Journal of Applied Mathematics & Bioinformatics, vol. 9, no. x, 2019, x-x
ISSN: 1792-6602(print), 1792-6939(online)
Scientific Press International Limited, 2019

Unsteady Fluid Flow Between Two Moving Parallel Porous Plates in Presence of Inclined Applied Magnetic Field

Idrissa KANE[1], Mathew KINYANJUI[2] and David THEURI[3]

Abstract

In this study, an unsteady fluid flow of a viscous, incompressible electrically conducting fluid between two moving parallel porous plates of infinite length in the x and z directions, subjected to a constant pressure gradient and a constant injection and suction, in presence of an inclined applied magnetic field whose lines are fixed relative to the moving plates, is investigated. The study is aimed to determine the profiles of velocity, temperature and the induced magnetic field, and the effects of various flow parameters, namely Magnetic parameter M, Reynold's number Re, Eckert number Ec, Prandtl number Pr, magnetic inclination α and injection parameter S_0 on the flow variables and the induced field.

Mathematics Subject Classification : xxxxx
Keywords: Magnetohydrodynamics, Porous Plates, Injection and Suction.

[1]Department of Mathematics, Pan African University of Basic Sciences, Technology and Innovation. e-mail: idrissakane18@gmail.com
[2]Department of Mathematics, Jomo Kenyatta University of Agriculture and Technology. e-mail: mathewkiny@jkuat.ac.ke
[3]Department of Mathematics, Jomo Kenyatta University of Agriculture and Technology. e-mail: dtheuri@jkuat.ac.ke

Article Info: *Received* : September 2, 2019. *Published online* : September ***, 2019

1 Introduction

MHD Couette flow is the flow of an electrically conducting fluid between two surfaces, one of which moves relatively to the other, in presence of a magnetic field. The configuration of Couette flow often takes the form of two parallel plates (called Planer-Couette flow) or the gap between two concentric cylinders (called Taylor-Couette flow). The equations describing MHD flow are a combination of continuity equation, Navier-stokes equations for fluids dynamics and Maxwell's equations for electromagnetism.
The MHD flow between porous plates studied has many important applications in areas such as the designing of cooling systems with liquid metals, geothermal reservoirs, in petroleum and mineral industries, in underground energy transport, MHD generators, pumps, flow meters, purification of crude oil, among many other areas [12].
Studies related to MHD flow between two parallel porous plates have been conducted on recent years by many other scientists and researchers.
[2] studied the unsteady magnetohydrodynamic Couette flow when the fluid flow is confined to porous boundaries with suction and injection considering two cases of interest, viz (i) impulsive movement of the lower plate and (ii) uniformly accelerated movement of the lower plate. They concluded that the suction exerted a retarding influence on the fluid velocity whereas injection has accelerating influence on the flow. [3] studied MHD flow between two parallel plates through porous medium with one in uniform motion and the other plate at rest and uniform suction at the stationary plate. They found that the axial velocity of the fluid decreases as density, time, and Hartmann number increases and that the transverse velocity of fluid increases as density, Hartmann number and suction increases. [4] analysed Unsteady MHD Couette flow between two infinite parallel porous plates in an inclined magnetic field with heat transfer and the lower plate considered porous. They concluded that magnetic field has significant effect on the flow. of an unsteady MHD Couette flow between two infinite parallel.[5] considered Steady MHD flow of viscous fluid between two parallel porous plates with heat transfer in an inclined magnetic field. They observed that fluid with high viscosity causes reversed flow and the applied magnetic force at different inclination controls this flow; also that the temperature distribution in fluid layers is directly linked to the viscosity.

[6] investigated Heat transfer between two parallel porous plates for Couette flow under pressure gradient and Hall current. They concluded that the Hall term gives rise to a velocity component w in the z-direction and affects the main velocity u in the x-direction and that the viscosity variation parameter has a marked effect on the velocity components u and w. They also found that porosity parameter has a marked effect on the velocity and temperature distributions and that by increasing Hartman number, the x-component of the velocity u and temperature θ will decrease, while the z-component of the velocity w will increase. [7] considered laminar viscous incompressible fluid between two infinite parallel plates when the upper plate is moving with constant velocity and the lower plate is held stationary under the influence of inclined magnetic field and concluded that the increase in magnetic field strength and magnetic inclination results into decreases in the velocity profiles. [8] considered magneto hydrodynamic flow between two parallel porous plates with injection and suction in the presence of a uniform transverse magnetic field with the magnetic field lines fixed relative to the moving plate with a constant pressure gradient and concluded that the magnetic field, pressure gradient, time and injection have an accelerating influence on the fluid flow with a constant pressure gradient in the direction of the flow on both cases of suction and injection while viscosity and suction exert a retarding influence. [9] analysed Hydromagnetic Fluid Flow between Parallel Plates where the upper plate is porous in Presence of Variable Transverse Magnetic Field. They found that: an increase in Suction parameter leads to a decrease in the velocity profile and an increase in the temperature profiles respectively; imposing transverse magnetic field decreases both velocity and temperature of the fluid; increasing Eckert number causes an increase in temperature profiles whereas increasing Prandtl number leads to a decrease in the temperature profiles. [10] investigated hydrodynamic radiating fluid flow past an infinite vertical porous plate in presence of chemical reaction and induced magnetic field and concluded that velocity decreases with increasing magnetic parameter, which is due to Lorenz force that opposes the fluid motion; velocity components are also reduced by the increased values of the permeability of the plate; but velocity increases with the increase of Grashof number. [10] also concluded that temperature increases as the Eckert number, magnetic strength, radiation and surface permeability increase; and that induced magnetic field was elevated near the plate

