The effect of magnetic field on thermo hydrodynamic behavior of nanofluid inside a channel

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Abstract: This paper presents a numerical study of the flow inside a channel. The effect of including nanofluids and magnetic field on the heat transfer and flow characteristics is studied. The effect of different parameters such as Hartmann number Ha, Reynolds number Re, and the nanoparticles volume fraction φ on heat transfer characteristics at different magnetic field angle γ was studied.

Keywords: Magnetic field inclination, Nanofluid, Nanoparticles, heat transfer, flow inside channel.

1. INTRODUCTION

The effect of magnetic field on heat transfer and nanofluid flow through a channel has been investigated experimentally or numerically by researchers due to its importance in industrials applications such as MHD generator, biofluids in human body, cooling devices and heat exchanger. Many researchers studied numerically or numerically the effect of presence of magnetic field in channel flows.

Aminossadati et al (2011) studied numerically laminar forced convection of nanofluid flow over a microchannel in the presence of magnetic field in order to determine the effect of parameters such as Reynolds number, Hartmann number on heat transfer and characteristics flow. The results show that the heat transfer is enhanced when Reynolds number and Hartmann number increases. As well as Nusselt number increases by increasing nanoparticles volume fraction. Rahman et al (2011) presented a numerical study of mixed convection flow in horizontal channel under magnetic field to investigate the effect of different parameters such as Rayleigh number Ra, Reynolds number Re, Hartmann number Ha on heat transfer and flow characteristics. Nasrin et al (2012) studied a combined convection flow and heat transfer characteristics inside a channel with heat generating hollow circular pipe using a volume finite element method to show the effect of magnetic field and joule heating. Results show that the rate heat transfer is maximum at the absence of MHD and joule heating effect. Hatami et al (2013) present a comparison between Homotopy Analysis Method (HAM)and fourth order Runge-Kutta numerical method to study MHD forced convection of nanofluid flow over stretching flat plate. Results show that HMA is a preferred method to solve this problem. Sheikholeslami et al (2015) studied forced convection heat transfer of Fe3O4- water nanofluid in a lid semi enclosure including a non-uniform magnetic field. Results show that Nusselt number increases by increasing Reynolds number and nanoparticles volume fraction but in other hand by increasing Hartmann number Nusselt number decreases. Heidary et al (2015) studied numerically a nanofluid heat transfer and flow over a straight channel in the presence of magnetic field. It is concluded that nanoparticles and magnetic field enhance heat transfer over 75%. Malvandi et al (2015) studied theoretically forced convection heat transfer of nanofluid in microchannels under uniform magnetic field.to show the effect of nanoparticles distribution on heat transfer. Karimipour et al (2016) simulated numerically laminar forced convection flow of nanofluid in microchannel using FORTRAN language computer code in order to investigate the effect of magnetic field on heat transfer and characteristics flow. It is observed that heat transfer enhanced by using nanofluids. Furthermore the presence of magnetic field has a significant effect on developed region at lower Reynolds numbers. Larimi et al (2016) investigated hydro-thermal characteristics of ferrofluid (water and Fe3O4) in a rib-channel exposed to several non-uniform transverse magnetic fields. Results show that local Nusselt increase by increasing the strength of magnetic field, especially in rib regions of the channel. Moreover magnetic field increases skin friction and pressure drop. Farshad et al (2019) present numerical analysis to show the impact of insering mmulti-channel twisted tape on hydrothermal characteristics of nanomaterial in a solar system. Shafiq et al (2019) investigated MHD forced convection flow of nanofluids using inclined MHD in Casson Axisymetric Marangoni flow. Results show that Casson fluid parameter and MHD inclination angle reduce factors fluid motion and Marangoni effect improves velocity of fluid. Selimefendigil et al (2019) studied numerically forced convection of pulsating nanofluid flow over corrugated parallel plate including an inclined magnetic field using Galerkin weighted residual finite element method. They analyzed the effects of Hartmann number, Reynolds number, solid particle volume fraction, magnetic inclination angle, number and height of corrugation wave, pulsation amplitude and frequency on heat transfer enhancement. Selimefendigil et al (2019) in their paper examined forced convection flow in a branching channel with elastic walls in the presence of magnetic field using Lagrangian-Eulerian method to describe the fluid motion. Results show that average Nusselt number decreases about 9% with the bigger size of elastic wall. However magnetic field increases the heat transfer rate. Erdem et al (2020) studied numerically Cu-water nanofluid in a pipe under perpendicular magnetic field using ANSYS Fluent commercial software. It is found that magnetic field strength, nanoparticles volume fraction and Reynolds number has an effect on heat transfer.

