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Research Article

The Impact of the Weak Magnetic Field on Hydromagnetic Nanofluid Flow Via Divergent and Convergent Channels

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Abstract

This paper has studied the effect of a low-intensity of magnetism acting on hydromagnetics of nanoparticles (Silver-water) via divergent-convergent channels. The study aimed at determining the effect of Hartmann and Reynolds numbers, the distribution of energy in the system, and the volume fraction of nanofluid particles on the movement of nanofluid particles, the distribution of temperature, and the distribution of concentration of nanofluid particles. The governing equations were transformed to a linear system of the differential equations and numerical solutions were found using the collocation technique and MATLAB was used to generate the results. It is discovered, varying the Reynolds values decreases the distribution of temperature for divergent medium. Variation in Reynolds values augments the distribution of temperature for the shrinking walls. The observation shows that increasing Hartmann values reduces the velocity profile in both channels which are diverging – converging channels. This is because Lorentz intensity is generated by the magnetism that alters the movement of nanofluid flow hence reduction in the velocity distribution. The concentration of nanofluid reduces in both channels when the distribution of energy in the system is augmented. The distribution of temperature increases in both channels when the energy in the system is augmented. Variation in the distribution of energy facilitates the transferring of heat to nanoparticles hence the temperature profile of nanofluid is increased. The distribution of the velocity is constant when varying the energy intensity. The heat generation resulted in a variation of temperature and had minimum impact on the movement of the nanoparticles for both channels. The concentration of nanofluid is increased in the divergent channel when Reynolds values are increased. The reduction occurs in the concentration of nanofluid when Reynolds values are increased. As the distance between molecules becomes wider due to augmenting the energy, this results in a reduction of concentration distribution of the nanofluid in both channels. These research findings are applied in medical sciences, engineering, geophysics, and astrophysics.

Keywords

Weak Magnetic Field, Reynolds Number, MHD Nanofluid, Divergent, and Convergent Channels

1. Introduction

Magnetohydrodynamics finds application in different fields. Astrophysics is one of the interesting areas of applications. The engineers use Magnetohydrodynamics principles for designing flow meters, pumps, and exchanging of heat as well as for solving propulsion of space vehicles, setting up electronic pieces of equipment for communication, information technological pieces of equipment for security purposes such as radars, fixing confinement schemes for con-

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trolled fusion, liquid metal cooling of nuclear reactors, plasma. Magnetohydrodynamics is utilized to design alternating current and direct current generators. Hydromagnetics is used to produce electrical energy extraction that is of great assistance in power convention. The combination of nanotechnology and biotechnological components has applications in pharmaceutical, agriculture, and biological sensors. Nanoparticles of Magnetohydrodynamics of incompressible viscous flow through diverging-converging channels are important in developing some mathematical and biological models and are applied in designing engineering schemes, space engineering, and materials that are chemically utilized in engineering.

Nanomaterials are very useful in industries, healthcare, and cosmetics for environmental preservation and purification of air.

Michael [1] was the first researcher to introduce the MHD. He had an experiment where the glass tubes containing Mercury were put under the influence of magnetism and he discovered that the current generated in the tube due to the effect of Mercury was interacting with the magnetic field. He observed that the generated current and magnetic force interacted and generated Lorentz intensity which altered the movement of the fluid flow.

Ritchie [2] conducted a study on a situation in which electromagnetism was considered. The magnetic and electric strengths were found to be perpendicular and the movement of the fluid flows for both was also perpendicular.

Hartmann et al [3] published a paper in which they investigated MHD flow taking into account two parallel nonconducting walls and considering the magnetic field normal to the wall. It was discovered that changing magnetic forces give some changes in the movement of the fluid flow.

Mishra [4] investigated MHD Nanoparticles and considered transferring of heat for silver-water in diverging-converging channels. It was discovered that the Eckert number gives an increment in the boundary thickness. The reduction is observed in the momentum boundary thickness when the porous parameter is augmented in the diverging-converging media.

Tesfaye et al [5] did an investigation on mass and temperature differences in the unsteady flow of Williamson Nanofluid taking into consideration the theory of boundary layer. They discovered that the concentration, temperature, and velocity boundary thickness are decreased when the stretching sheet surface is far away. Variations in the Williamson values slow the movement of the fluid flow and give a significant increment in the temperature and concentration of the surface. The variation in the magnetic field and thermal values gives an increase in mass transfer and changes in temperature differences in the boundary layer.

Jafari et al [6] researched MHD Nanofluid flow and found that the blood carries the high blood temperature, the density of the blood flow, the blood flow velocity, the artery radius, and the difference of temperature that surrounds the artery during circulation.

Shira et al [7] researched hydromagnetics of the blood flow and accounted for heat transfer and human breast tumor oxygen transport exposed to irradiation laser and they discovered that the high temperature radioactive in blood vessels and the impact of radiation in the blood are influential to bio-medical experts for treating hyperthermia. The electromagnetic radiation is utilized to overheat cancerous tissues.

Felicien Habiyaremye et al. [8]. Researched MHD incompressible fluid flow of electrically conducting viscous flow and the plates were vertically placed under the influence of magnetism. Reducing the negative values of Hartmann brings an increment in the movement of the flow. Variation in Hartmann values reduces movement of fluid flow. The laminar and turbulent fluid flows are determined by how small and big the inertial forces are. It was discovered that variation in the inertial forces augments the movement of the fluid flow and reducing the inertial forces reduces the velocity profile of the fluid flow, this is because the Reynolds number is a ratio of inertial force to viscous force..