by increasing magnetic Prandtl number while this trend is reversed away from the plate. [11] studied the effect of injection/suction on the free convective flow through the porous medium bounded by two infinite vertical plates with chemical reaction. They concluded that Velocity decreases with increasing values of chemical reaction parameter, Hartmann number and Schmidt number while temperature decreases with increasing values of Prandtl number Pr. [12] studied Unsteady hydromagnetic flow between parallel plates both moving in presence of a constant pressure gradient. They concluded that the magnetic field, pressure gradient, time and injection have an accelerating influence on the fluid flow with a constant pressure gradient in the direction of the flow on both cases of suction and injection; also, that the injection and suction of fluid from either of the plates has a significant effect on the velocity profiles with injection leading to increased velocities and suction leading to decreased velocities of the fluid. Unsteady Stokes flow of dusty fluid between two parallel plates through porous medium in the presence of magnetic field was analysed by [13]. They concluded that the velocity of dust particle is higher than that velocity of the fluid for all the parameters of the problem; the velocity of the fluid and dust particle decreases as density and number of dust particles increase.

2 Mathematical Formulation

The problem concerns the flow of an electrically conducting fluid between two moving parallel porous plates assumed to be along $y = 0$ and $y = h$ of infinite length in x and z directions with a constant pressure gradient, suction and injection through the walls of the channel in presence of an inclined applied uniform magnetic field $\overrightarrow{B_0}$ taking into account the induced magnetic field. The applied magnetic field is inclined to the (x, y) plane at an angle α from x-axis. Initially (when time $t \leq 0$), the fluid and the porous plates of the channel are assumed to be at rest with the initial temperature T_0. When time $t > 0$, the two plates start moving with a constant velocity u_0 in the x-direction with a temperature T_p; a constant pressure gradient ∇p is imposed in the x-direction, and a constant suction from above and injection from below, with velocity v_0, are impulsively applied.

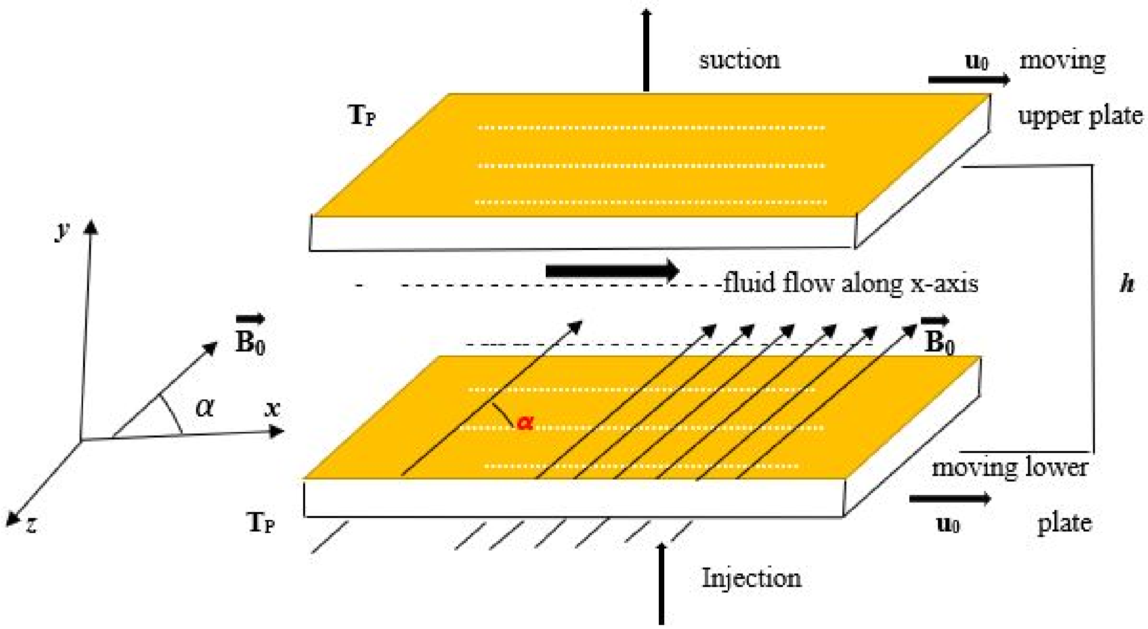

Figure 1: Flow Problem Configuration.

Since the plates are of infinite length in the x and z-directions, the physical quantities do not depend on x and z. The velocity of the fluid and the magnetic induction vector are given as:
$\overrightarrow{q} = (u, v_0, 0)$ $\quad \overrightarrow{B} = (B_0 \cos\alpha + b_x, B_0 \sin\alpha + b_y, 0) = (B_x, B_y, 0)$
where $\overrightarrow{b} = (b_x, b_y, 0)$ represents the induced magnetic field.
In order to describe and analyse the problem mathematically, the following assumptions are made:

1. The fluid flow is restricted to a laminar domain
2. The fluid is incompressible and Newtonian
3. Electrical and thermal conductivities, Dynamic viscosity are constant.
4. There is no chemical reaction
5. There is no applied external electric field.
6. The plates are non-conducting and uniformly porous.

Momentum equation:

$$\frac{\partial \overrightarrow{q}}{\partial t} + \left(\overrightarrow{q} \cdot \overrightarrow{\nabla}\right)\overrightarrow{q} = -\frac{1}{\rho}\overrightarrow{\nabla} P + \nu \nabla^2 \overrightarrow{q} + \frac{1}{\rho}\overrightarrow{F} \tag{1}$$

Where $F = J \times B$ is the Lorentz force
Equation (1) reduces to:

$$\frac{\partial u}{\partial t} + v_0 \frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \nu \frac{\partial^2 u}{\partial y^2} + \frac{1}{\rho}F_x \tag{2}$$

Where F_x is the $x - direction$ component of Lorentz force and is given by:

$$F_x = \sigma\Big[u\Big(B_0 \sin\alpha)^2 - v_0\Big(b_x + B_0\cos\alpha\Big)\Big(B_0 \sin\alpha\Big)\Big] \tag{3}$$

