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Magneto hydrodynamics Stokes Fluid Flow Problem Through A Porous Media Over A Non-Linearly Stretching Surface With Heat Transfer

J.K. Ndung'u, M. N. Kinyanjui, K. Giterere

Abstract*— *Unsteady magneto hydrodynamic Stokes fluid flow problem through a porous media over a non- linearly stretching surface with heat transfer has been investigated. The flow takes place between two parallel flat sheets that are made of an electrically non-conducting material. The governing equation for the fluid flow includes continuity equation, momentum equation and the energy equation. Finite difference technique is used to solve the non-linear partial differential equations. The coupled non linear partial differential equations governing the flow has been solved numerically using the finite difference method. The results are presented graphically and the observations discussed. A change in various parameters has been observed on how they affect the velocity and temperature on the surface of the stretching sheet. Observations and discussions on the effect of varying various parameters such as magnetic parameter M, Reynold's number Re, prandtl number Pr, Eckert number Ec, Joules heating parameter R and injection parameter wo on the velocity profiles and temperature profiles is done. A change in the value of the parameters mentioned above was observed on whether they cause an increase, a decrease or have no effect on the velocity and Temperature profiles respectively. The result obtained in this research can be applied by engineers in the designing of cooling systems with liquid metals, geothermal reservoirs, in petroleum and mineral industries, in underground energy transport, accelerators,* **MHD** *generators, pumps, flow meters, purification of crude oil, polymer technology and in controlling boundary layer flow over aircraft wings by injection or suction of fluid out of or into the wing.

Index Terms—**Magneto-hydrodynamic, velocity, temperature, Permeability.**

I. INTRODUCTION

Magneto-hydrodynamic (MHD) fluid flow is the study of flow of an electrically conducting fluid in presence of a magnetic field. MHD studies the dynamics of the interaction of electrically conducting fluids and electromagnetic field. The electrically conducting fluid in presence of variable magnetic fields is an important phenomenon in our day-to-day lives. Fluid is a substance that undergoes continuous deformation when acted upon by an external force however small the force may be. Ahmed [1] who carried out an analytical study of a two dimensional unsteady MHD free convective flow past a vertical porous plate immersed in a porous medium with Hall currents, thermal diffusion and heat source, the influence of certain flow parameters on velocity, temperature, species concentration, and shearing stress at the plate were investigated his study concluded that the concentration at the surface of the plate increases under the Soret effect and the Soret effect causes the main-flow shear stress to rise and the cross flow shear stress to fall. A decrease in the Soret effect leads to an increase in the main flow and cross flow velocities. Kinyanjui [2] carried a study on MHD Stokes problem for a vertical infinite plate in a dissipative rotating fluid with Hall currents. The study noted that an increase in Hall current does not affect the temperature profiles though it produces a slight increase in primary velocity profiles and a significant decrease in secondary velocity profiles far from the plate. Tania[3] studied the effects of radiation, heat generation and viscous dissipation on MHD free convection flow along a stretching sheet. The study found that larger values of buoyancy parameter can be used to control the temperature and concentration boundary layers; and that suction stabilizes the boundary layer growth. The boundary layers were found to be highly influenced by the Prandtl number. The study also concluded that magnetic field can be used to control the flow characteristics and has significant effect on heat and mass transfer. In the study, increasing radiation reduced the momentum boundary layer and the thermal boundary layer thicknesses. The presence of a heavier species (large Sc) decreased the fluid velocity, heat transfer and the concentration in the boundary layer. Large values of heat source parameter Q had a significant effect on the velocity and temperature distributions whereas such large values reduced the concentration distribution in the boundary layer. Eckert number was found to have a significant effect on the boundary layer growth. Jha [4] investigated Hall and ion-slip effects on unsteady MHDCouette flow in a rotating system with suction and injection. He concluded that an increase in hall parameter leads to a decrease in primary velocity and an increase in secondary velocity.Chamkah [5] have investigated the effects of magnetic field on natural convection flow past a vertical surface. The study concludes that the natural convection is reduced which causes the fluid flows to be very slow. This velocity reduction

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causes an increase in thermal boundary layer thickness, which in turn, increases the rate of heat transfer and decreases the local Nusselt number.O.D Makinde [6] have studied mass diffusion effects on natural convection flow past a flat plate. The study found out that Increasing the heat absorption parameter reduces both velocity and temperature i.e.retards and cools the flow in the porous regime. Therefore a desired temperature can be maintained by controlling the heat absorption effect in practical chemical engineering applications. Sparrow [7] on a new buoyancy model replacing the standard pseudo density difference for internal natural convection in gases. The study concluded that the model compared well with the vertical flat plate data without changes. However, in the hot wall and cold wall box it had a delayed transition with respect to the data and significantly under predicted the heat transfer. Patil [8] have examined the role of internal heat generation or absorption effects on the flow and heat transfer over a moving vertical plate. The study concluded that Heat source/sink effect is less in permeable than in impermeable stretching sheet. In this study, authors have considered the steady flow and heat transfer characteristics. Unsteady mixed convection flows do not necessarily possess similarity solutions in many practical applications. The unsteadiness and nonsimilarity in such flows may be due to the free stream velocity or due to the curvature of the body or due to the surface mass transfer or even possibly due to all these effects. Extensive researches have been done, including those cited above, on the flow between parallel plates. However, no emphasis has been given to the problems analyzed by Giterere*et al* [9] with consideration of nonlinear stretching plate. This work aims at presenting findings on study of MHD Stoke fluid flow problem past porous non-linearly stretching plates with heat transfer. This has varied applications in dyeing industries.

II. MATHEMATICAL ANALYSIS

Flow configuration

This study has considered the analysis of the unsteady MHD Stoke fluid flow problem past porous non-linearly stretching plates with heat transfer. The flow is in the x-direction while a uniform magnetic field is applied parallel to the z-axis.