Jeffery et al [9] investigated the steady motion of viscous flow in two dimensions via diverging–converging media. Makinde [10] did a study on two-dimensional fluid flow in diverging asymmetrical medium.

Makinde [11] investigated the laminar flow using cylindrical channels and stretching walls and the perturbation series was taken into consideration.

Felicien Habiyaremye et al [12] investigated the MHD fluid flow of nanoparticles via diverging-converging channels under mass and heat transfer. It was found that the volume fraction of nanofluid particles reduces velocity distribution for diverging channels. Variation in the volume fraction of nanoparticles augments the movement of nanofluid. Variation in the volume fraction of nanofluid particles for both divergent and convergent media reduces the distribution of temperature. Augmenting the volume fraction of nanofluid particles leads to an increment in the distribution of concentration of nanofluid for both media.

Makinde [13] investigated the impact of strong intensity of magnetism on hydromagnetic fluid flow for diverging and converging media. The governing equations were transformed into linear systems of differential equations and numerical solutions were obtained using perturbation technique. He found that velocity distribution far away reduces as the Reynolds magnetic values vary. Increasing Reynolds magnetic values results in reversing the flow.

Edward Richard Onyango et al [14] did a study on mass and temperature differences of the hydromagnetics of Jeffery-Hamel flow taking into account the inclined magnetic field. It was found that by increasing some dimensionless parameters, velocity increases, also the injection values are changed.

Virginia Kitetu et al [15] investigated the MHD nanofluid flow considering the suction stretching surface. They found that variation in the volume fraction of nanoparticles decreases velocity distribution while augmenting the volume fraction of nanoparticles increases the temperature distribution of nanofluid. They also discovered that there is an augment in the energy distribution due to the low movement of molecules that increases the heat in the nanoparticles. They found that variation in the volume fraction of nanoparticles reduces the concentration distribution of nanofluid.

Felicien Habiyaremye et al [16] conducted research on the influence of strong intensity of magnetism on the Magnetohydrodynamic flow of nanoparticles via divergent and convergent channels taking into consideration mass transfer and heat transfer. They discovered that variation in the Schmidt values gives an increment of the velocity distribution of nanofluid. It was observed that augmenting the Schmidt values gives a decrease in the distribution of temperature at stretching walls and also gives an increment in the convergent channel. Variation in the Schmidt values gives a rise in the concentration distribution. It was also observed that variation in the Schmidt values gives a rise in the distribution of the magnetic field of the nanoparticles for stretching walls and a reduction is observed for the case of shrinking walls. Augmenting the volume fraction of nanoparticles gives a rise in the distribution of the magnetic field. Variation in the magnetic strength values gives a rise in the distribution of the magnetic field of the nanofluid.

These research findings are applied in medical sciences, engineering, geophysics, and astrophysics.

MHD flows of nanoparticles have attracted many researchers in recent years and it is observed that there is still a need for more investigations in this area. The researcher has done an investigation on the MHD flow of nanoparticles through divergent and convergent media under the influence of weak magnetic strength.

2. The Effect of Weak Magnetic Field on MHD Nanofluid Flow

2.1. Mathematical Formulation

In this paper, the flow is considered two-dimensional, steady and the movement of fluid is given by

$$\vec{V} = \vec{V}(r, \theta) \tag{1}$$

In this paper, the assumptions are taken into account, the flow assumes incompressibility, two-dimensional, and steady. The induced magnetic field is constant. It does not vary with fluid flow variables. The tangential velocity is constant. From Figure 1, the walls of the channels are stationary, at the walls, there is no variation in the temperature and concentration at the walls. At the centre of a medium, the distribution of temperature and the concentration of the nanoparticles reach highest point and the velocity is maximum.

The governing equations of the nanofluid flow in the cylindrical coordinates are as follows: the continuity equation, equations of motion, equation of energy, and equation of concentration. These equations are illustrated

$$\rho_{nf}\left[\frac{1}{r}\frac{\partial}{\partial r}(rV_r)+\frac{1}{r}\frac{\partial}{\partial \theta}(V_\theta)+\frac{\partial}{\partial r}(V_z)\right]=0 \tag{2}$$

$$V_r\frac{\partial V_r}{\partial r}+\frac{V_\theta}{r}\frac{\partial V_r}{\partial \theta}+V_z\frac{\partial V_r}{\partial z}-\frac{V_\theta}{r}=-\frac{1}{\rho_{nf}}\frac{\partial P}{\partial r}+\frac{\mu_{nf}}{\rho_{nf}}\left[\frac{\partial^2 V_r}{\partial r^2}-\frac{1}{r^3}\frac{\partial V_r}{\partial r}+\frac{1}{r^2}\frac{\partial^2 V_r}{\partial \theta^2}+\frac{\partial^2 V_r}{\partial z^2}-\frac{V_r}{r^2}-\frac{2}{r^2}\frac{\partial V_\theta}{\partial r}\right]+\frac{1}{\rho_{nf}}\vec{F}_r \tag{3}$$

$$V_r\frac{\partial V_\theta}{\partial r}+\frac{V_\theta}{r}\frac{\partial V_\theta}{\partial \theta}+V_z\frac{\partial V_\theta}{\partial z}-\frac{V_\theta}{r}=-\frac{1}{\rho_{nf}}\frac{1}{r}\frac{\partial P}{\partial \theta}+\frac{\mu_{nf}}{\rho_{nf}}\left[\frac{\partial^2 V_\theta}{\partial r^2}-\frac{1}{r^3}\frac{\partial V_\theta}{\partial r}+\frac{1}{r^2}\frac{\partial^2 V_\theta}{\partial \theta^2}+\frac{\partial^2 V_\theta}{\partial z^2}-\frac{V_r}{r^2}+\frac{2}{r^2}\frac{\partial V_r}{\partial \theta}\right]+\frac{1}{\rho_{nf}}\vec{F}_\theta \tag{4}$$

