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Turbulent Hydro magnetic Flow with Radiative Heat over Moving Vertical Porous Plate in a Rotating System

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Abstract: This paper entails numerical investigation of the combined effects of radiation, magnetic fields viscosity, porosity and rotation past a moving vertical porous plate on flow variables. The governing equations considered are reduced to specific form with respect to the geometry of the problem under study and resulted to non- linear partial differential equations. Turbulent modeling is done using the time-averaged approach known as Reynolds-averaged Navier–Stokes equations. The resulting final set of equations are non linear thus no analytical method could be applied to obtain the solution. They are converted to a system of linear equations and numerical techniques are used to obtain the approximate solutions. The solution is generated by computer generated program code developed in MATLAB version 7.90.529(R2009b). Graphical results showing the effects of varying various thermo physical parameters on the velocity and temperature profiles are presented and discussed. The results obtained are useful in engineering, mining, industries and many other scientific fields.

Index Terms— **Fluid, Magneto hydro magnetic, Turbulent.**

I. INTRODUCTION

The study of flows of electrically conducting fluids is known as magneto hydrodynamics. Such flows are relevant due to the applications they have in industries, engineering, mining, science and technological processes. Over the years, lots of researches pertaining to turbulent hydro magnetic flows have been done. Some of the works include; Seth *et al* [1] studied effects of Hall current and rotation on unsteady MHD Couette flow in the presence of an inclined angle of inclination of magnetic field. The results showed that magnetic field has accelerating influence on the fluid velocity in both the primary and secondary flow directions. Magiri *et al* [2] studied Hydro magnetic turbulent flow past a semi-infinite vertical plate subjected to heat flux. The results showed that increase in Hall parameter leads to an increase in primary velocity profiles.

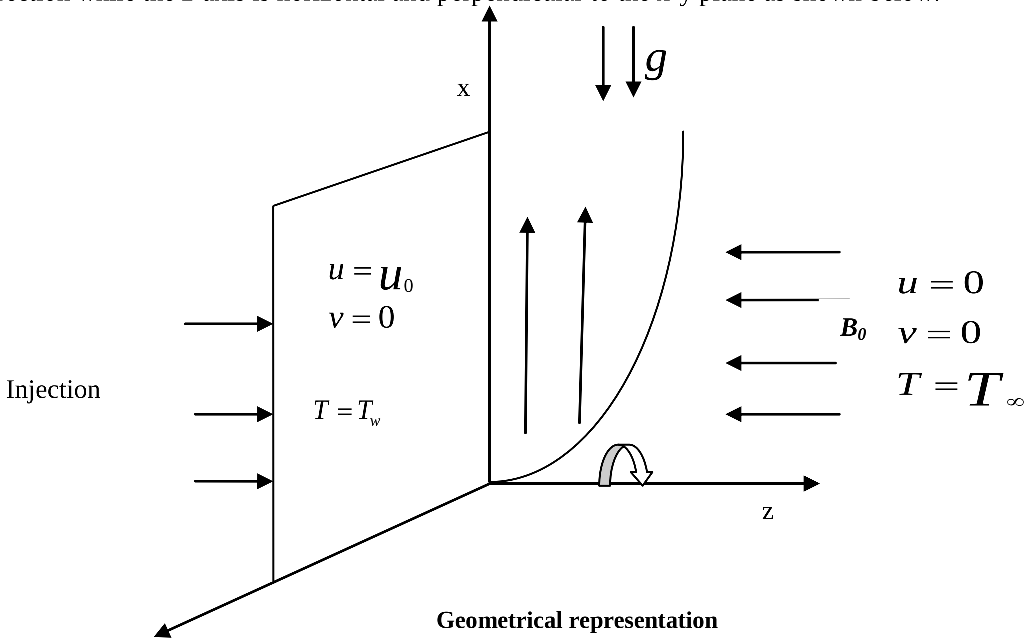
Idowu *et al* [3] Heat and mass transfer of magneto hydrodynamic (Mhd) and dissipative fluid flow past a moving vertical porous plate with variable suction. The conclusion was that as permeability parameter, increases the peak value of velocity tends to increase. Sigey *et al.* [4] studied Magneto hydrodynamic (MHD) free convective flow past an infinite vertical porous plate with joule heating and reveal that an increase in joules heating parameter causes an increase in the velocity and temperature profiles uniformly near the plate but remain constantly distributed away from the plate.