In this case where the magnetic field lines are fixed relative to the moving plates, from the model by [1], the velocity is considered as a relative velocity and reflects how fast the fluid is moving relative to the plates. The equation of motion hence becomes:

$$\frac{\partial u}{\partial t} + v_0 \frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \nu \frac{\partial^2 u}{\partial y^2} + \frac{\sigma}{\rho} B_0 \sin\alpha\Big[B_0 \sin\alpha\Big(u - u_0\Big) - v_0\Big(b_x + B_0 \cos\alpha\Big)\Big] \tag{4}$$

Energy equation:

$$\rho C_p \frac{DT}{Dt} = k\nabla^2 T + \mu\phi + \frac{J^2}{\sigma} \tag{5}$$

where $\frac{D}{Dt}$ is the material derivative.
The viscous dissipation function ϕ in three dimensions is expressed as:

$$\begin{aligned}\phi =& 2\Big[\Big(\frac{\partial u}{\partial x}\Big)^2 + \Big(\frac{\partial v}{\partial y}\Big)^2 + \Big(\frac{\partial w}{\partial z}\Big)^2\Big] + \Big[\Big(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\Big)^2 + \Big(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\Big)^2 + \Big(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\Big)^2\Big] \\ & - \frac{2}{3}\Big(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\Big)^2\end{aligned} \tag{6}$$

For the present analysis, the viscous dissipation reduces to:

$$\phi = \Big(\frac{\partial u}{\partial y}\Big)^2$$

The joule heating term becomes:

$$\frac{J^2}{\sigma} = \sigma\Big[uB_0 \sin\alpha - v_0\Big(b_x + B_0 \cos\alpha\Big)\Big]^2$$

Again, since the magnetic lines are fixed relative to the moving plates, the velocity is replaced by the relative velocity in the current density, thus the viscous dissipation term is finally written as:

$$\frac{J^2}{\sigma} = \sigma\Big[\Big(u - u_0\Big)B_0 \sin\alpha - v_0\Big(b_x + B_0 \cos\alpha\Big)\Big]^2$$

Substituting these in equation (5), yields:

$$\rho C_p\Big(\frac{\partial T}{\partial t}+v_0\frac{\partial T}{\partial y}\Big) = k\frac{\partial^2 T}{\partial y^2}+\mu\Big(\frac{\partial u}{\partial y}\Big)^2+\sigma\Big[\Big(u-u_0\Big)B_0 \sin\alpha-v_0\Big(b_x+B_0 \cos\alpha\Big)\Big]^2 \tag{7}$$

Induction equation

$$\frac{\partial \overrightarrow{B}}{\partial t} = \frac{1}{\sigma\mu_e}\nabla^2\overrightarrow{B} + \overrightarrow{\nabla} \times (\overrightarrow{q} \times \overrightarrow{B}) \tag{8}$$

where $\frac{1}{\sigma\mu_e}$ is the magnetic diffusivity of the fluid.
Using the information above and evaluating the terms in equation (8), it reduces to:

$$\frac{\partial b_x}{\partial t} + v_0\frac{\partial b_x}{\partial y} = \frac{1}{\sigma\mu_e}\frac{\partial^2 b_x}{\partial y^2} + B_0 \sin\alpha\frac{\partial u}{\partial y} \tag{9}$$

Initial and boundary conditions of this flow problem are as follows:

$$t = 0 : \begin{cases} u = 0 \\ T = T_0 \\ b_x = 0 \end{cases} \tag{10}$$

$$t > 0 : \begin{cases} u = u_0 \\ T = T_p \qquad \text{at } y = 0 \text{ and } y = h \\ b_x = 0 \end{cases} \tag{11}$$

Non-dimensionalization

The following non-dimensional transformations have been used to transform the governing equations into their non-dimensional forms:
$t^* = \frac{t\nu}{h^2}, \qquad y^* = \frac{y}{h}, \qquad u^* = \frac{uh}{\nu}, \qquad x^* = \frac{x}{h},$
$T^* = \frac{T-T_0}{T_p-T_0}, \qquad b_x^* = \frac{\sigma h^2 B_0}{\mu} b_x, \qquad p^* = \frac{h^2 p}{\rho\nu^2},$
Therefore it can be deduced that:
$t = \frac{t^* h^2}{\nu}, \quad y = y^* h, \quad x = x^* h, \quad u = \frac{u^*\nu}{h}$
$T = T^*(T_p - T_0) + T_0, \quad b_x = \frac{\mu}{\sigma h^2 B_0} b_x^*, \qquad p = \frac{\rho\nu^2 p^*}{h^2}$
Considering these, the equations (4), (7) and (9) become:

$$\frac{\partial u^*}{\partial t^*} + S_0 \frac{\partial u^*}{\partial y^*} = \beta + \frac{\partial^2 u^*}{\partial y^{*2}} + M \sin\alpha \left[\left(u^* - Re \right) \sin\alpha - S_0 \left(\frac{b_x^*}{M} + \cos\alpha \right) \right] \quad (12)$$

$$\frac{\partial T^*}{\partial t^*} + S_0 \frac{\partial T^*}{\partial y^*} = \frac{1}{Pr} \frac{\partial^2 T^*}{\partial y^{*2}} + \frac{Ec}{Re^2} \left(\frac{\partial u^*}{\partial y^*} \right)^2 + \frac{M Ec}{Re^2} \left[\left(u^* - Re \right) \sin\alpha - S_0 \left(\frac{b_x^*}{M} + \cos\alpha \right) \right]^2 \quad (13)$$

$$\frac{\partial b_x^*}{\partial t^*} + S_0 \frac{\partial b_x^*}{\partial y^*} = \frac{1}{Pr_M} \frac{\partial^2 b_x^*}{\partial y^{*2}} + M \sin\alpha \frac{\partial u^*}{\partial y^*} \quad (14)$$