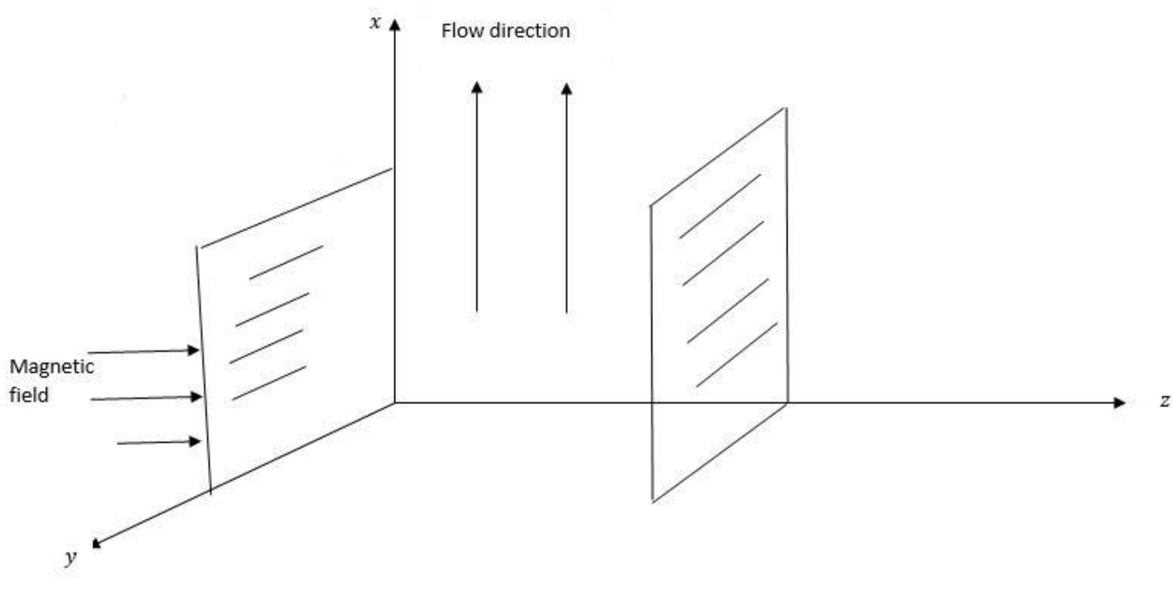

Fig 1: Flow configuration

Governing equations

Equation of conservation of mass

The equation of continuity is derived from the law of conservation of mass which states that under normal conditions mass can neither be created nor destroyed. It is derived by taking a mass balance on the fluid entering and leaving a volume element in the flow field. For an unsteady fluid flow, from Kinyanjui et al. [8], the tensor form of the equation of continuity is;

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$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho . u_i)}{\partial x_i} = 0 \quad (1)$$

Where i =1, 2, 3 represent the x, y and z directions respectively.
Since the density of the fluid is a constant equation (1) reduces to:

$$\frac{\rho \partial u_i}{\partial x_i} = 0 \quad (2)$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (3)$$

Taking $\frac{\partial v}{\partial y} = 0$ since the flow is infinite in y-axis then equation (3) reduces to,

$$\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0 \quad (4)$$

Equations of conservation of momentum

This equation is also known as the momentum equation and is derived from the Newton's second law of motion. The law requires that the sum of all the forces acting on a control volume must be equal to the rate of change of fluid momentum within the control volume. The equation of conservation of momentum is given by;

$$\frac{\partial \boldsymbol{q}}{\partial t} + \boldsymbol{q}(\nabla . \mathbf{q}) = -\frac{1}{\rho}\nabla p + \frac{\mu}{\rho}\nabla^2 \boldsymbol{q} + \boldsymbol{F_i} \quad (5)$$

The terms to be added for body forces F_i are:

1. The porous media term which is given by $\frac{\mu}{k_p} u$

2. The buoyancy term will be given by $\beta g(T - T_\infty)$

3. The Lorentz force which is given by $-\sigma v \boldsymbol{B_0^2} i - \sigma v \boldsymbol{B_0^2} j$

The equation of momentum components in x and y axis will be as below
X-axis component of momentum equation

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + w_0\frac{\partial u}{\partial z} = \frac{\mu}{\rho}\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial z^2}\right] - \frac{\mu}{k_p}u - \frac{\sigma u B_0^2}{\rho} + \beta g(T - T_\infty) \quad (6)$$

Y-axis component of momentum equation

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + w_0\frac{\partial v}{\partial z} = \frac{\mu}{\rho}\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial z^2}\right] - \frac{\mu}{k_p}v - \frac{\sigma v B_0^2}{\rho} \quad (7)$$

Equation of conservation of energy

This is derived from the first law of thermodynamics, it state that the increase in internal energy dE of a system from the surrounding is equal to the amount of work done by the system to the surrounding. The equation is the work-energy relationship that shows that for work to be done, energy must be spent. It is given by;

$$\rho c_p \frac{DT}{Dt} = K\nabla^2 T + \mu\emptyset + \frac{J^2}{\sigma} \quad (8)$$

Where $\mu\emptyset = \mu\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2$ is the viscous dispation term
and $\frac{J^2}{\sigma} = \sigma B_0^2(u^2 + v^2)$ is the Joule heating term.
Equation (8) on expanding yields to:

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + w\frac{\partial T}{\partial z} = \frac{k}{\rho c_p}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) + \frac{\mu}{\rho c_p}\left(\frac{\partial u}{\partial x}\right)^2 + \frac{\mu}{\rho c_p}\left(\frac{\partial u}{\partial z}\right)^2 + \frac{\sigma B_0^2(u^2+v^2)}{\rho c_p} \quad (9)$$

The solution procedure

The following transformations have been used to non-dimensionalize the equations.