Sandeep, N., & Sugunamma, V. [5] investigated Radiation and Inclined Magnetic Field Effects on Unsteady Hydro magnetic Free Convection Flow past an Impulsively Moving Vertical Plate in a Porous Medium. It is observed that an increase in porosity parameter causes an increase in velocity. Kimeu. B. [6] Investigation of Hydro Magnetic Steady Flow between Two Infinite Parallel Vertical Porous Plates shows that as the suction velocity parameter increases the velocity decreases. Mayaka *et al* [7] studied MHD Turbulent flow in a porous medium with Hall currents, Joule's heating and mass transfer. He noted that the mass transfer velocity accelerates all the flow variables. This is because increased injection rates enhance transfer from the plate to the rest of the fluid which leads to enhanced boundary layers.

Dawit *et al* [8] examined turbulent hydro magnetic flow with radiative heat over a moving vertical plate in a rotating system and found that increases the secondary skin friction while an increase in the Ohmic heating, thermal radiation and Prandtl number decreases the secondary skin friction at the plate surface. More research has been carried out but none of them have comprehensively considered turbulent hydro magnetic flow with radiative heat past a moving vertical porous plate in a rotating system. This prompted the study.

II. MATHEMATICAL ANALYSIS

Consider turbulent flow of an incompressible fluid with radiative heat past a moving vertical porous plate in a rotating system in presence of a uniform magnetic field Bo. The fluid and the plate are moving upwards in the x-direction while the z-axis is horizontal and perpendicular to the x-y plane as shown below.



Geometrical representation

Initially the temperature of the plate and the fluid are assumed to be equal. At time t>0, the plate begins to move impulsively along the x-direction with initial velocity U_0 while its temperature is maintained at a temperature T_w which is higher than that of the surrounding T_∞. From the above geometry of problem, hydro magnetic flow of incompressible, viscous electrically conducting fluid in a rotating frame with radiative heat and Hall effects the equations governing the momentum along the x-direction, y-direction and the energy equation takes the form

Momentum equation in the x-direction

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} - 2v\Omega = v\nabla^2 u + \beta g(T - T_\infty) - \frac{\sigma B_0^2(u - mv)}{\rho(1+m^2)} - \frac{v}{k}u \tag{1}$$

Momentum equation in the y-direction

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} + 2u\Omega = v\nabla^2 v - \frac{\sigma B_0^2(v + mu)}{\rho(1+m^2)} - \frac{v}{k}v \tag{2}$$

Energy equation

$$\rho C_p\left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} - w_0\frac{\partial T}{\partial w}\right) = k\nabla^2 T + \mu\phi - \frac{\partial q_r}{\partial z} - \sigma B_0^2\left(\frac{(mv-u)^2 + (v+mu)^2}{(1+m^2)^2}\right) \tag{3}$$

Turbulent modeling

Turbulent flows are flows characterized by rapid fluctuations in flow variables with respect to time and space. Many approaches can be employed to account for turbulence in flow but this paper considers Reynolds Averaged Navier Stokes equations approach to transform equations governing the lamina flow into turbulent flows. Under this approach, a general variable say ψ for a given turbulent flow at a given instant is given

$\psi = \overline{\psi} + \psi'$ where $\overline{\psi}$ is the mean value that lays the basis of studying spatial variation while ψ' is the fluctuating component. Using this averaging technique together with Boussinesq approximations and turbulent mixing length hypothesis, the equations governing the turbulent flow takes the form;

$$\frac{\partial \bar{u}}{\partial t} - w_0 \frac{\partial \bar{u}}{\partial z} - 2\bar{v}\Omega = \nu \frac{\partial^2 \bar{u}}{\partial z^2} + \frac{d}{dz}\left(n^2 z^2 \left(\frac{\partial \bar{u}}{\partial z} \right)^2 \right) + \beta g\left(\bar{T} - T_\infty\right) - \frac{\sigma B_0^2 (\bar{u} - m\bar{v})}{\rho(1+m^2)} - \frac{\nu}{k}\bar{u} \tag{4}$$

$$\frac{\partial \bar{v}}{\partial t} - w_0 \frac{\partial \bar{v}}{\partial z} + 2\bar{u}\Omega = \nu \frac{\partial^2 \bar{v}}{\partial z^2} + \frac{\partial}{\partial z}\left(n^2 z^2 \left(\frac{\partial \bar{v}}{\partial z} \right)^2 \right) - \frac{\sigma B_0^2 (\bar{v} + m\bar{u})}{\rho(1+m^2)} - \frac{\nu}{k}\bar{u} \tag{5}$$

$$\frac{\partial \bar{T}}{\partial t} - w_0 \frac{\partial \bar{T}}{\partial z} = \bar{u}\frac{k\nabla^2 \bar{T}}{\rho C_p} + \frac{\partial}{\partial z}\left(\frac{n^2 z^2}{\Pr t} \frac{\partial \bar{u}}{\partial z} \frac{\partial \bar{T}}{\partial z} \right) - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial z} + \frac{\mu}{\rho C_p}\left(\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 \right) \tag{6}$$