Equations (12), (13), and (14) are respectively the equations of Momentum, Energy and Induction in dimensionless form.
The initial and boundary conditions in dimensionless form become:

$$t^* = 0 : \begin{cases} u^* = 0 \\ T^* = 0 \\ b_x^* = 0 \end{cases} \quad (15)$$

$$t^* > 0 : \begin{cases} u^* = Re \\ T^* = 1 \qquad \text{at } y^* = 0 \text{ and } y^* = 1 \\ b_x^* = 0 \end{cases} \quad (16)$$

3 Results and Discussion

The Crank-Nicholson method has been used to obtain the numerical scheme for solving numerically the governing equations of the present flow problem. The numerical results have been obtained by implementing the corresponding Finite difference equations in a computer program.
The trends obtained by varying various fluid flow parameters, namely Magnetic parameter M, Reynold's number Re, Injection parameter S_0, Prandtl number Pr, Eckert number Ec, Magnetic Prandtl number Pr_M and magnetic inclination α are discussed and explained.

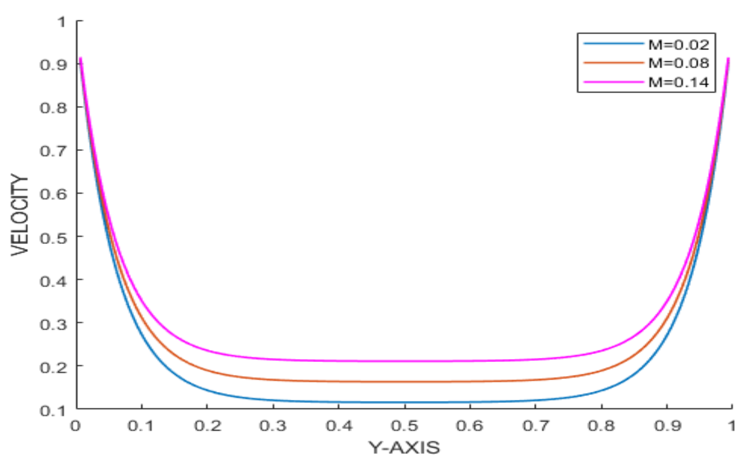

Figure 2: Effects of Magnetic parameter on velocity profiles

From Figure (2), it is observed that increasing Magnetic parameter (M) leads to an increase in the velocity profiles. The Magnetic parameter is the ratio of the magnetic forces to viscous forces. The magnetic field lines are applied in the direction of the flow, inclined at an angle α to the plates. Following the motion of the electrically conducting fluid through those lines, the Lorentz force is generated. Since the magnetic field lines, in this case, are fixed relative to the moving plates, the velocity of the fluid in the Lorentz force is replaced by the relative velocity. The $x - direction$ component of Lorentz force then becomes positive, so, Lorentz force facilitates the fluid motion. An increase in the magnetic parameter, meaning an increase in the magnetic forces, leads to an increase in Lorentz force and therefore an increase in the fluid velocity.

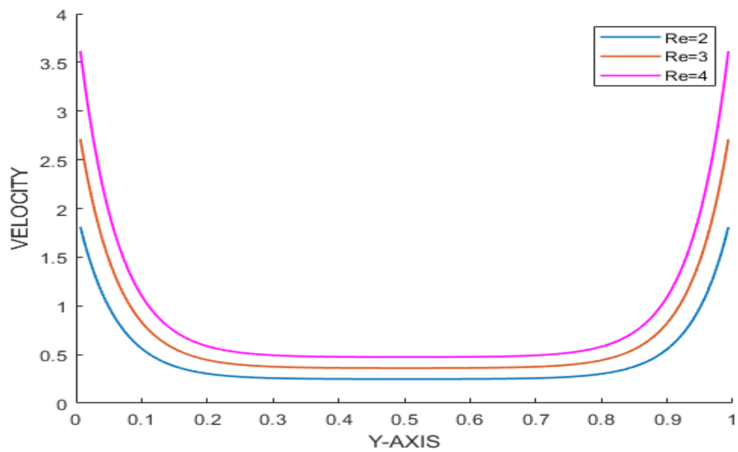

Figure 3: Effects of Reynold's number on velocity profiles

From Figure (3), the fluid velocity increases with increasing Reynold's number. Reynold's number is the ratio of the inertia forces to viscous forces, thus increasing Reynold's number implies a decrease in the viscous forces which oppose the motion of the fluid. Therefore an increase in Reynold's number leads to an increase in the velocity profiles.

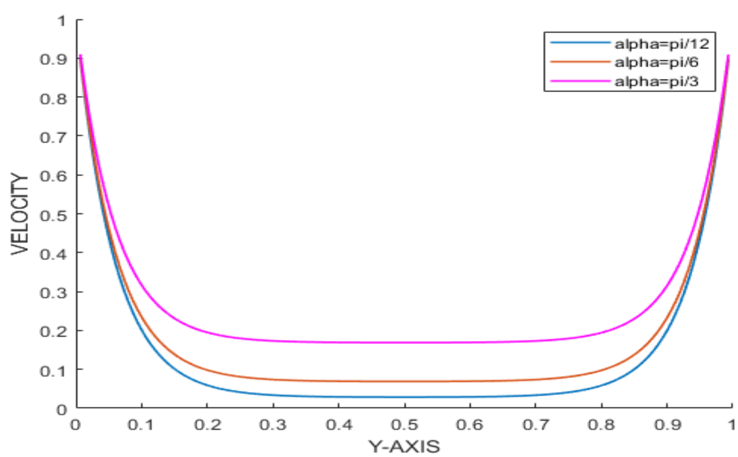

Figure 4: Effects of Angle of inclination on velocity profiles

From Figure (4), it is noted that fluid velocity increases as α increases. The magnetic field lines are applied at the angle α from the plate. The $x-$*component* of the Lorentz force is proportional to $\sin\alpha$, and the sin function is increasing on the interval $[0, \pi/2]$. Therefore, since the Lorentz force acts on the direction of the flow, an increase in the angle of inclination α leads to an increase in the Lorentz force, and hence, an increase in the velocity profiles.