$$V_r\frac{\partial T}{\partial r}+\frac{V_\theta}{r}\frac{\partial T}{\partial \theta}+V_z\frac{\partial T}{\partial z}=-\frac{K_{nf}}{(\rho C_P)_{nf}}\left[\frac{\partial^2 T}{\partial r^2}-\frac{1}{r^3}\frac{\partial T}{\partial r}+\frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2}+\frac{\partial^2 T}{\partial z^2}\right]+\frac{K_T}{\rho C_P}\left[\frac{\partial^2 C}{\partial r^2}-\frac{1}{r^3}\frac{\partial C}{\partial r}+\frac{1}{r^2}\frac{\partial^2 C}{\partial \theta^2}+\frac{\partial^2 C}{\partial z^2}\right]+\phi+\frac{1}{(\rho C_P)_{nf}}\left[\frac{W_0}{r^2}+\vec{J}\times\vec{B}\right] \tag{5}$$

$$V_r\frac{\partial C}{\partial r}+V_\theta\frac{\partial C}{\partial \theta}+V_z\frac{\partial C}{\partial z}=D_B\left[\frac{\partial^2 C}{\partial r^2}-\frac{1}{r^3}\frac{\partial C}{\partial r}+\frac{1}{r^2}\frac{\partial^2 C}{\partial \theta^2}+\frac{\partial^2 C}{\partial z^2}\right]+D_T\left[\frac{\partial^2 T}{\partial r^2}-\frac{1}{r^3}\frac{\partial T}{\partial r}+\frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2}+\frac{\partial^2 T}{\partial z^2}\right]+N\nabla C \tag{6}$$

2.2. Thermophysical Characteristics

Haroun et al [17] did a study on nanoparticles and they discovered that Nanofluids enhance effectiveness of transferring heat of fluids. Nanofluids' Thermophysical properties are critical for showing the temperature differences. Characteristics of Nanofluids (silver-water) are shown in Table 1.

This study considers the hydromagnetic Nanofluid flow, where θ is the angle of the channel that is found between the walls. The β represents the angle of the upper wall and $-\beta$ stands for the angle at the lower wall of medium. The boundary conditions that are used for current research for the current study

$$V_r = 0, V_\theta = b_0, T = T_w, C = C_w \text{ at } \theta = \pm\beta$$

$$V_r = P, V_\theta = 0, T = T_b, C = C_b \text{ at } \theta = 0$$

T_w stands for the temperature at the wall T_b represents free stream temperature, P stands for free stream velocity, C_w represents the concentration at lower medium and C_b stands for concentration at upper medium.

2.3. Nanofluid' Viscosity and Thermal Conductivity of Nanoparticles

Maxwell [18] discovered a model which shows effectiveness of thermal conductivity which is shown below. Einstein [19] presented the effectiveness of spherical solid suspension. Brinkman [20] showed a viscosity correlation equation of nanoparticles. Park et al [21] discovered the specific heat at a constant temperature. Xuan et al [22] presented the nanoparticle and distribution of energy considering pressure as constant.

$$\frac{K_{nf}}{K_f} = \frac{K_s+2K_f+2\phi(K_f-K_s)}{K_s+2K_f+2\phi(K_s-K_f)} \tag{7}$$

$$\frac{\mu_{nf}}{\mu_f} = \frac{1}{(1-\phi)^{2.5}} \tag{8}$$

$$\rho_{nf} = (1-\phi)\rho_s + \phi\rho_s \tag{9}$$

$$(\rho C_p)_{nf} = (1-\phi)(\rho C_P)_f + \phi(\rho C_P)_s \tag{10}$$

2.4. Transformation of Governing Equations

2.4.1. Transformation Using Similarity Relation

The governing equations are transformed using similarity relation, that is the partial differential equations (2), (3), (4),(5), and (6) are reduced to the linear system of differential equations. Nanofluids movement is transformed using the following relations

$$V_r(r,\theta) = \frac{Pf(\eta)}{r} \tag{11}$$

$$V_\theta(r,\theta) = \frac{Pg(\eta)}{r} \tag{12}$$

Temperature and concentration are transformed using the following relations

$$\theta(\eta) = \frac{T-T_b}{T_w-T_b} \tag{13}$$

$$\phi(\eta) = \frac{C-C_b}{C_w-C_b} \tag{14}$$

Where

$$\eta = \frac{\theta}{\beta} \tag{15}$$

2.4.2. Conversion of Governing Equations

The transformation of the equations that govern the nanofluid is done using the relations (11) to (14).