2. DESCRIPTION OF THE PROBLEM

The geometry of the physical problem is presented in the figure above; it's a channel. H is the height of the step. 13H is the length channel. A parabolic profile of velocity and uniform temperature are imposed in the inlet. Tc is the temperature of straight wall and Th is the temperature of the downstream wall. Magnetic field was located below the channel. In this paper different magnetic field inclination were calculated for different fins orientations angles.

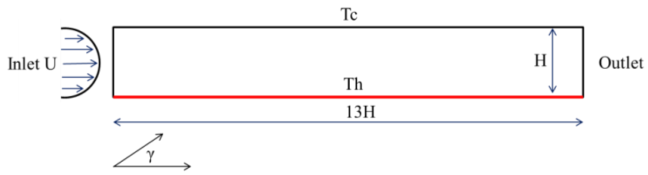


Figure 1.Geometry of the problem

2. GOVERNING EQUATIONS

The governing equations of continuity, momentum and energy are expressed as follows [1]:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (1)$$

$$\rho_{nf}\left[\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}v\frac{\partial u}{\partial y}\right]=-\frac{\partial P}{\partial x}+\mu_{nf}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)$$
$$+\sigma_{nf}B_0^2(u\sin\gamma\cos\gamma-v sin^2 y) \qquad (2)$$

$$\rho_{nf}\left[\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}v\frac{\partial v}{\partial y}\right]=-\frac{\partial P}{\partial y}+\mu_{nf}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)$$
$$+\sigma_{nf}B_0^2(u\sin\gamma\cos\gamma-v cos^2 y) \qquad (3)$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}v\frac{\partial T}{\partial y}=-\frac{\partial P}{\partial y}+\sigma_{nf}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \qquad (4)$$

3. EFFECTIVE THERMO PHYSICAL PROPERTIES OF THE NANOFLUID [1]:

Density: $\rho_{nf}=\varphi\rho_s+(1-\varphi)\rho_f$

Dynamic viscosity: $\mu_{nf}=\mu_f(1-\varphi)^{-25}$

Thermal diffusivity: $a_{nf}=\frac{k_{nf}}{(\rho Cp)_{nf}}$

Thermal conductivity: $k_{nf}=\frac{k_s+2k_f-2\varphi(k_f-k_s)}{k_s+2k_f+\varphi(k_f-k_s)}k_f$

Thermal expansion coefficient :

$(\rho\beta)_{nf}=\varphi(\rho\beta)_s+(1-\varphi)(\rho\beta)_f$

Specific heat: $(\rho Cp)_{nf}=\varphi(\rho Cp)_s+(1-\varphi)(\rho Cp)_f$

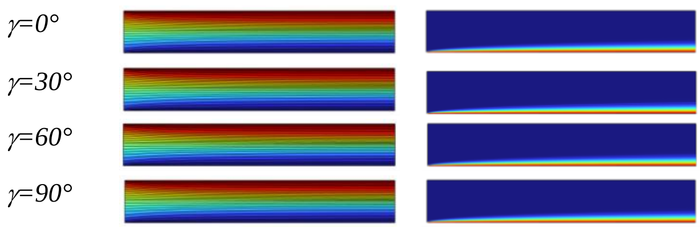
Electrical conductivity: $\sigma_{nf}=\sigma_f\left[1+\frac{3(\sigma-1)\varphi}{(\sigma+2)-(\sigma-1)\varphi}\right], \sigma=\frac{\sigma_s}{\sigma_f}$