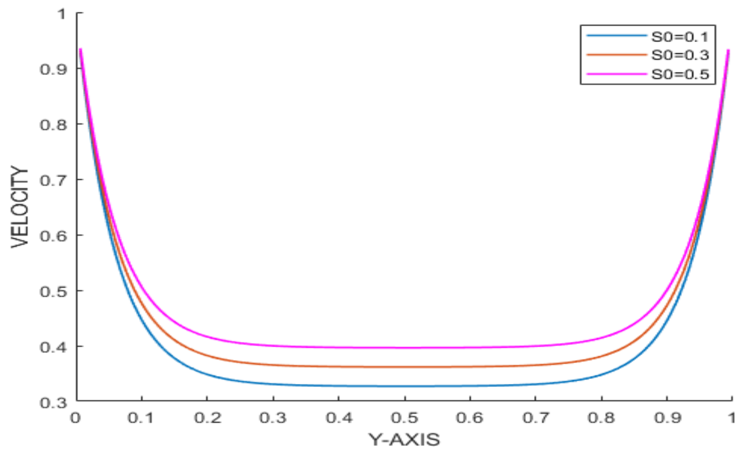

Figure 5: Effects of Injection parameter on velocity profiles

From Figure (5), it is noted that fluid velocity increases with increasing S_0. The Injection parameter, S_0 increases with increasing the injection velocity v_0, and Lorentz force is increased by increasing the injection velocity. Since the Lorentz force acts in the direction of the flow, therefore increasing S_0 leads to an increase in the Lorentz force, and hence an increase in the velocity profiles.

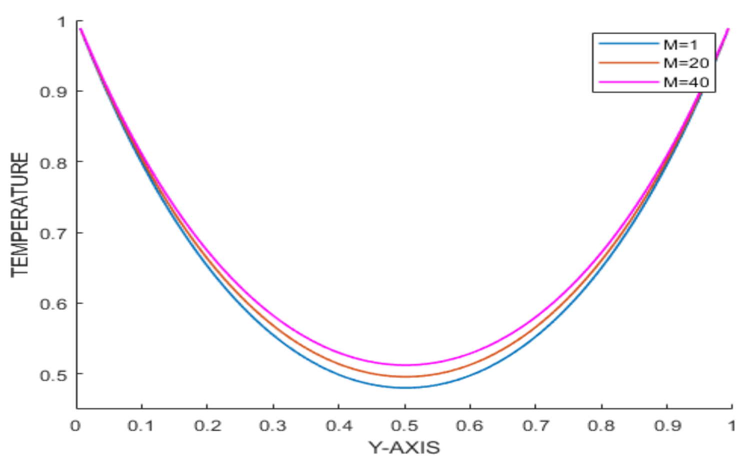

Figure 6: Effects of Magnetic parameter on Temperature profiles

From Figure (6), it is noted that fluid temperature increases as M increases. The magnetic parameter (M) is the ratio of the magnetic forces to viscous forces. Increasing M implies a decrease in viscous forces which oppose the fluid motion. When the viscous forces decrease, the velocity of the fluid increases which increases the collision of the fluid particles leading to an increase of the self-heating effects due to the dissipation of heat in the boundary layers. Hence increasing M leads to an increase in temperature profiles.

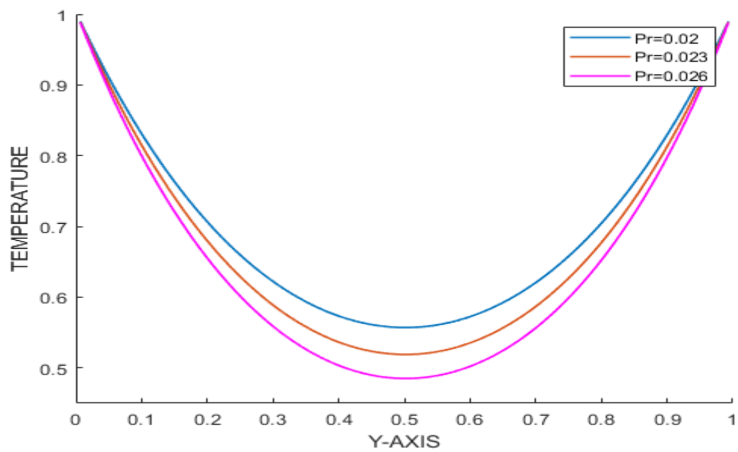

Figure 7: Effects of Prandtl number on Temperature profiles

From Figure (7), it is observed that increasing Pr decreases fluid temperature. Prandtl number (Pr) is the ratio of momentum diffusivity to thermal diffusivity. A fluid with high Prandtl number possesses a relatively small thermal conductivity. Thus, as Pr increases, there will be a reduction of the thermal boundary layer thickness and hence a decrease in the temperature profiles.