The continuity equation is satisfied.

$$\rho_{nf}\left[\frac{1}{r}\frac{\partial}{\partial r}(rV_r)\right] = \rho_{nf}\left[-\frac{P}{r^2}f + \frac{Q}{r^2}f\right] = 0 \tag{16}$$

Using the transformation relations shown above, the movement of the Nanofluid flow, the temperature and concentration become

$$f''' = -\frac{2\beta^2}{r}ReK_1(1-\phi)^{2.5}v_f ff' - \beta\frac{b_0}{P}Re(\beta f - f'') - 5\beta^2 f' - \beta^3 f + \frac{2\beta^3}{r}f - \beta^3 b_0 - H_a\sqrt{\frac{\sigma_{nf}}{\mu_{nf}}}\frac{P\beta^2}{r}\left\{\omega f' - f\omega' + \frac{3\beta}{r}\omega f\right\} + (H_a)^2\frac{\beta^2}{r^2}f' + \frac{\sigma_{nf}}{\mu_{nf}}2Pb_0\beta^3\omega^2 \tag{17}$$

$$\theta'' = \beta\frac{K_2}{K_3}b_0P_r\theta' - D_f\phi'' - E_cP_r\left\{4\beta^2f^2 + \frac{r^2}{P^2}\beta^2(b_0)^2 - 2\frac{r^2}{P}b_0\beta f' + f'^2\right\} - r^2\beta^2E_c\lambda P_r\theta + \frac{\beta^2}{rP}(1-\phi)^{2.5}\mu_f(H_a)^2E_cP_rf - \frac{\beta^2}{P}(1-\phi)^{2.5}\mu_f\sqrt{\frac{\sigma_{nf}}{\mu_{nf}}}H_aE_cf\omega \tag{18}$$

$$\phi'' = P\beta rK_1(1-\phi)^{-2.5}b_0S_c\phi' - S_cS_r\theta'' - \frac{RS_cRe\beta}{P}\phi' \tag{19}$$

Where $K_1 = \left[\phi\left\{\frac{\rho_s}{\rho_f}\right\} + (1-\phi)\right]$, $K_2 = \left[\phi\left\{\frac{(\rho C_P)_s}{(\rho C_P)_f}\right\} + (1-\phi)\right]$, $K_3 = \frac{K_s+2K_f+2\phi(K_f-K_s)}{K_s+2K_f+2\phi(K_s-K_f)}$,
$K_4 = \left[\phi\left\{\frac{\sigma_s}{\sigma_f}\right\} + (1-\phi)\right]$, Reynolds number is given by $R_e = \frac{rP}{v}$, The Hartmann number is defined by $(H_a)^2 = \frac{\sigma_{nf}}{\mu_{nf}}r^2(H_0)^2$, Prandtl number is defined by $P_r = \frac{\mu C_P}{K}$, the heat generation parameter is given by $\lambda = \frac{W_0(T_w-T_\infty)}{P^2}$.

Equations (17), (18), (19) are of higher order, and reduction is done to achieve a linear system of differential equations.

$$y_1 = f, y_2 = f', y_3 = f'', y_4 = \theta, y_5 = \theta', y_6 = \phi, y_7 = \phi' \tag{20}$$

From equation (20) we get

$$y'_1 = y_2 \tag{21}$$

$$y'_2 = y_3 \tag{22}$$

$$y'_3 = f''' = -\frac{2\beta^2}{r}ReK_1(1-\phi)^{2.5}\nu_f ff' - \beta\frac{b_0}{P}Re(\beta f - f'') - 5\beta^2 f' - \beta^3 f + \frac{2\beta^3}{r}f - \beta^3 b_0 - H_a\sqrt{\frac{\sigma_{nf}}{\mu_{nf}}}\frac{P\beta^2}{r}\left\{\omega f' - f\omega' + \frac{3\beta}{r}\omega f\right\} + (H_a)^2\frac{\beta^2}{r^2}f' + \frac{\sigma_{nf}}{\mu_{nf}}2Pb_0\beta^3\omega^2 : \mathrm{N} \tag{23}$$

$$y'_4 = y_5 \tag{24}$$

$$y'_5 = \theta'' = \beta\frac{K_2}{K_3}b_0P_r\theta' - D_f\phi'' - E_cP_r\left\{4\beta^2 f^2 + \frac{r^2}{P^2}\beta^2(b_0)^2 - 2\frac{r^2}{P}b_0\beta f' + f'^2\right\}$$

$$- r^2\beta^2E_c\lambda P_r\theta + \frac{\beta^2}{rP}(1-\phi)^{2.5}\mu_f(H_a)^2E_cP_rf - \frac{\beta^2}{P}(1-\phi)^{2.5}\mu_f\sqrt{\frac{\sigma_{nf}}{\mu_{nf}}}H_aE_cf\omega : \mathrm{M} \tag{25}$$

$$y'_6 = y_7 \tag{26}$$

$$y'_7 = \phi'' = P\beta rK_1(1-\phi)^{-2.5}b_0S_c\phi' - S_cS_r\theta'' - \frac{RS_cR_e\beta}{P}\phi' : \mathrm{Q} \tag{27}$$

The equations (21) to (26) give the following systems of linear equations

$$y' = F(\eta, y) \tag{28}$$

$$y = \begin{pmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \\ y_7 \end{pmatrix} \quad F = \begin{pmatrix} y_2 \\ y_3 \\ \mathrm{N} \\ y_5 \\ \mathrm{M} \\ y_7 \\ \mathrm{Q} \end{pmatrix} \tag{29}$$

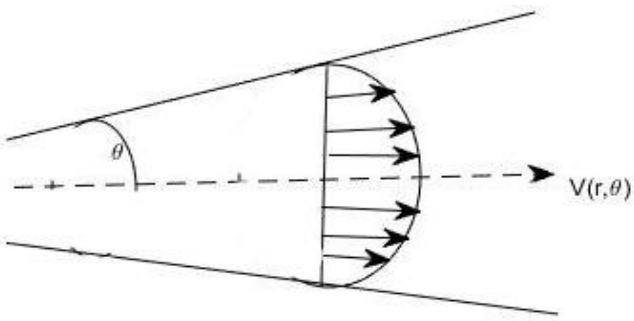

Figure 1. *Flow Diagram of Impact of the Weak Magnetic Field on Magnetohydrodynamic Nanofluid Flow through Diverging- Converging Channels.*