The governing equations (5) and (7), are solved using a finite difference scheme as proposed by Sparrow [7].

$$u^* = \frac{u}{U_\infty},\ v^* = \frac{v}{U_\infty},\ w_0^* = \frac{w_0}{U_\infty},\ t^* = \frac{u_\infty t}{H},\ y^* = \frac{y}{H},\ x^* = \frac{x}{h},\ z^* = \frac{z}{H},\ T^* = \frac{T - T_\infty}{T_w - T_\infty} \quad (10)$$

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After performing the non –dimensionalization process equations (6), (7) and (9) are written in finite form and expressions for $u_{i,j}^{k+1}$, $v_{i,j}^{k+1}$ and $T_{i,j}^{k+1}$ obtained from the respective equation as below:

$$u_{i,j}^{k+1} = (u_{i,j}^{k} - \Delta t \frac{u_{i,j}^{k}}{2\Delta x}\left(-u_{i-1,j}^{k+1} + u_{i,j}^{k} - u_{i-1,j}^{k}\right) - \Delta t \frac{w}{2\Delta z}(-u_{i,j-1}^{k+1} + u_{i,j}^{k} - u_{i,j-1}^{k+1} + \frac{\Delta t}{2Re(\Delta x)^2}\left(u_{i+1,j}^{k+1} + u_{i-1,j}^{k+1} + u_{i+1,j}^{k} - 2u_{i,j}^{k} + u_{i-1,j}^{k}\right) + \frac{\Delta t}{2Re(\Delta z)^2}\left(u_{i,j+1}^{k+1} + u_{i,j-1}^{k+1} + u_{i,j+1}^{k} - 2u_{i,j}^{k} + u_{i,j-1}^{k}\right) + \frac{\Delta t}{2} u_{i,j}^{k}(M + X_i) + \frac{Gr}{2}\left(T_{i,j}^{k+1} + T_{i,j}^{k}\right))/(1 + \frac{\Delta t u_{i,j}^{k}}{2\Delta x} + \frac{\Delta t w}{2\Delta z} + \frac{\Delta t}{Re(\Delta x)^2} + \frac{\Delta t}{Re(\Delta z)^2} + \frac{\Delta t M}{2} + \frac{\Delta t X_i}{2}$$

(11)

$$v_{i,j}^{k+1} = (\frac{v_{i,j}^{k}}{\Delta t} - \frac{u_{i,j}^{k}}{2\Delta x}\left(-v_{i-1,j}^{k+1} + v_{i,j}^{k} - v_{i-1,j}^{k}\right) - \frac{w}{2\Delta z}\left(-v_{i,j-1}^{k+1} + v_{i,j}^{k} - v_{i,j-1}^{k}\right) + \frac{1}{2Re(\Delta x)^2}\left(v_{i+1,j}^{k+1} + v_{i-1,j}^{k+1} + v_{i+1,j}^{k} - 2v_{i,j}^{k} + v_{i-1,j}^{k}\right) + \frac{1}{2Re(\Delta z)^2}\left(v_{i,j+1}^{k+1} + v_{i,j-1}^{k+1} + v_{i,j+1}^{k} - 2v_{i,j}^{k} + v_{i,j-1}^{k}\right) - \frac{m}{2} v_{i,j}^{k+1} - \frac{m}{2} v_{i,j}^{k} - \frac{X_i}{2} v_{i,j}^{k+1} - \frac{X_i}{2} v_{i,j}^{k})/\left(1 + \frac{\Delta t u_{i,j}^{k}}{2\Delta x} + \frac{\Delta t w}{2\Delta z} + \frac{\Delta t}{2Re(\Delta x)^2} + \frac{\Delta t M}{2} + \frac{\Delta t X_i}{2}\right)$$

(12)

$$T_{i,j}^{k+1} = T_{i,j}^{k} - \frac{\Delta t u_{i,j}^{k}}{2\Delta x}\left(-T_{i-1,j}^{k+1} + T_{i,j}^{k} - T_{i-1,j}^{k}\right) - \frac{\Delta t w}{2\Delta z}\left(-T_{i,j-1}^{k+1} + T_{i,j}^{k} - T_{i,j-1}^{k}\right)\frac{\Delta t}{2RePr(\Delta x)^2}(T_{i+1,j}^{k+1} + T_{i-1,j}^{k+1} + T_{i+1,j}^{k} - 2T_{i,j}^{k} + T_{i-1,j}^{k} + \frac{\Delta t}{2RePr(\Delta z)^2}(T_{i,j+1}^{k+1} + T_{i,j-1}^{k+1} + T_{i,j+1}^{k} - 2T_{i,j}^{k} + T_{i,j-1}^{k} + \frac{\Delta t Ec}{Re}\left(u_{i,j}^{k+1} - u_{i-1,j}^{k+1} + u_{i,j}^{k} - u_{i-1,j}^{k}\right)^2 + \frac{\Delta t Ec}{Re}\left(v_{i,j}^{k+1} - v_{i,j-1}^{k+1} + v_{i,j}^{k} - v_{i,j-1}^{k}\right)^2 + \Delta t ReR\left(\left(u_{i,j}^{k}\right)^2 + \left(v_{i,j}^{k}\right)^2\right)/(1 + \frac{\Delta t u_{i,j}^{k}}{2\Delta x} + \frac{w}{2\Delta z} + \frac{\Delta t}{RePr(\Delta x)^2} + \frac{\Delta t}{RePr(\Delta z)^2})$$

(13)

The initial and boundary conditions are as given below;

At the entrance $0 \leq z \leq H$

$t^* \leq 0, u^* \leq 0, v^* \leq 0, w^* \leq 0$, $T^* \leq 0$ (14)

$t^* \geq 0, u^* = 1, v^* \leq 0, T^* = 1$

At the porous wall:

$t^* \geq 0, u^* = Hx^n$, $T^* = 1,$

(15)

On the other surface at z=H:

$t > 0$, $u^* = 0$, $T = T_\infty, T^* = \frac{T_\infty - T_\infty}{T_w - T_\infty} = 0$ (16)

III. RESULTS AND DISCUSSION

The following are the results obtained after equations (11), (12) and (13) are implemented on a matlab code to obtain solutions and are presented graphically as shown below;

It is observed that an increase in Eckert number results to increase in both primary and secondary velocity profiles. Increase in Eckert number is attributed to increased kinetic energy when the fluid absorbs more heat energy that is released from the internal viscous forces. Increase in temperature of the fluid increases the kinetic energy of the fluid particles which results to increase in primary and secondary velocity profiles of the fluid.