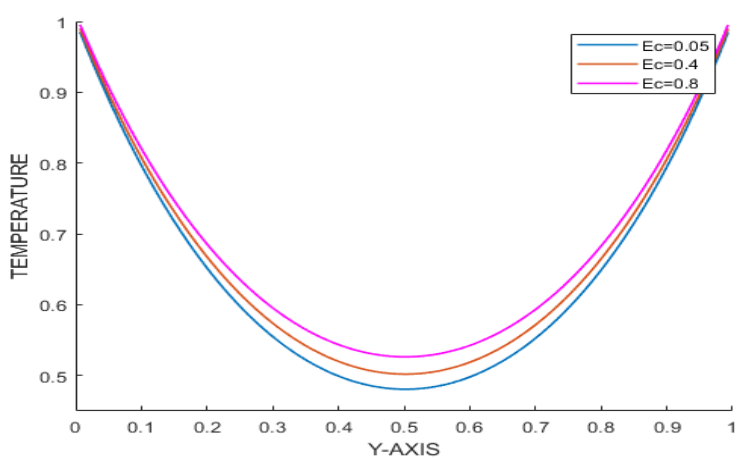

Figure 8: Effects of Eckert number on Temperature profiles

From Figure (8), it is observed that increasing Eckert number (Ec) leads to increase fluid temperature. Ec is the ratio of kinetic energy to the enthalpy. Increasing Ec leads to increase the kinetic energy. The kinetic energy increases with increasing the fluid velocity. As the fluid velocity increases, the collision of the fluid particles increases causing the dissipation of heat in the boundary layers and hence an increase in fluid temperature.

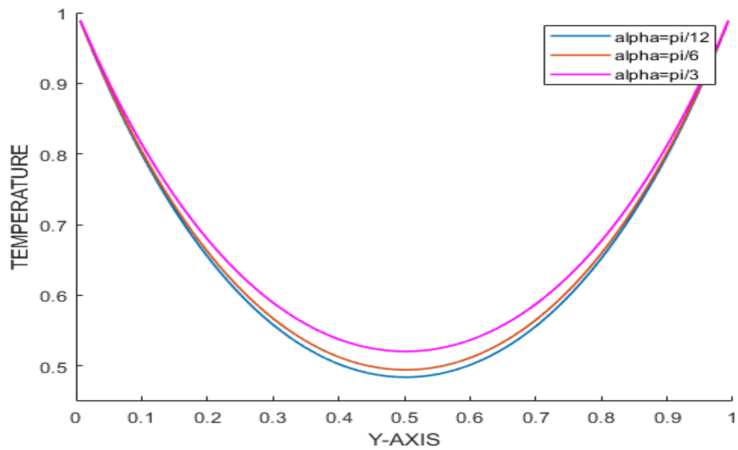

Figure 9: Effects of Angle of inclination on Temperature profiles

From Figure (9), it is observed that an increase in the angle of inclination (α) leads to an increase in the temperature profiles. By increasing α, the fluid velocity increases, thus, the collision of fluid particles increases which brings about dissipation of heat and hence an increase in the temperature profiles.

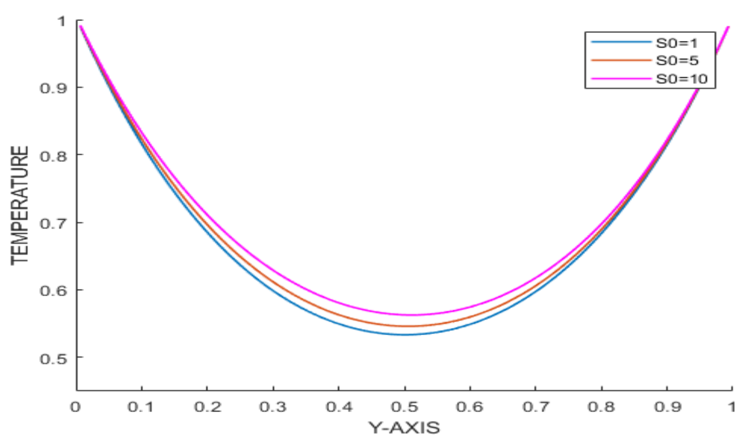

Figure 10: Effects of Injection parameter on Temperature profiles

From Figure (10), it is oberseved that increasing injection parameter increases the temperature profiles.
An increase in Injection parameter implies an increase of the injection velocity v_0. The Joule heating term in Energy equation is increased by increasing the injection velocity. Therefore, increasing S_0 leads to an increase in Joule heating term, and hence, an increase in the temperature profiles.

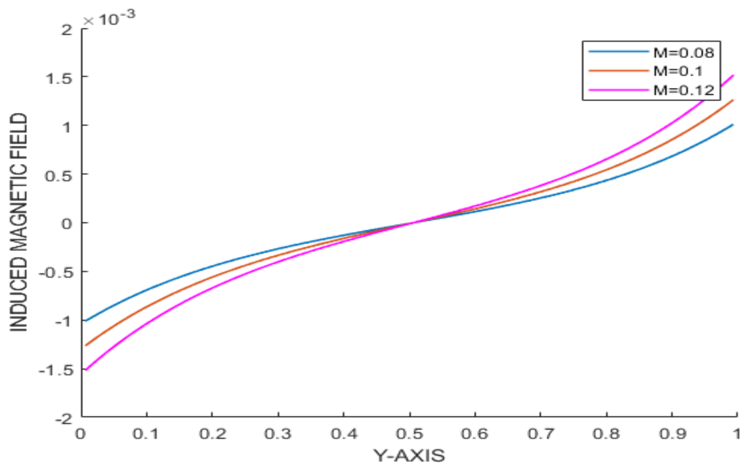

Figure 11: Effects of Magnetic parameter on the Induced magnetic field

From Figure (11), it is observed that an increase in magnetic parameter M leads to an increase in the induced magnetic field on the interval $0.5 < y < 1$ and a decrease on $0 < y < 0.5$.
Increasing M implies increase in magnetic forces, implying also an increase of the magnitude of the applied magnetic strength. The induced magnetic field itself, is generated as a result of the motion of the electrically conducting fluid in presence of magnetic field, so, as the magnitude of that field increases, the magnitude of the induced field also increases.
The induced magnetic field is negative on the interval $0 < y < 0.5$ and positive on $0.5 < y < 1$. Since the magnitude of the induced field increases on both intervals by increasing M, hence, as M increases, the induced field profile decreases on $0 < y < 0.5$ and increases on $0.5 < y < 1$. Therefore an increase in M leads to a decrease in the induced field profile on the interval $0 < y < 0.5$ and an increase on $0.5 < y < 1$.