3. Results and Discussions

Table 1. *Thermophysical Characteristics of Silver and Water.*

Nanoparticles	C_P	K	ρ	σ
Water	997.1	4179	0.613	0.06
Silver	10500	235	4291	6.3×10^7

Table 2. *Values of Physical Parameters.*

R_e	H_a	ψ	λ
15	0.00	0.2	0
20	0.05	0.5	2
25	0.07	0.7	5

The Magnetohydrodynamic nanofluid flows have attracted many researchers in recent years. A research has been done on MHD nanofluid flows via diverging and converging channels considering mass and heat transfer with variable magnetic fields. [12] Investigation of MHD flows of nanoparticles via divergent and convergent media under a strong magnetic field was done [16]. In their investigations, they insisted on the impact of variable magnetic field, mass, and heat transfer on MHD nanofluid flows.

In the current paper, we bring the newness of taking into consideration the weak magnetic field on the MHD flow of nanoparticles which was a gap to be filled and was not addressed in previous studies.

The results of parameter variations are presented (the effect of Hartmann and Reynolds numbers, the distribution of energy in the system, and the volume fraction of nanofluid particles on the movement of nanofluid particles, the distribution of temperature, and the distribution of concentration of nanofluid particles).

The value of Prandtl number becomes 6.2 because of the nanoparticle (water).

Table 2 gives physical values of different parameters.

In the results, solid lines represent divergent channels and dotted lines stand for convergent channels.

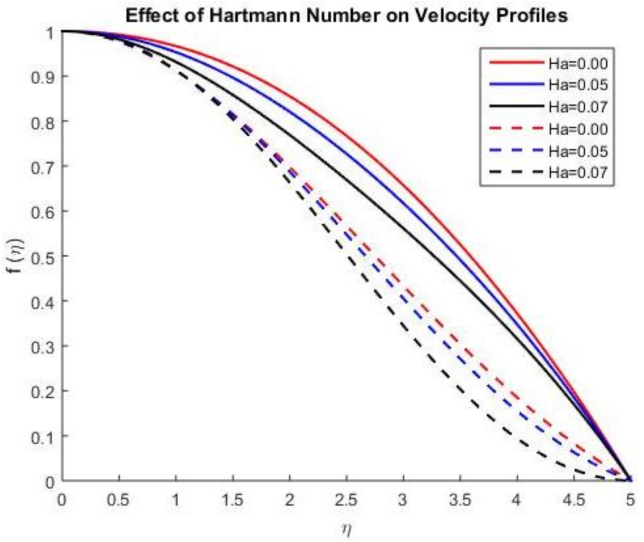

Figure 2*. Effect of Hartmann Number on Velocity Distribution in Divergent-Convergent Channels.*

From Figure 2. Variation in Hartmann values reduces the velocity profile in both channels which is diverging-converging channels. This is because the magnetic field produces Lorentz force which opposes the direction of the velocity of the nanofluid hence reduction in the velocity distribution.

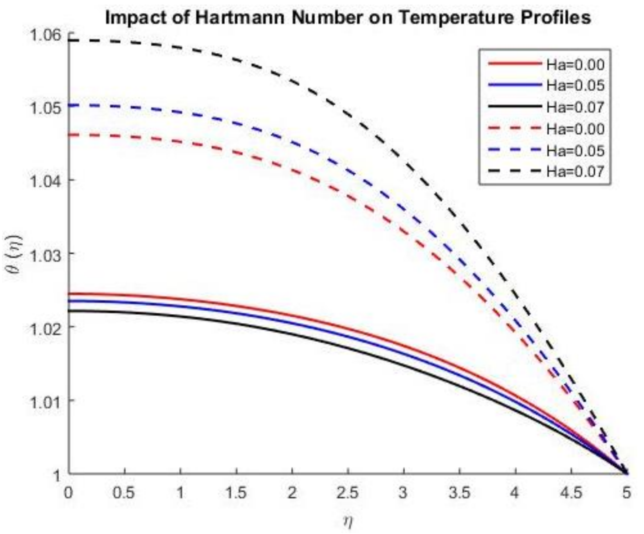

Figure 3*. Impact of Hartmann on Temperature Distribution in Divergent-Convergent Channels.*

From figure 3. Varying Hartmann values reduces the distribution of temperature in the diverging channel. This is because an augment in the Hartmann values augments the viscosity that thickens boundary layer hence reduction for the temperature distribution. Varying Hartmann values augments the distribution of temperature in the converging channel. This is because variation in Hartmann values gives a rise in the viscous forces which leads to an increase in the temperature distribution hence increased in the temperature profile in a diverging channel.