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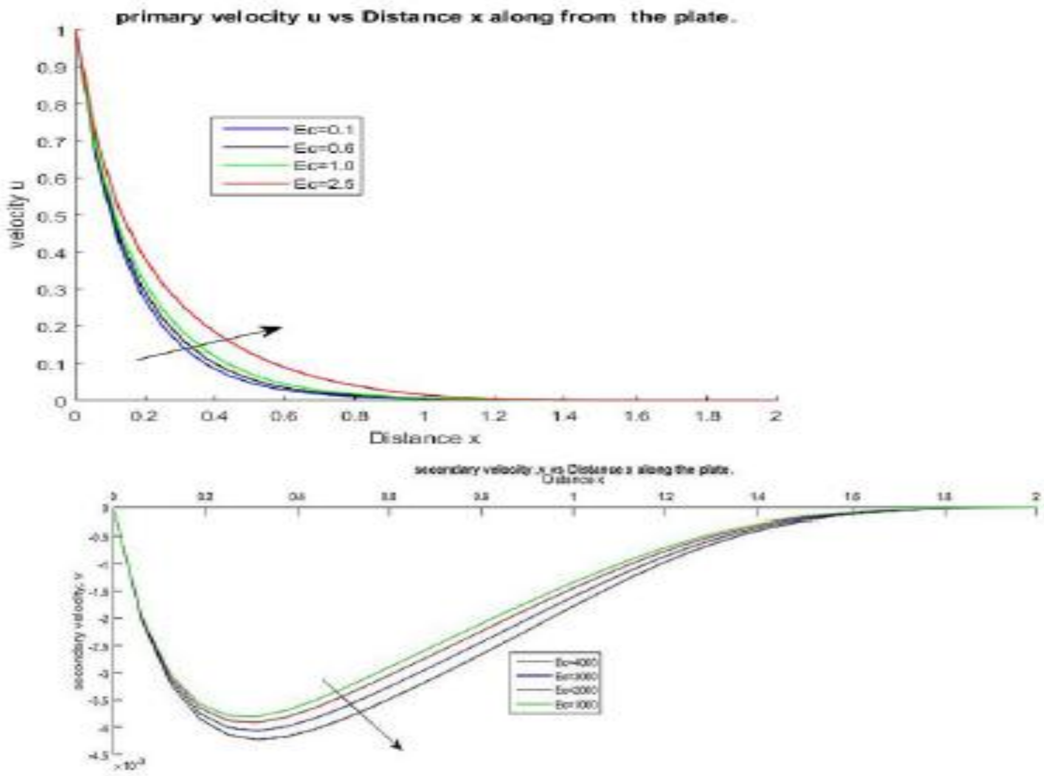

Fig.2: Graphs of primary velocity and secondary velocity profiles while varying Eckert number, (Ec)

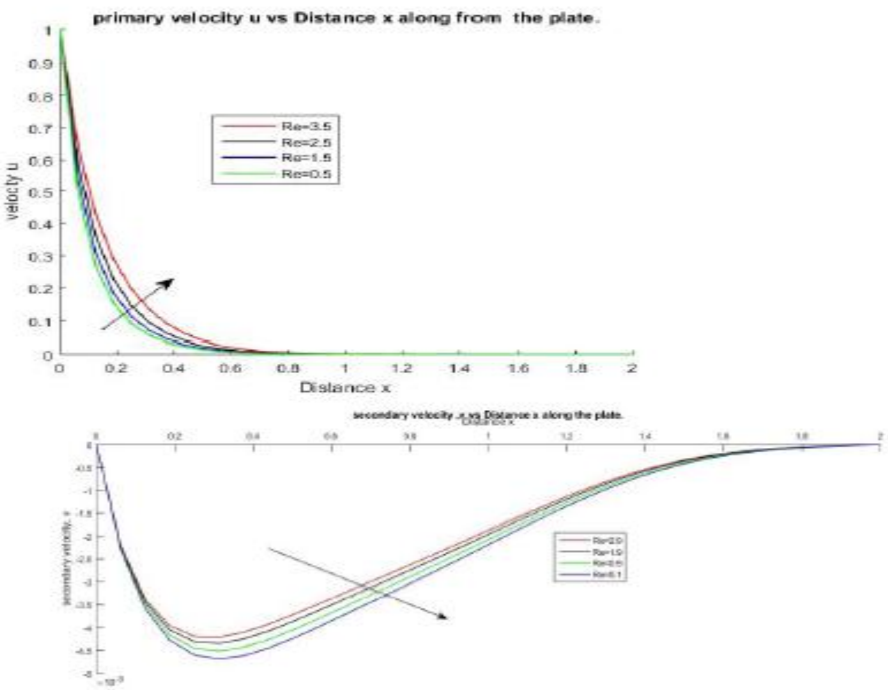

Fig.3: Graphs of primary velocity and secondary velocity profiles while varying Reynolds number, Re

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It is observed that an increase in Reynolds number leads to an increase in both the primary velocity profile and also the secondary velocity profile.

The Reynolds number represents the ratio of the inertial to viscosity forces. Increase in Reynolds number results to a larger inertia force that in turn translates to higher velocities.

When Reynolds number (Re) is small, it means that the viscous force is predominant and thus imposes drug in the fluid decreasing the velocity of the flow. When Reynolds number (Re) is large, the inertia force is predominant hence an increase in velocities.