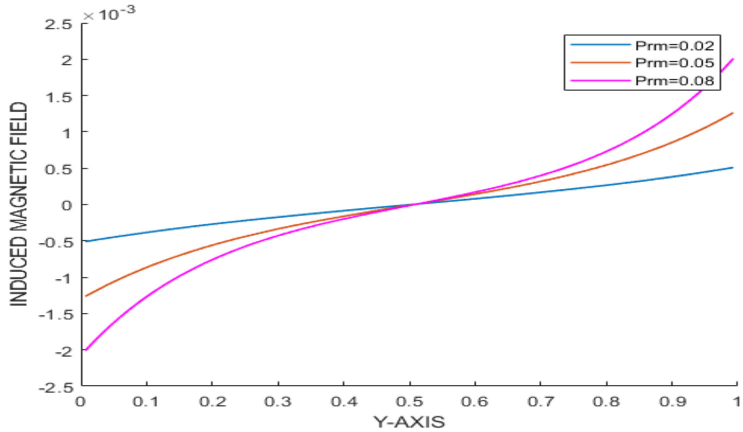

Figure 12: Effects of Magnetic Prandtl number on the induced magnetic field

From Figure (12), it is observed that an increase in Pr_M leads to a decrease in the induced magnetic field on the interval $0.5 < y < 1$ and a decrease on $0 < y < 0.5$.
Pr_M is the ratio of momentum diffusivity to magnetic diffusivity. Increasing Pr_M implies increasing the electrical conductivity of the fluid which makes the fluid more conducting, and hence, increases the magnitude of the induced magnetic field thus generated. Therefore, increasing Pr_M leads to an increase in magnitude of the induced field, and hence, a decrease in the induced field profile on the lower half of the channel and an increase on the upper half.

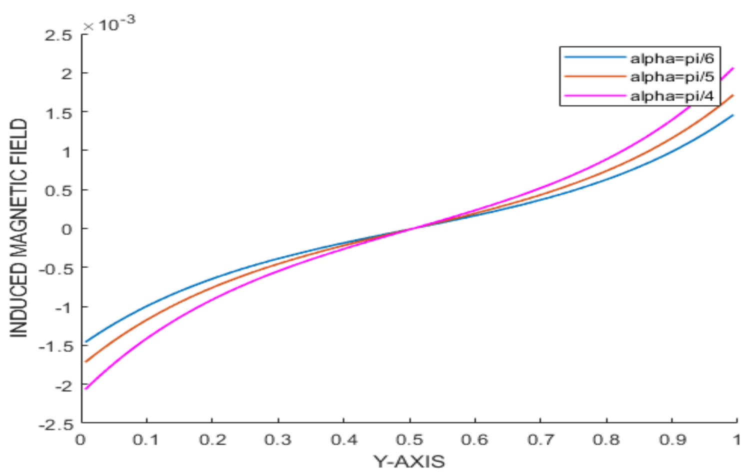

Figure 13: Effects of Angle of inclination on the induced magnetic field

From Figure (13), it is observed that increasing α leads to a decrease in the induced magnetic field on $0 < y < 0.5$ and the reverse effect on $0.5 < y < 1$. It is noted that in the Induction equation, the induced magnetic field increases with increase of the velocity gradient $\frac{\partial u}{\partial y}$. The velocity gradient in Induction equation is amplified by $\sin\alpha$. So, as α increases, the term $\sin\alpha\frac{\partial u}{\partial y}$ decreases on $[0 \quad 0.5]$ and increases on $[0.5 \quad 1]$ because the velocity gradient $\frac{\partial u}{\partial y}$ is negative on $[0 \quad 0.5]$ and positive on $[0.5 \quad 1]$. Therefore, increasing the magnetic inclination leads to an increase in the induced magnetic field.

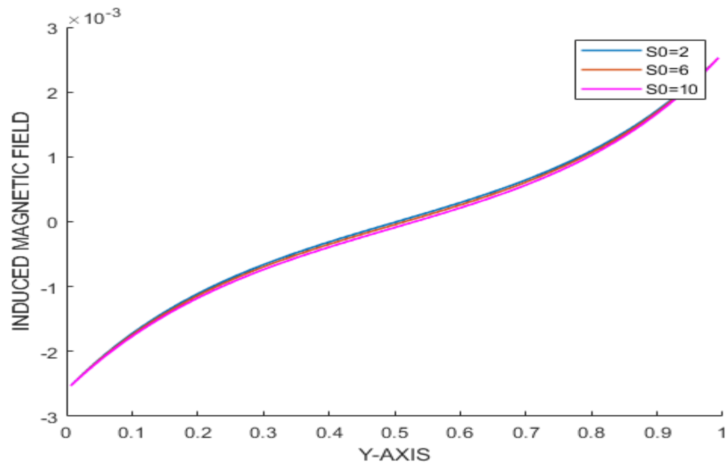

Figure 14: Effects of Injection parameter on the Induced magnetic field

From Figure (14), it is observed that increasing injection parameter leads to a decrease in the induced magnetic field. This is due to the fact that, as the injection velocity increases, the gradient of the induced magnetic field decreases which then leads to a decrease in the induced magnetic field.

4 Conclusion

The unsteady fluid flow between two moving plates in presence of an inclined applied magnetic field with magnetic fields lines fixed relative to the moving plates has been studied. The obtained model has been solved using Crank Nicholson method and simulated with MATLAB.

The effects of flow parameters have been determined. From the results obtained, the following conclusions have been outlined:

The velocity increases with an increase in the magnetic parameter M, Reynold's number Re, the magnetic inclination α and the Injection parameter S_0.