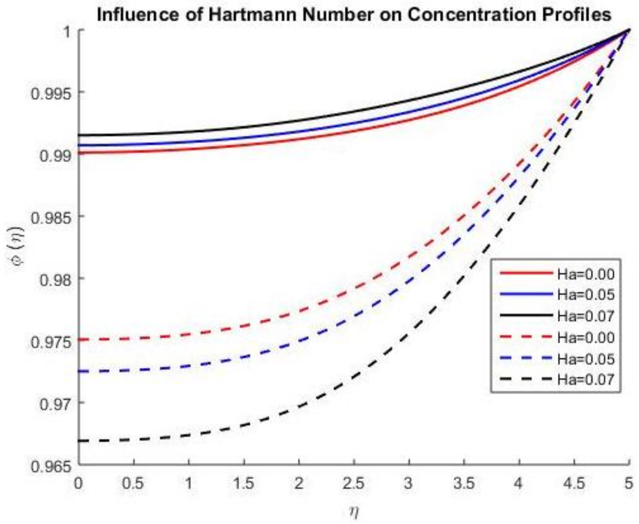

Figure 4*. Effect of Hartmann Number on Concentration Distribution in Divergent-Convergent Channels.*

From Figure 4. The increase in the Hartmann values augments the concentration of nanofluid in the diverging channel. The increase of the Hartmann values brings a reduction in the drag forces that gives an increment in the nanofluid concentration distribution. While augmenting the values of Hartmann in a converging channel reduces the concentration. The variation of the Hartmann values leads to a reduction in the concentration distribution. This is because the viscous forces are reduced hence a decrease in the concentration distribution of nanofluid.

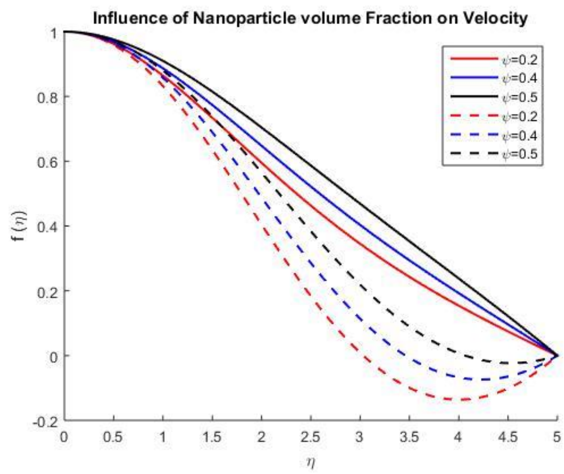

Figure 5*. Influence of Nanoparticle Volume Fraction on Velocity Distribution in Divergent-Convergent Channels..*

From Figure 5. Increasing the volume fraction of nanoparticles gives an increment in the concentration of the nanofluid for both channels. The temperature increases for both channels because the nanoparticles give rise to the distribution of energy in the boundary layer of the channel which increases the velocity distribution of the nanofluid.

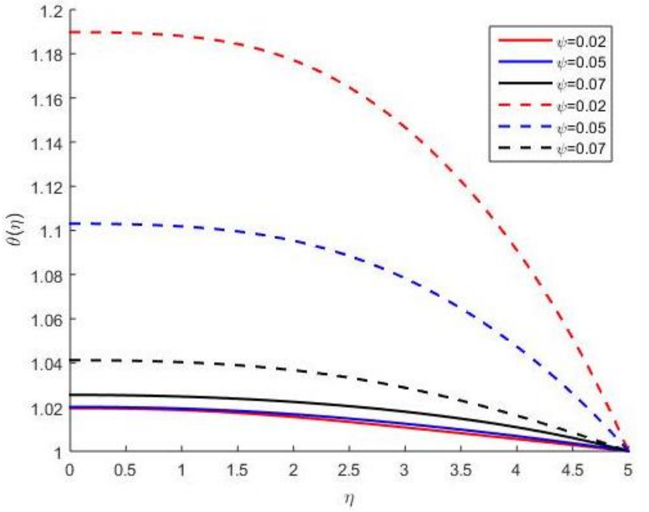

Figure 6. *Effect of Nanoparticle Volume Fraction on Temperature Profile in Divergent-Convergent Channels..*

From Figure 6. Augmenting the values of the volume fraction of nanoparticles increases temperature distribution for diverging medium. This is because the nanoparticles increase the energy distribution of the nanofluid hence increased temperature distribution in diverging medium. The reduction happens in the converging channel when the values of the nanoparticle of volume fraction is increased. The nanoparticles thicken the boundary layer hence decreasing the temperature distribution of the nanofluid.

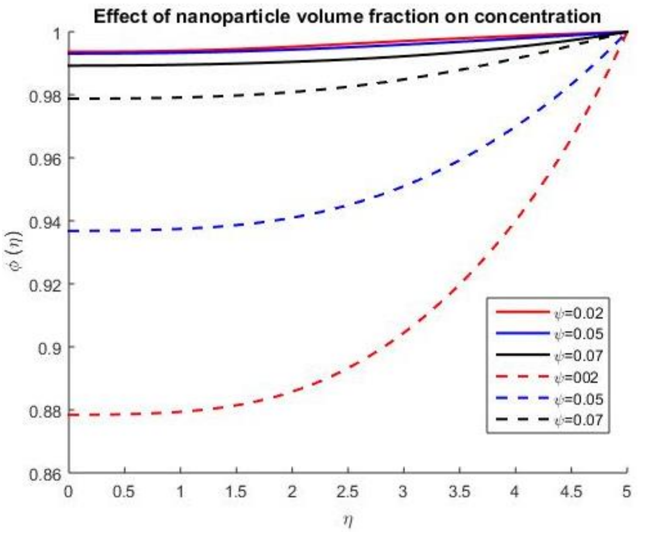

Figure 7. *Impact of Nanoparticle Volume Fraction on Concentration Profile in Divergent-Convergent Channels..*

From Figure 7. When the values of the nanoparticle of volume fraction is increased, the concentration of nanofluid is reduced in the divergent channel. The concentration distribution is augmented when the values of nanoparticle volume fraction is increased in convergent channel. The kinetic energy becomes low when the energy distribution and thickness of boundary layer reduce hence increased concentration profile of the nanofluid.