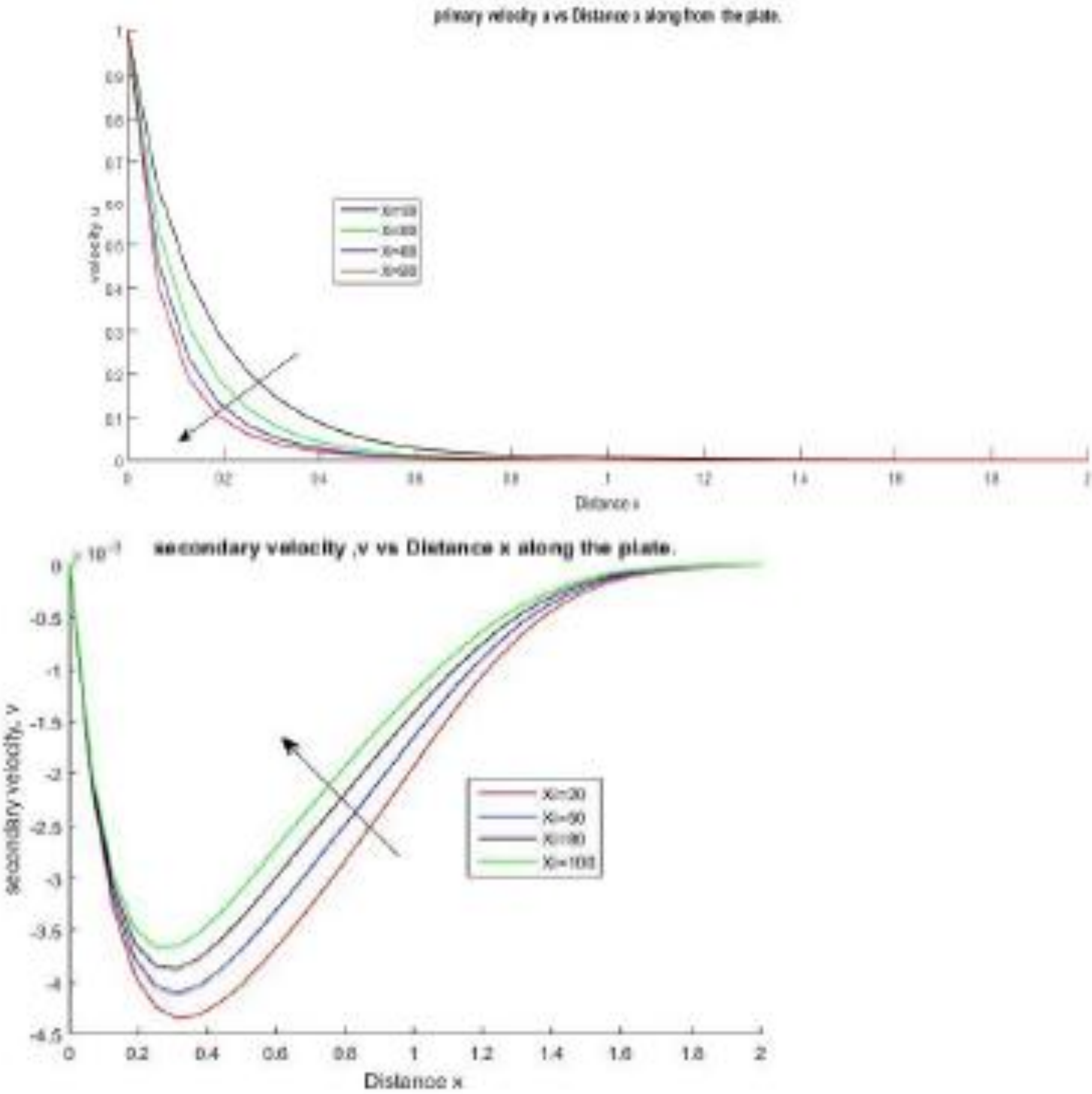

Fig.4. Graphs of primary velocity and secondary velocity profiles while varying permeability parameter, Xi

The Permeability parameter Xi is inversely proportional to the actual permeability k of the porous medium and thus increase in permeability parameter increases the porosity of the plate. Increased porosity reduces the acceleration of the flow and as a result primary and secondary velocities decreases.

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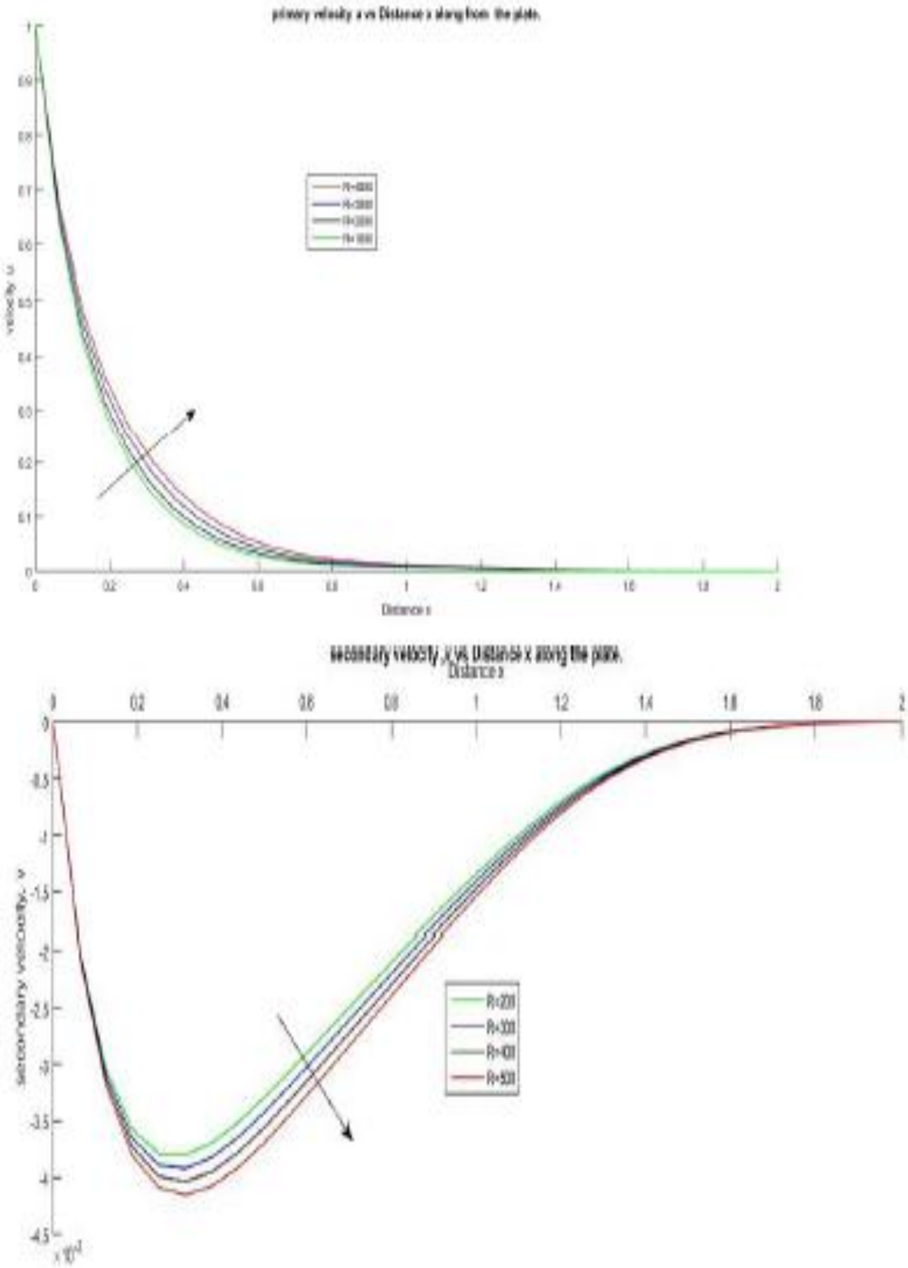