The temperature increases with an increase in M, α, Eckert number Ec and the Injection parameter S_0. However, the temperature decreases as Prandtl number Pr increases.

An increase in M, magnetic Prandtl number Pr_M and α leads to a decrease in the induced magnetic field in the lower half of the channel and an increase in the upper half of the channel. Increasing S_0 leads to a decrease in the induced field but the effect is not well pronounced.

ACKNOWLEDGEMENTS.

The first author wishes to address sincere thanks to the African Union together with the Pan African University, Institute for Basic Sciences Technology and Innovation for funding and supporting this research.

References

[1] Rossow, Vernon J, On flow of electrically conducting fluids over a flat plate in the presence of a transverse magnetic field, *Journal name*, (1958).

[2] Seth, GS and Ansari, S and Nandkeolyar, R, Unsteady hydromagnetic couette flow within a porous channel, *Tamkang journal of Science and Engineering*, **14**(1), (2011), 7 - 14.

[3] Ismail, A Mohamed and Ganesh, S and Kirubhashankar, CK, Unsteady MHD flow between two parallel plates through porous medium with one plate moving uniformly and the other plate at rest with uniform suction, *Int. J. Sci. Eng. Tech. Res*, **3**, (2014), 6 - 10.

[4] Joseph, KM and Daniel, S and Joseph, GM, Unsteady MHD Couette flow between two infinite parallel porous plates in an inclined magnetic field with heat transfer, *International Journal of Mathematics and Statistics Invention*, **2**(3), (2014), 103 - 110.

[5] Kuiry, DR and Bahadur, Surya, Steady MHD flow of viscous fluid between two parallel porous plates with heat transfer in an inclined magnetic field, *Journal of Scientific Research*, **7**(3), (2015), 21 - 31.

[6] Attia, Hazem A and Abbas, W and Abdeen, Mostafa AM and Said, Ahmed AM, Heat transfer between two parallel porous plates for Couette flow under pressure gradient and Hall current, *Sadhana*, **40**(1), (2015), 183 - 197.

[7] Kiema, DW and Manyonge, WA and Bitok, JK and Adenyah, RK and Barasa, JS, On the steady MHD couette flow between two infinite parallel plates in an uniform transverse magnetic field, *Journal of Applied Mathematics and Bioinformatics*, **5**(1), (2015), 87 - 99.

[8] Onyango, Edward Richard and Kinyanjui, Mathew Ngugi and Uppal, Surindar Mohan, Unsteady Hydromagnetic Couette Flow with Magnetic Field Lines Fixed Relative to the Moving Upper Plate, *American Journal of Applied Mathematics*, **3**(5), (2015), 206 - 214.

[9] Mbugua, ZM and Kinyanjui, MN and Giterere, K and Kiogora, PR, Hydromagnetic Fluid Flow between Porous Parallel Plates in Presence of Variable Transverse Magnetic Field, *International Journal of Engineering Science and Innovative Technology*, **4**(5), (2015), 14 - 22.

[10] Kibet Kiprop, Mathew Ngugi Kinyanjui, Jackson Kioko Kwanza, Hydrodynamic Radiating Fluid Flow Past an Infinite Vertical Porous Plate in Presence of Chemical Reaction and Induced Magnetic Field, *American Journal of Applied Mathematics*, **4**(2), (2016), 62 - 74.

[11] Swapna, Y and Raju, MC and Sharma, RP and Varma, SVK, Chemical reaction, thermal radiation and injection/suction effects on MHD mixed convective oscillatory flow through a porous medium bounded by two vertical porous plates, *Bull. Cal. Math. Soc*, **109**(3), (2017), 189 - 210.

[12] Onyango, ER and Kinyanjui, MN and Kimathi, M, Unsteady hydromagnetic flow between parallel plates both moving in the presence of a constant pressure gradient, *International Journal of Engineering Science and Innovative Technology, IJESIT*, **6**(1), (2017), 77 - 89.

[13] Sasikala, R and Govindarajan, A and Gayathri, R, Unsteady stokes flow of dusty fluid between two parallel plates through porous medium in the presence of magnetic field, *Journal of Physics: Conference Series*, **1000**(1), (2018), 012151.

Nomenclature

B	Magnetic induction vector, $[wbm^{-2}]$
B_0	Applied uniform magnetic vector, $[wbm^{-2}]$
H	Magnetic field intensity, $[wbm^{-2}]$
E	Electric field intensity, $[v]$
D	Electric displacement $[Cm^{-2}]$
J	Induction current density, $[AM^{-2}]$
T	Temperature of the fluid, $[K]$
T_p	Temperature of the moving plates $[K]$
T_0	Temperature at rest $[K]$
P	Pressure force, $[Nm^{-2}]$
q	Velocity vector, $[ms^{-1}]$
u_o	velocity of the moving plates, $[ms^{-1}]$
v_o	Injection velocity, $[ms^{-1}]$
k	thermal conductivity, $[Wm^{-1}K^{-1}]$
F	Body forces, $[N]$
$\frac{D}{Dt}$	Material derivative, $(\frac{\partial}{\partial t} + u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} + w\frac{\partial}{\partial z})$
ρ	Fluid density, $[kgm^{-3}]$
ρ_e	Charge density, $[C]$
μ	Coefficient of viscosity, $[kgm^{-1}s]$
μ_e	Magnetic permeability, $[Hm^{-1}]$
σ	Electrical conductivity, $[\Omega^{-1}m^{-1}]$
α	Magnetic inclination, $[rad]$
∇	Gradient operator, $(i\frac{\partial}{\partial x} + j\frac{\partial}{\partial y} + k\frac{\partial}{\partial z})$
∇^2	Laplacian operator $(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2})$
ν	Kinematic viscosity $[m^2s^{-1}]$
ϕ	Viscous dissipation function, $[s^{-1}]$