From the assumptions made, the boundary conditions

$$\bar{u} = U_0, \quad \bar{v} = 0 \quad \bar{T} = T_w \quad \text{at } z = o \tag{7}$$

$$\bar{u} = 0, \quad \bar{v} = 0 \quad \bar{T} = T_\infty \quad \text{at } z = \infty \tag{8}$$

Transforming equations 4-6 and the boundary conditions into their corresponding dimensionless forms yields;

$$\frac{\partial U}{\partial t} - w_0 \frac{\partial U}{\partial \eta} - 2RV = \frac{\partial^2 U}{\partial \eta^2} + \frac{\partial}{\partial \eta}\left(n^2 \eta^2 \left(\frac{\partial U}{\partial \eta} \right)^2 \right) + Gr\theta - M\left(\frac{U - mV}{1+m^2} \right) - XU \tag{9}$$

$$\frac{\partial V}{\partial t} - w_0 \frac{\partial V}{\partial \eta} - 2RU = \frac{\partial^2 V}{\partial \eta^2} + \frac{\partial}{\partial \eta}\left(n^2 \eta^2 \left(\frac{\partial V}{\partial \eta} \right)^2 \right) - M\left(\frac{V + mU}{1+m^2} \right) - XV \tag{10}$$

$$\frac{\partial \theta}{\partial t} - wo \frac{\partial \theta}{\partial \eta} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial \eta^2} + \frac{\partial}{d\eta}\left(\frac{n^2 \eta^2}{\Pr_t} \frac{\partial U}{\partial \eta} \frac{\partial \theta}{\partial \eta} \right) + Nr\theta + Ec\left(\left(\frac{\partial U}{\partial \eta} \right)^2 + \left(\frac{\partial V}{\partial \eta} \right)^2 \right) +$$

$$MEc\left(\frac{(U - mV)^2 + (V + mU)^2}{(1+m^2)^2} \right) \tag{11}$$

The boundary conditions in their non dimensional form are:

$$U = 1, \quad V = 0, \quad T = 1 \quad \text{at } \eta = o \tag{12}$$

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$$U = 0, \qquad V = 0 \qquad T = 0 \text{ at } \eta = \infty \tag{13}$$

Solution procedure

The partial derivatives of U, V *and* T are expressed using finite difference approximation. The equations in finite differences form are re-arranged to yield the following;

$$\begin{aligned}
U_i^{k+1} = {} & (U_i^k + \frac{\Delta t Wo}{2\Delta\eta}\left(-U_{i-1}^{k+1} + U_i^k - U_{i-1}^k\right) + \Delta t R\left(V_i^{k+1} + V_i^k\right) + \frac{\Delta t}{2(\Delta\eta)^2} \\
& \left(U_{i+1}^{k+1} + U_{i-1}^{k+1} + U_{+1i}^k - 2U_i^k + U_{i-1}^k\right) + \frac{N^2\eta_i\Delta t}{8(\Delta\eta)^2}\left(U_{i+1}^{k+1} - U_{i-1}^{k+1} + U_{i+1}^k - U_{i-1}^k\right)^2 + \frac{(N\eta_i)^2\Delta t}{4(\Delta\eta)^3} \\
& \left(U_i^{k+1} - U_{i-1}^{k+1} + U_i^k - U_{i-1}^k\right)\left(U_{i+1}^{k+1} + U_{i-1}^{k+1} + U_{+1i}^k - 2U_i^k + U_{i-1}^k\right) + \frac{Gr\theta\Delta t}{2}\left(T_i^{k+1} + T_i^k\right) \\
& - \frac{\Delta t M}{2\left(1+m^2\right)}\left(\left(U_i^k\right) - m\left(V_i^{k+1} + V_i^k\right)\right) - \frac{X\Delta t}{2}U_i^k)/(1 - \frac{\Delta t Wo}{2\Delta\eta} + \frac{\Delta t}{(\Delta\eta)^2} - \frac{(N\eta_i)^2\Delta t}{2(\Delta\eta)^3} \\
& \left(U_i^{k+1} - U_{i-1}^{k+1} + U_i^k - U_{i-1}^k\right) + \frac{\Delta t M}{2\left(1+m^2\right)} + \frac{X\Delta t}{2})
\end{aligned}$$