Fig.5: Graphs of primary velocity and secondary velocity profiles while varying Joule heating parameter, R

Joule heating occurs as the conducting fluid flows in a magnetic field where a electric current is induced. This current causes heating and the temperature increases the increase in temperature causes a corresponding increase in internal energy of the fluid hence an increase in both primary velocity profile and also the secondary velocity profile.

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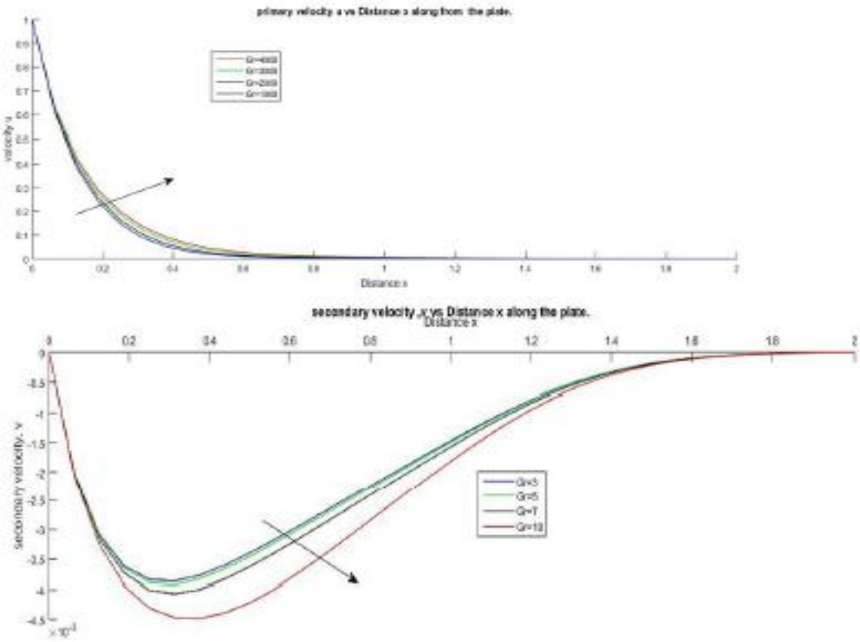

Fig 6: Graphs of primary velocity and secondary velocity profiles while varying Grash of number, Gr

It is observed that as Grashoff number increases the velocity increases. Grashoff number gives the ratio of buoyancy forces to the viscous forces. When the Grashoff number increases velocity increases too showing the buoyancy forces are more significant in this flow. Velocity of the fluid increases because the fluid flow is assisted by the free convection currents.

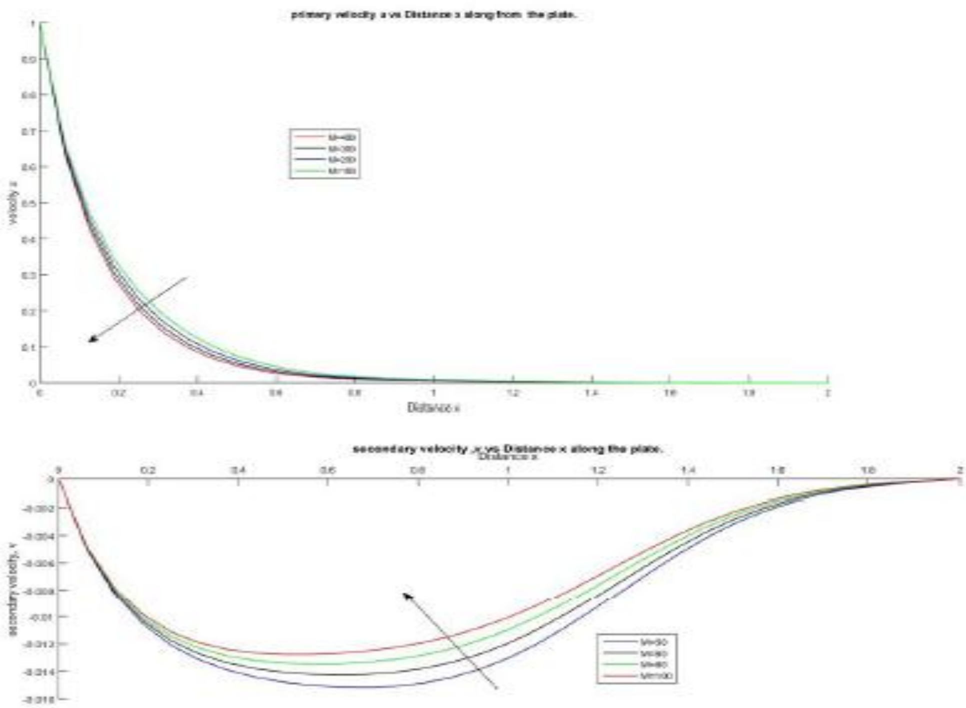

Fig 7: Graphs of primary velocity and secondary velocity profiles while varying Magnetic parameter, M

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An increase in magnetic parameter M leads to a decrease in both primary and secondary velocity profile of the fluid. The presence of a magnetic field in an electrically conducting fluid induces a magnetic force which acts against the flow if the magnetic field is applied in the normal direction as considered in the present study. This type of resistive force tends to oppose the flow hence a reduction in primary and secondary velocities.