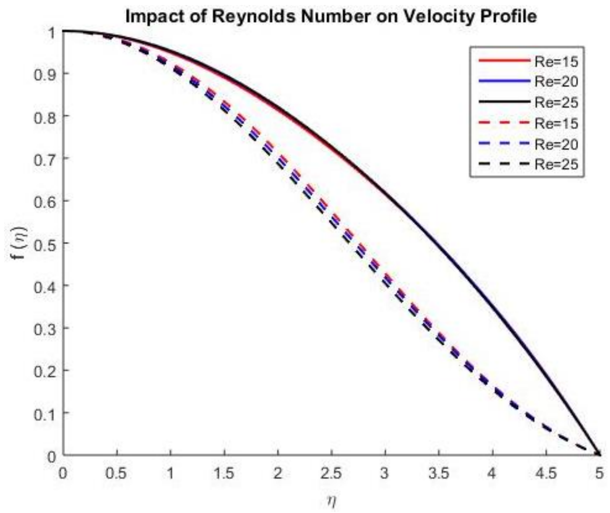

Figure 8. *Influence of Reynolds Number on Velocity Profile in Divergent-Convergent Channels..*

From Figure 8. Variation in the Reynolds values gives an increment in the nanofluid movement in diverging channel. The Reynolds number is the ratio of inertia forces to viscous forces. The higher the Reynolds number the higher the velocity. Increasing Reynolds values reduces the velocity profile in the converging channel. This is due to the thickening of the boundary layer in converging channel because of the increase of the inertia forces.

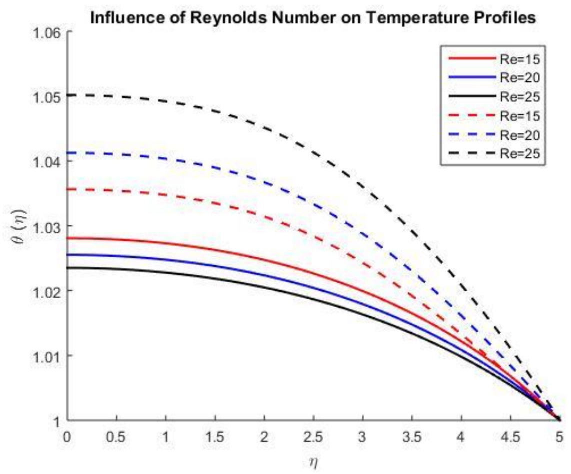

Figure 9. *Effect of Reynolds Number on Temperature Distribution in Divergent-Convergent Channels..*

From Figure 9. Variation in Reynolds values reduces temperature distribution. The viscosity and temperature are inversely related. Augmenting viscosity gives a reduction for the distribution of temperature. Augmenting the Reynolds values increases the temperature profile in convergent channel.

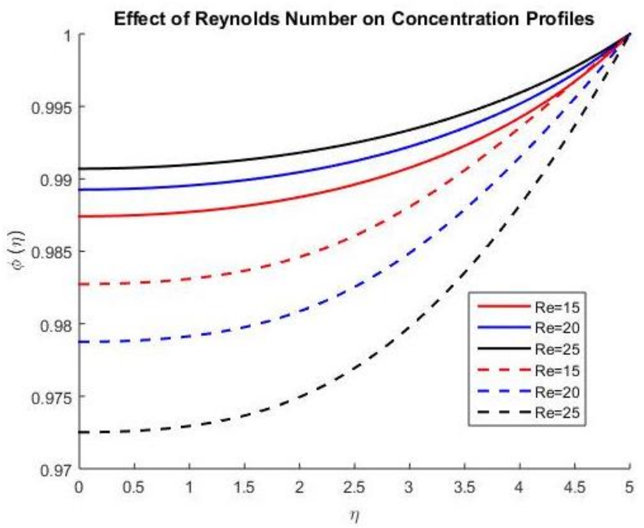

Figure 10. *Impact of Reynolds Number on Concentration distribution in Divergent-Convergent Channels.*

From Figure 10. The concentration of nanofluid is increased in the divergent channel when Reynolds values is increased. The reduction occurs in the concentration of nanofluid when Reynolds values are increased. As the distance between molecules become wider due to the distribution of energy, this gives a reduction of concentration distribution of the nanofluid in both channels.

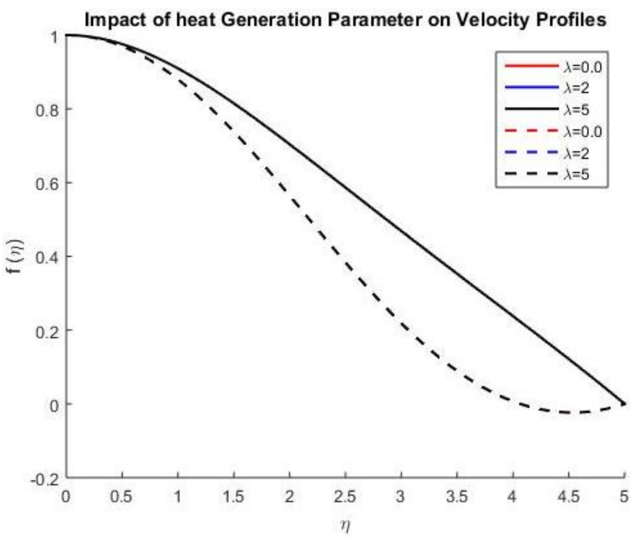

Figure 11. *Effect of Heat Generation Parameter on Velocity Distribution in Divergent –Convergent Channels.*

From Figure 11. The distribution of the velocity is constant when the distribution of energy is considered. The heat generation resulted from the variation in temperature and do not affect velocity distribution of the nanofluid in both channels.