$$\begin{aligned}
V_i^{k+1} = {} & (V_i^k + \frac{\Delta t Wo}{2\Delta\eta}\left(-V_{i-1}^{k+1} + V_i^k - V_{i-1}^k\right) + \Delta t R\left(U_i^{k+1} + U_i^k\right) + \\
& \frac{\Delta t}{2(\Delta\eta)^2}\left(V_{i+1}^{k+1} + V_{i-1}^{k+1} + V_{+1i}^k - 2V_i^k + V_{i-1}^k\right) + \frac{N^2\eta_i\Delta t}{8(\Delta\eta)^2}\left(V_{i+1}^{k+1} - V_{i-1}^{k+1} + V_{i+1}^k - V_{i-1}^k\right)^2 \\
& + \frac{(N\eta_i)^2\Delta t}{4(\Delta\eta)^3}\left(V_i^{k+1} - V_{i-1}^{k+1} + V_i^k - V_{i-1}^k\right)\left(V_{i+1}^{k+1} + V_{i-1}^{k+1} + V_{+1i}^k - 2V_i^k + V_{i-1}^k\right) \\
& - \frac{\Delta t M}{2\left(1+m^2\right)}\left(m\left(U_i^{k+1} + U_i^k\right) + \left(V_i^k\right)\right) - \frac{X\Delta t}{2}V_i^k)/(1 - \frac{\Delta t Wo}{2\Delta\eta} + \frac{\Delta t}{(\Delta\eta)^2} \\
& - \frac{(N\eta_i)^2\Delta t}{2(\Delta\eta)^3}\left(V_i^{k+1} - V_{i-1}^{k+1} + V_i^k - V_{i-1}^k\right) + \frac{\Delta t M}{2\left(1+m^2\right)} + \frac{X\Delta t}{2})
\end{aligned}$$

$$\begin{aligned}
T_i^{k+1} = {} & (T_i^k + \frac{Wo}{2\Delta\eta}\left(-T_{i-1}^{k+1} + T_i^k - T_{i-1}^k\right) + \frac{\Delta t}{2\Pr(\Delta\eta)^2}\left(T_{i+1}^{k+1} + T_{i-1}^{k+1} + T_{+1i}^k - 2T_i^k + T_{i-1}^k\right) + \\
& \frac{Nr\theta\Delta t}{2}T_i^k + \frac{N^2\eta_i\Delta t}{4\Pr t(\Delta\eta)^2}\left(U_i^{k+1} - U_{i-1}^{k+1} + U_i^k - U_{i-1}^k\right)\left(T_{i+1}^{k+1} - T_{i-1}^{k+1} + T_{i+1}^k - T_{i-1}^k\right) + \\
& \frac{(N\eta_i)^2\Delta t}{4\Pr t(\Delta\eta)^3}\left(U_i^{k+1} - U_{i-1}^{k+1} + U_i^k - U_{i-1}^k\right)\left(T_{i+1}^{k+1} + T_{i-1}^{k+1} + T_{+1i}^k - 2T_i^k + T_{i-1}^k\right) \\
& + \frac{(N\eta_i)^2\Delta t}{8\Pr t(\Delta\eta)^3}\left(T_{i+1}^{k+1} - T_{i-1}^{k+1} + T_{i+1}^k - T_{i-1}^k\right)\left(U_{i+1}^{k+1} - 2U_i^{k+1} + U_{i-1}^{k+1} + U_{i+1}^k - 2U_i^k + U_{i-1}^k\right) \\
& + \frac{Ec\Delta t}{4(\Delta\eta)^2}\left[\left(U_i^{k+1} - U_{i-1}^{k+1} + U_i^k - U_{i-1}^k\right)^2 + \left(V_i^{k+1} - V_{i-1}^{k+1} + V_i^k - V_{i-1}^k\right)^2\right] \\
& + \frac{MEc\Delta t}{4\left(1+m^2\right)^2}\left[\left(\left(U_i^{k+1} + U_i^k\right)^2 - m\left(V_i^{k+1} + V_i^k\right)^2\right)\right]/(1 - \frac{Wo\Delta t}{2\Delta\eta} + \frac{\Delta t}{\Pr(\Delta\eta)^2} - \\
& \frac{(N\eta_i)^2\Delta t}{2\Pr t(\Delta\eta)^3}\left(U_i^{k+1} - U_{i-1}^{k+1} + U_i^k - U_{i-1}^k\right) - \frac{Nr\theta\Delta t}{2})
\end{aligned}$$