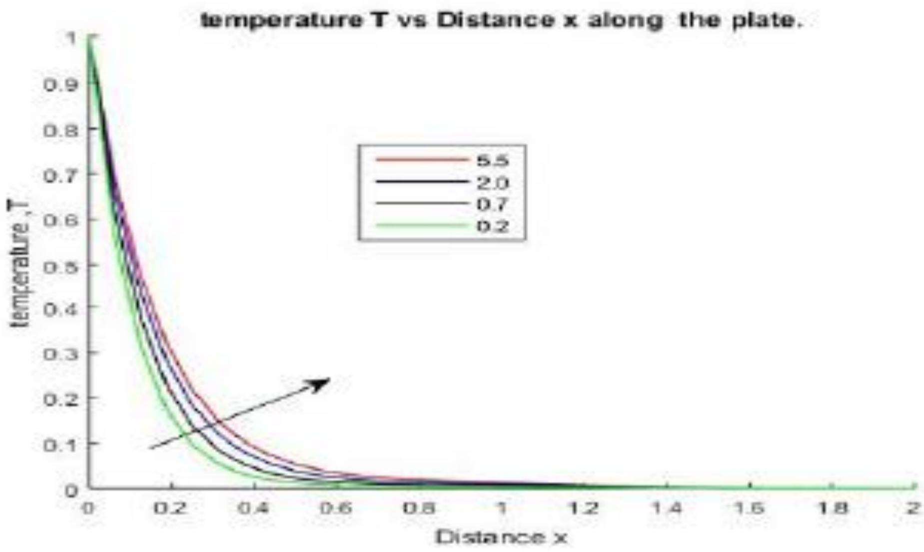

Fig 8: Graphs of temperature profiles while varying Prandtl number, Pr

An increase in prandtl number leads to an increase in temperature. Since the fluid under study is of low viscousity, thermal forces are therefore more significant leading to an increase in temperature.

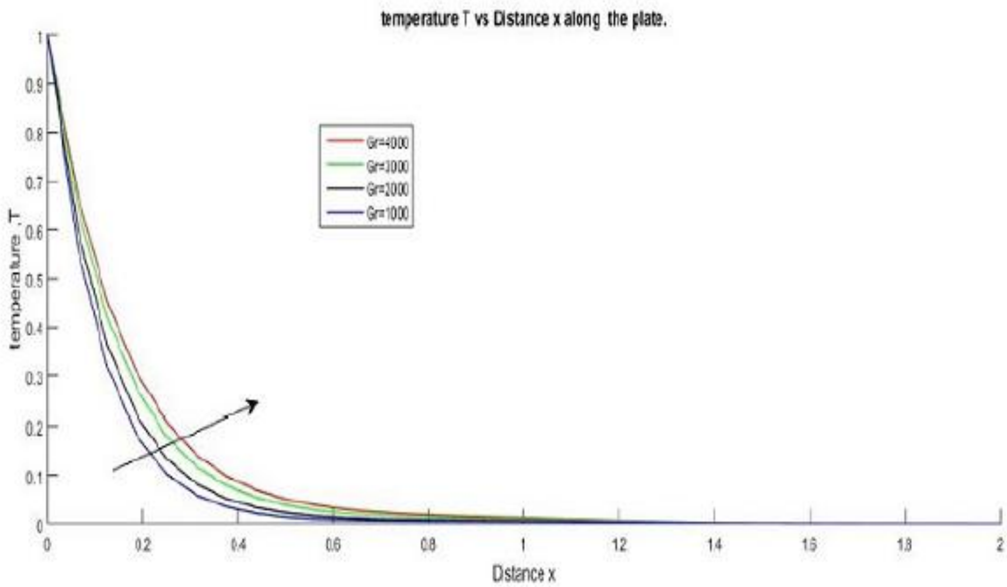

Fig 9: Graphs of temperature profiles while varying Grash of number, Gr

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An increase in grash of number leads to an increase in velocity. This causes an increase in kinetic energy as the fluid flows hence an increase in internal energy hence an increase in temperature.