4. RESULTS AND DISCUSSION

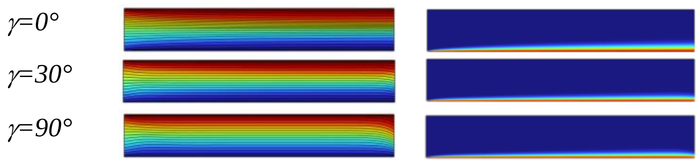
Numerical simulations in this study are performed for various values of Hartman number Ha (Ha= 0, 25 and 50), Reynolds numbers Re (Re= 5, 10 and 100), magnetic field inclination γ (γ= 0, 60 and 90), and the nanoparticle volume fraction φ (φ = 0, 0.02 and 0.04). The effects of the different parameters on the streamlines, isotherms and average Nusselt number are presented and interpreted in this study. The obtained results of streamlines and isotherms are presented in Figures. 2-4 as contour maps as well as the variations of average Nusselt number are presented in graphs in Figures. 5-10.

4.1 Streamlines and isotherms

a) Ha=0



b) Ha=25



c) Ha=50

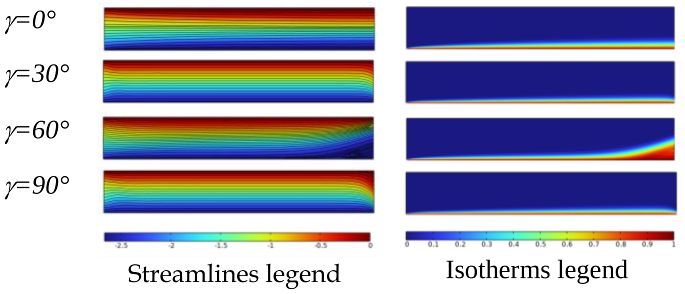
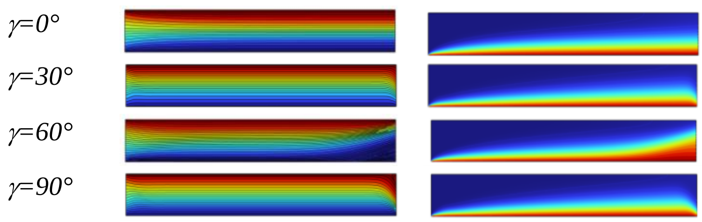


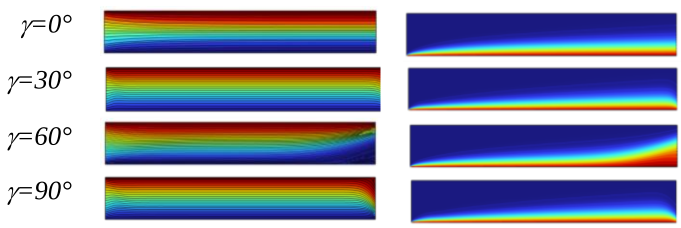
Figure 2: Streamlines and isotherms at different magnetic field inclination γ for *Ha = 0, Ha = 25, Ha = 50, Pr = 6.2, Re = 100,γ = 0°* and *φ =0.04*

Figure 2 presents the distribution of the stream function, the pattern of streamlines, and temperature contours within the channel for different angles of the magnetic field γ, namely 0, 30, 60, and 90°. At γ=0 the contours of streamlines are arranged and horizontally parallel. However by increasing the magnetic field inclination angle 30° to 90° streamlines became inclined in the direction of magnetic field, this is due to Lorentz force affecting the flow to the direction of magnetic field. For the isotherms it noted that the thermal boundary layer decrease by increasing the magnetic field inclination so the heat transfer became more important.

a) Re=5



b) Re=10



c) Re=100

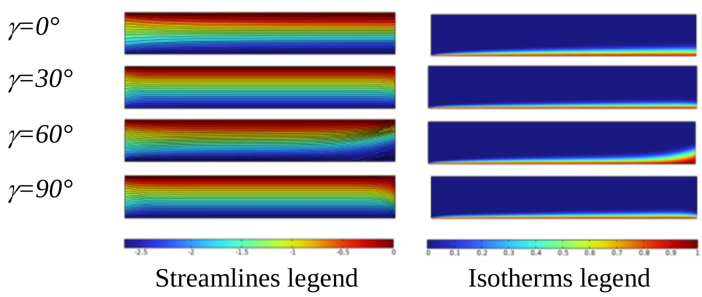
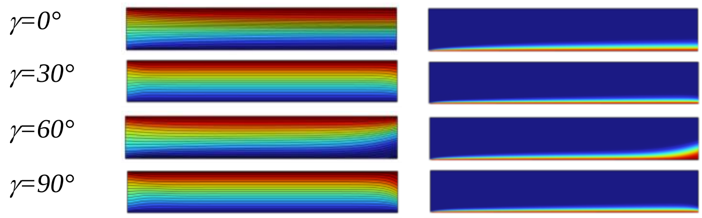