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subject to the conditions:

$$U(\eta,0)= 1, V(\eta,0)= 0\, and\, T(\eta,0)= 1\} \quad t<0$$

$$U(0,k)= 1, V(0,k)= 0\, and\, T(0,k)= 1\} \quad k>0$$

$$U(\eta,k)= 0, V(\eta,k)= 0\ and\ \ T(\eta,k)= 0 \quad k>0$$

The solution is generated using a computer code written in MATLAB software to produce the results shown.

III. RESULTS AND DISCUSSION

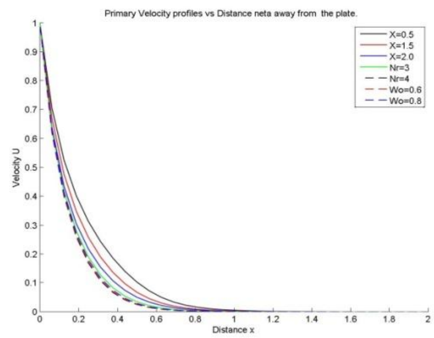

Fig 1

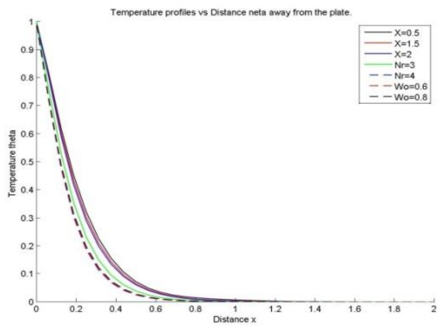

Fig 2

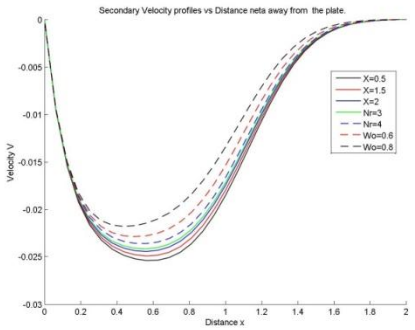

fig 3

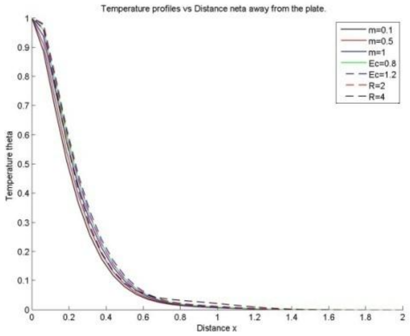

fig 4

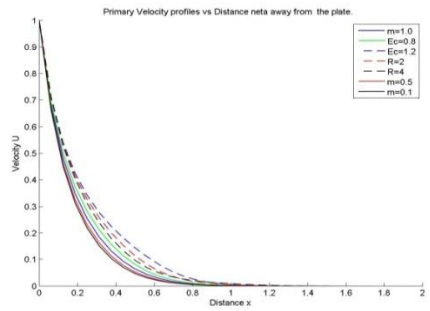

fig 5

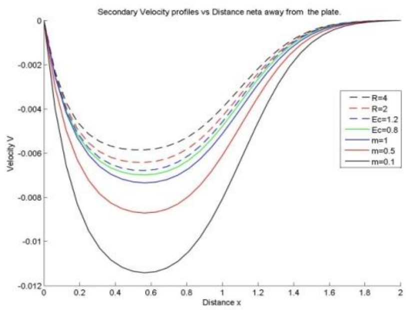

fig 6

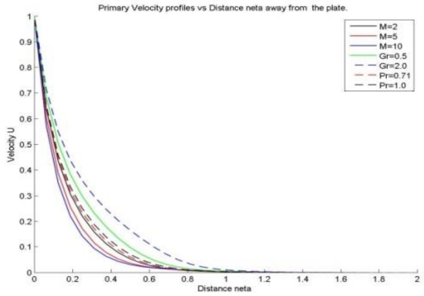

fig 7

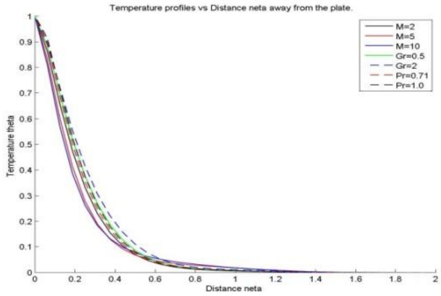

fig 8

The figures 1 and 2 show that increase in permeability parameter leads to a decrease in magnitude of both the primary and secondary velocity profiles of the flow. Figure.3 shows increase in permeability parameter results to a decrease in temperature of the fluid. Increase in permeability parameter increases the porosity of the plate. Increased porosity reduces the acceleration of the flow and in turn primary and secondary velocities decreases. Reduced acceleration decreases the movement of particles (convection) and thus reduces transfer of heat and temperature leading to decrease in primary velocity profiles and temperature profiles. Radiation emitted by a body is due to thermal agitation of its molecules. Heat loss leads to temperature decrease and thus thermal boundary layer of the fluid reduces. Reduced temperature of the fluid flow due to radiation leads to decreased kinetic energy of the fluid particles. This is reflected by reduction of the velocity profiles of the fluid. Increase in the magnitude of the Injection parameter w_0 leads to an increase in the velocity and temperature profiles respectively.

Figures 4, 5 and 6 show; increase in Eckert number results to increase in both primary and secondary velocity profiles. Increase in Eckert number may be 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 also increases the increases the movement (kinetic energy) of the fluid particles which results to increase in primary as well as secondary velocity profiles of the fluid. Increase in Hall parameter m enhances both primary and secondary velocity profiles. This is due to the fact that the effective conductivity decreases with the increase in Hall parameter which reduces the magnetic damping force hence the increase in velocity. From figure 4 increase in the value of rotation R results to decrease in the magnitude of primary velocity profiles but increase in secondary velocity profiles. This is because increase in rotation parameter implies that angular velocity is increased which more or less disorients and retards the fluid motion decreasing the fluid primary velocity while increasing secondary velocity.