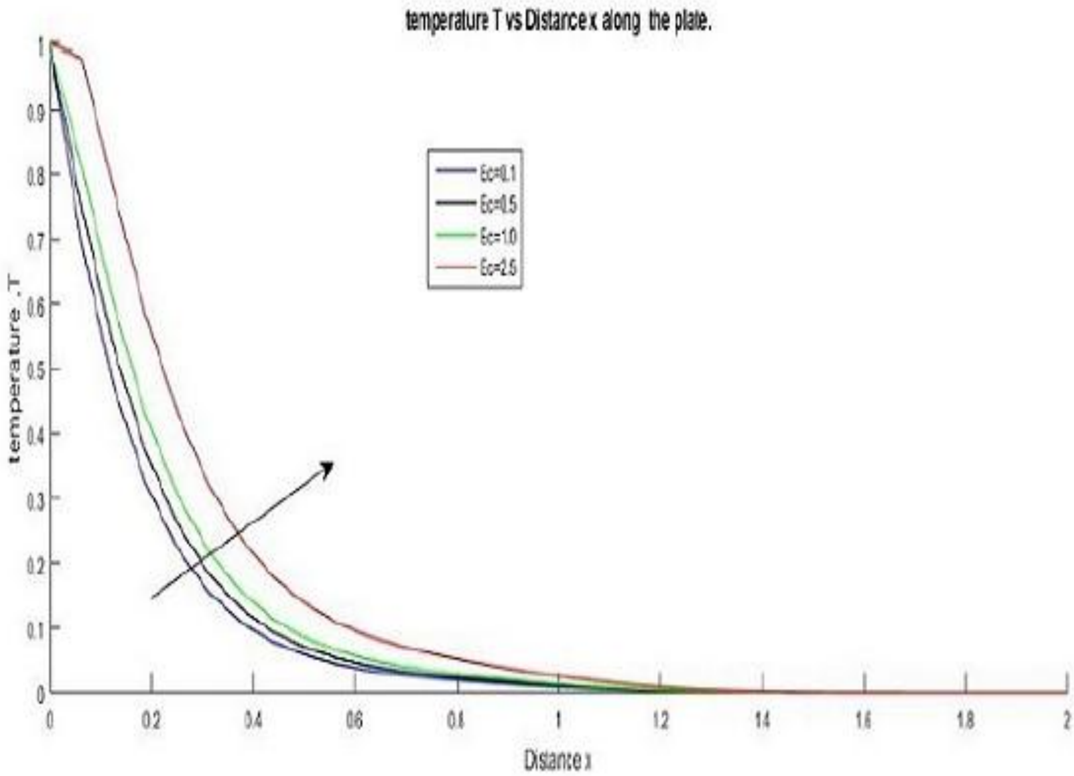

Fig 10: Graphs of temperature profile while varying Eckert number, Ec

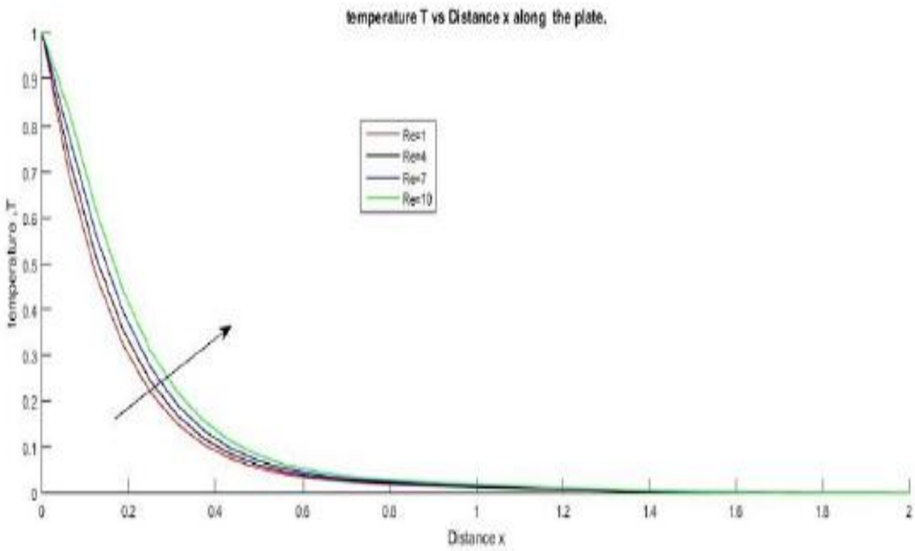

Fig 11: Graphs of temperature profiles while varying Reynolds number, Re

It is observed that increase in Eckert number results to increase in temperature profile. A positive Eckert number implies heating of the fluid as it absorbs heat from the stretching surface. Increase in Eckert number is as a result of increased kinetic energy when the fluid absorbs more heat energy that is released from the internal viscous forces which leads to an increase in temperature. An increase in Reynolds's number causes a decrease in temperature initially but after overcoming the stretching forces the temperature is observed to increase as the distance along the plate's increases.

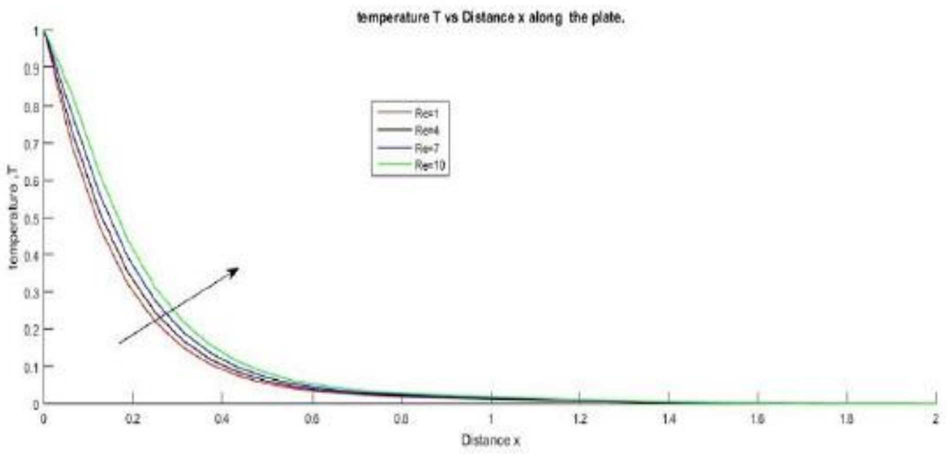

Fig 12: Graphs of temperature profiles while varying joule heating parameter, R

An increase in joule heating parameter causes an increase in temperature. As the current is induced in the flowing fluid, heat is generated due to the resistance to the flow of electric current hence an increase in temperature.

IV. CONCLUSION

The results obtained in Chapter 4 show that the rates of heat transfer influenced by the Magnetic number M, hydrodynamic Reynolds number Re, Prandtl number Pr, Eckert number Ec, Joule heating parameter and the permeability parameter. For instance the current study has shown that imposing a transverse magnetic field to a flow reduces the velocity of the fluid and decreases the temperature of the fluid. Increasing the value of Eckert number (Ec) leads to an increase temperature profiles.

V. VALIDATION

It is found that an increase in permeability parameter leads to a decrease in both the velocity profiles and the temperature profiles respectively. The results are similar to those of Muondwe (2014) who found that increase in the magnetic parameter retarded the motion of the fluid. Other results agrees with Muondwe's results. In this thesis, the study of magneto hydrodynamic flow through a porous media in a magnetic field is not exhaustive but can provide a basis for further research while considering other areas like magnetohydromagnetic fluid flow through porous media confined in a parallel plates in presence of variable transverse magnetic field when the sheets confining the fluid are not parallel.

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NOMENCLATURE

B	Magnetic flux density Wbm^{-2}
E	Electric field strength, Vm^{-1}
Ec	Eckert number

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H Magnetic field strength, Wbm^{-2}
J Electric current density, Am^{-2}
M Magnetic parameter
Pr Prandtl number
ρ Density of the fluid, Kg/m^3
Re Reynold's number
R Joules heating parameter
μ Coefficient of Viscosity, $kgm^{-1}s^{-1}$
s_o Dimensional Suction velocity, m/s
t Dimensional time, s
u_o Velocity of the moving plate, ms^{-1}

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