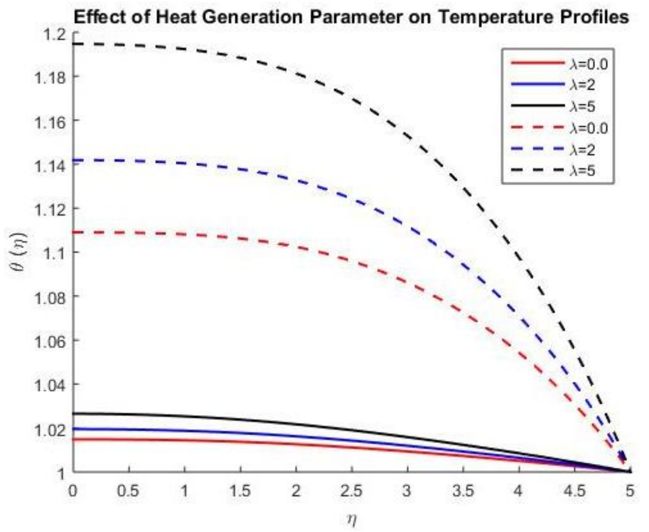

Figure 12. *Impact of Heat Generation Parameter on Temperature Distribution in Divergent-Convergent Channels..*

From Figure 12. The temperature increases in both channels when the distribution of energy is augmented. The variation in heat generation increases the transferring of heat to nanofluid hence the nanofluid temperature profile is increased.

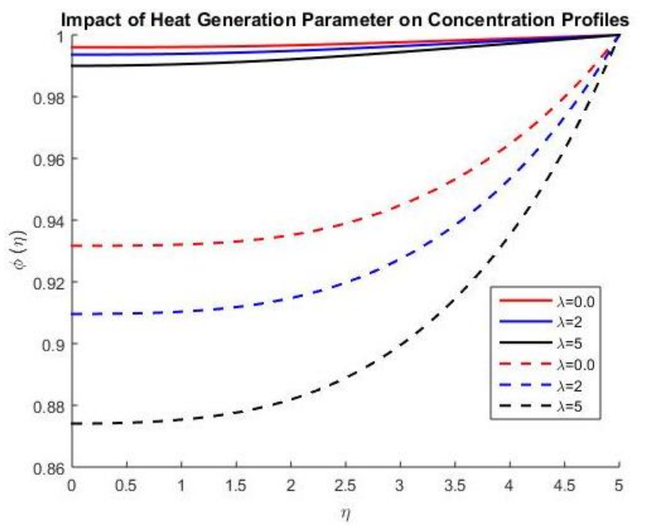

Figure 13. *Influence of Heat Generation Parameter on Concentration Distribution in Divergent-Convergent Channels.*

From Figure 13 Nanofluid concentration decreases in both channels when the distribution of energy is increased. Distance between Nanofluids substance become large due to the increment in the temperature which augments the energy. Hence reduced concentration distribution of the nanofluid.

4. Conclusion

From the results, the following observations were noted.

1. Variation in the Hartmann values reduces the velocity profile in both channels
2. Increasing the Hartmann values reduces the temperature profile in diverging channel.
3. Variation in the Hartmann values increases the temperature profile in converging channel.
4. The increase in the Hartmann values augments the concentration of nanofluid in the diverging channel.
5. Augmenting the values of Hartmann in converging channel reduces the concentration distribution of the nanofluid.
6. Increasing volume fraction of nanoparticles increases nanofluid' concentration in both channels.
7. Augmenting values of volume fraction of nanoparticles increases distribution of temperature in diverging channel.
8. The reduction happens in the converging channel when volume fraction of nanoparticles values are increased.
9. Increasing volume fraction of nanoparticles, then concentration of nanofluid is reduced in the divergent channel.
10. The concentration distribution is augmented when the values of volume fraction of nanoparticle is increased in convergent channel.
11. Augmenting Reynolds values increases nanofluid' velocity in diverging channel.
12. Augmenting Reynolds values reduces distribution of velocity for convergent medium. This is because boundary layer thickens in convergent medium due to the increase of the inertial forces.

5. Recommendations

Magnetohydrodynamics is wide area of research, we recommend that the researchers can carry out the following topics.

1. The effect of Nusselt number of Magnetohydrodynamic nanofluid through divergent-convergent channels.
2. MHD flow of nanoparticles in stretching surface with mass and heat transfer.
3. Effect of chemical reactions on Magnetohydrodynamic flow of nanoparticles via diverging-converging channels.

Abbreviations

λ: Heat Generation Parameter
ψ: Volume Fraction of Nanoparticles
Ag: Silver
B_0: Magnetic Field
D_m: Concentration Mass Diffusivity
D_f: Dufour Number
E_c: Eckert Number
Ha: Hartmann Number
K: Thermal Conductivity
K_{nf}: Nanofluid Thermal Conductivity
K_T: Thermal Diffusion Ratio
Re: Reynolds Number
S_c: Schmidt Number
MHD: Magnetohydrodynamics
PDEs: Partial Differential Equations
ODEs: Ordinary Differential Equations

Conflicts of Interest

The authors declare no conflict of interest.

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