Figures 7 and 8 show variation of velocity and temperature profiles with change in local Grashoff number Gr. In figure 7 it is noted that the momentum layer thickness is enhanced by cooling (Gr>0) of the plate by convection currents due to buoyancy forces and velocity decreases with heating of the plate by convectional currents (Gr>0). Figure 8 shows that the fluid temperature within the boundary layer regime is enhanced by plate cooling while the heating of the plate by buoyancy force decreases the boundary layer thickness. This can be explained by the fact that the heat is transferred from the plate to the fluid by buoyancy force during cooling leading to a rise in the mean temperature. Figures 7 and 8 shows that primary and secondary velocity profiles diminish with increase in magnetic parameter while the thermal boundary layer is enhances by temperature increase. Introduction of strong magnetic field normal to the direction of electrically conducting fluid results to emergence of a resistive force to not only the main flow but also secondary flow. This resistive force called Lorentz force resists the flow of fluid resulting to deceleration of the fluid and thus the fluid velocity profiles reduces. Figure 8 shows that increase in magnetic parameter M results to slight rise in temperature of the fluid. The increased fluid temperature results to non- uniform changes in fluid properties such as fluid density and conductivity. Thus energy is converted from electrical power supply to the fluid or any other medium that is in thermal contact. This heat is known as joules heating.

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IV. CONCLUSION

Numerical investigation of the combined effects of radiation, magnetic fields, viscosity, porosity and rotation past a moving vertical porous plate in a rotating system has been carried out. The results obtained more or less agree with those obtained from earlier published works by other authors. This proves the validity of the developed governing equations as well as the method of solution. The future scope of work can factor in ion slip currents, variable magnetic field and variable suction.

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Nomeclature

Roman Symbol **Quantity**

Gr_θ : Local temperature Grashoff number

m: Hall parameter

M: Magnetic parameter

q_r: Radiative heat flux, $[Wm^{-2}]$

X: Permeability parameter

R: Rotation parameter

K: Thermal conductivity of porous medium, $[wm^{-1}K^{-1}]$

U_i : Velocity tensor, $[ms^{-1}]$

k :Darcy permeability, $[m^2]$

Pr: Prandtl number

Ec: Eckert number

ρ: Fluid density, $[kgm^{-3}]$

μ: coefficient of viscosity, $[kgm^{-1}s]$

ϕ: Viscous dissipation functions, $[s^{-1}]$

Ω: Angular velocity, $[s^{-1}]$

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