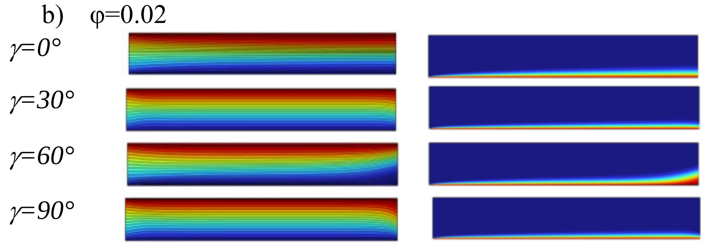
Figure 3: Streamlines and isotherms at different magnetic field inclination γ for Re=5, Re=10, Re=100, Pr = 6.2, Ha = 25, and φ = 0.05

Figure 3 illustrates the stream function distribution, streamlines, and temperature distribution inside the channel for different Reynolds numbers, namely 5, 10, and 100. As Reynolds number increases Re=100 the inertia forces increases the flow became faster. The thermal boundary layer decreases by increasing Reynolds number and improves the heat transfer.

a) φ=0



b) φ=0.02



c) φ=0.04

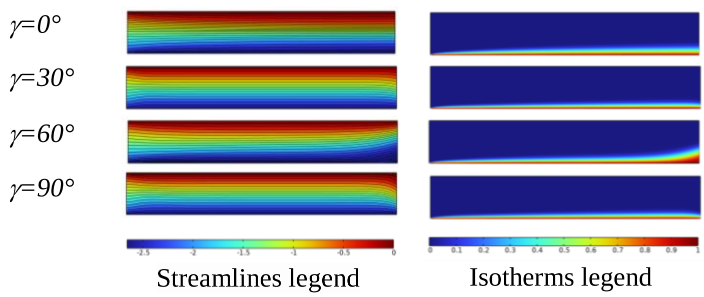


Figure 4: Streamlines and isotherms at different magnetic field inclination γ for φ =0, φ =0.02, φ =0.04, Pr = 6.2, Ha = 25, and Re = 100

Figure 4 presents streamlines and isotherms contours inside a channel for different nanoparticles volume fraction φ, namely 0, 0.02 and 0.04. By increasing the concentration of nanoparticles on base fluid the thermal conductivity increases so the heat transfer enhanced, furthermore the thermal boundary layer decreases to improve the heat transfer .

4.2 Effect of magnetic field inclination angle γ on average Nusselt number Nu_av at different Hartmann number:

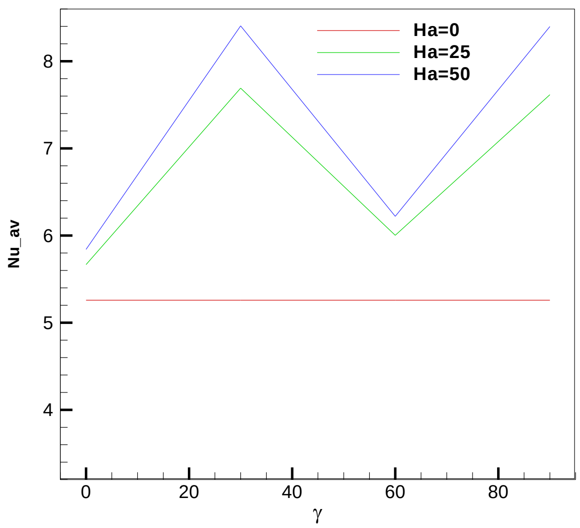


Figure 5: Average Nusselt number variation with the magnetic field inclination angle γ at different Hartmann numbers Ha

Figure 5 presents the variation of average Nusselt number with magnetic field inclination angle γ at different Hartmann number Ha. Figure shows that in absence of magnetic field makes average Nusselt number fixed at value 5.2 for all inclination angle: However by increasing the magnetic field inclination the average Nusselt number take the maximum value equal to 8.4 at γ=90 when the magnetic field was perpendicular to the flow. These behaviors are due to the fact that the inclination of the magnetic field gives different effects of the Hartmann number.

