this area.

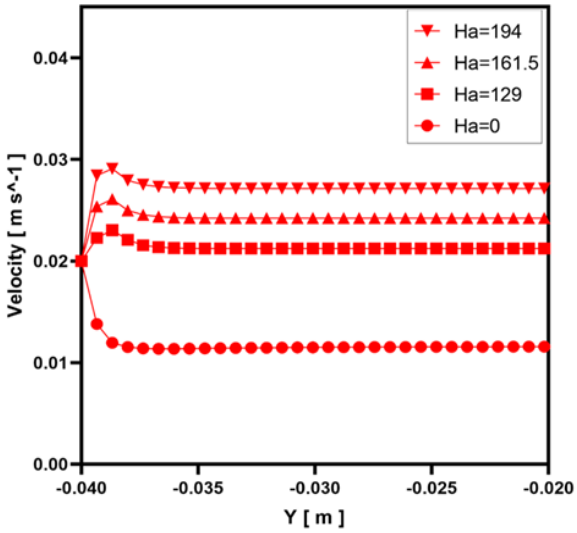


Figure 6. Velocity changes under the application of magnetic field in Z direction with increasing Hartmann number in the boundary layer region

4. Conclusions

1- In Mixed convection heat transfer, the buoyancy force has a significant effect on increasing heat transfer. The direction of flow from bottom to top with the Richard Soden number of 10 without the presence of magnetic field has improved the Nusselt number by 11.30% compared to the direction of top to bottom flow.

2- Applying the magnetic field in the Z direction (perpendicular to the flow axis) has caused the M-shaped velocity distribution, which due to the fluid-constant boundary condition, increasing the velocity in the vicinity of the walls has improved the heat transfer and decreased the temperature of the surfaces.

3- With Richardson number 1 and flow direction from bottom to top, the effect of applying magnetic field in the Z direction (perpendicular to the flow axis) with Hartmann number 129, 164.5 and 194 respectively 11.29, 13.63 and 15.88 percent of the number It has improved Nusselt.

4- With the Richardson number of 1 and the flow direction from the bottom to the top, the effect of applying the magnetic field in the X direction (perpendicular to the flow axis) with the Hartmann number of 64.6, 129 and 194, respectively, is 7.08, 8.28 and 8.76% of the Nusselt number. has improved.

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