4.3 Effect of magnetic field inclination angle γ on average Nusselt number Nu_av at different Reynolds number:

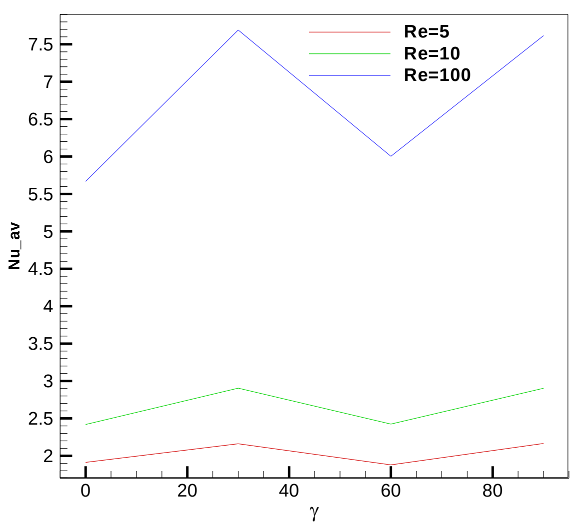


Figure 6: Average Nusselt number variation with the magnetic field inclination angle γ at different Reynolds numbers Re

Figure 6 illustrate the variation of average Nusselt number with magnetic field inclination angle for different Reynolds number. It is observed that at γ=90 average Nusselt number takes the maximum value 8.4 when the magnetic field was perpendicular to the flow and assure good contact with the heated wall witch improve the heat transfer.

4. 4 Effect of magnetic field inclination angle γ on average Nusselt number Nu_av at different nanoparticles concentration φ:

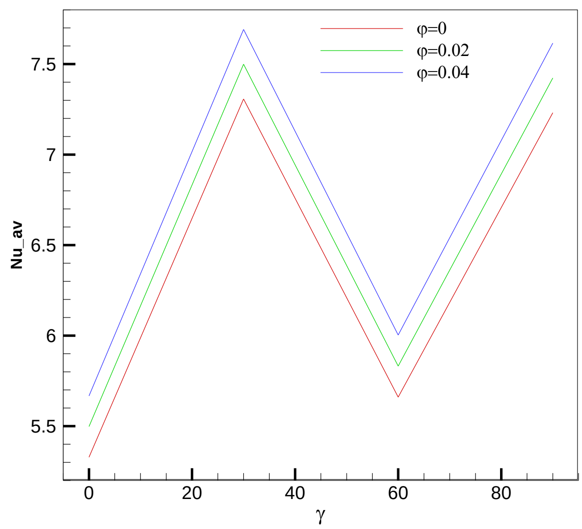


Figure 7: Average Nusselt number variation with the magnetic field inclination angle γ at different nanoparticles volume fraction φ

Figure 7 presents the distribution of average Nusselt number for different magnetic field inclination angle at different nanoparticles volume fraction. It is noted that the increase of nanoparticles concentration in a perpendicular magnetic field to the flow assure a good contact with hot wall to improve the heat transfer. This is due to the conductivity of nanoparticles.

6. CONCLUSIONS

In this work, numerical study of heat transfer enhancement and flow characteristics in channel including a magnetic field is studied.

The following results can be drawn:

- As increases the Hartmann number the average Nusselt number decreases, that is due to the presence of the Lorentz force.

- As Reynolds number increases the average Nusselt number increases too and the heat transfer enhanced.
- As γ increases the average Nusselt number increases too until the maximum value equal to 8.4 at at γ=90°.
- As nanoparticles volume fraction increases the average Nusselt number increases too due to conductivity of the nanoparticles .

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