

# Unsteady Magnetohydrodynamic (Mhd) Free Convective Isothermal Vertical Plate in A Porous Medium with Radiation Effect

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## ABSTRACT

Unsteady MHD free convection isothermal vertical plate in a porous medium with radiation effect has been studied numerically. Implicit finite difference technique is used as the main tool for the numerical approach. Numerical solutions for the effects of radiation on a MHD convective heat transfer past a semi-infinite porous plate with a magnetic field are obtained. It is assumed that the porous plate moves with a constant velocity in the direction of fluid flow, and the free stream velocity follows the exponentially increasing small numerical law. The magnetic field acts perpendicular to the porous surface which absorbs the fluid with a suction velocity varying with time. The governing equations for the flow are transformed into a system of nonlinear ordinary differential equations by implicit finite difference technique and then are solved numerically by using the numerical method. A representative set of computational results for the velocity, temperature and concentration profiles as well as Local skin-friction coefficient, Local Nusselt number and Local Sherwood number are presented graphically for various governing parameters such as Magnetic parameter, Reynolds number, Eckert, Schmidt number, and Kinematics. In the present analysis various comparisons with previously published work are performed and the results are found to be in a good agreement.

**Keywords:** Isothermal, free convective, thermal radiation, Mass fluxes, heat generating.

### Nomenclatures

MHD Magneto-hydrodynamic  
Pr. Prandtl number  
 $\nu$  Ratio of kinematics viscosity  
Sc. Schmidt number  
D. Coefficient of mass diffusion  
Gr. Grashof number  
d. Radiative heat flux  
Ec Dissipation parameter  
 $k$  Permeability,  
K Thermal conductivity,

$c_p$  Specific Heat at Constant Pressure,  
 $c_s$  Concentration Susceptibility,  
q Constant Heat flux per unit area  
s Micro rotational constant  
 $D_m$  Coefficient of mass diffusivity  
 $k_T$  Thermal diffusion ratio  
K Thermal conductivity  
Q Constant heat flux per unit area  
J Micro inertia per unit mass

## 1.0 INTRODUCTION

It is known that the effects of radiation on MHD flow and heat transfer problem have become more important industrially. At high operating temperature, radiation effects can be quite significant. The investigations on free convection flow with thermal radiation and mass transfer past a moving vertical porous plate was studied by Makinde (2005). Muchumaraswamy and Ghetta (2013) analyzed the chemical reaction effects on MHD flow past a linearly accelerated vertical plate with variable temperature and mass diffusion in the presence of thermal radiation. Many processes in engineering areas occur at high temperature and a knowledge of radiation heat transfer becomes very important for the design of the pertinent equipment. Nuclear power plants, gas turbines and the various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering areas Abdul and Amer (2019). Convection boundary layer with suction and mass transfer in a porous medium was studied by Bajwa *et al.* (2022). His results confirmed the hypothesis that suction stabilizes the boundary layer

and allows the most efficient method in boundary layer control yet known.

In spite of all these studies, the unsteady MHD convective heat transfer in the presence of radiation has received attention such as Hermamalini and Kumar (2015), Srihari *et al.* (2017), Ojemeru *et al.* (2019), Kumar *et al.* (2019), Yasin *et al.* (2019). Hence, the main objective of the present investigation is to consider the case of a semi-infinite moving porous plate in a porous medium with the presence of radiation and constant velocity in the flow direction when the magnetic field is imposed transverse to the plate and subjected to variable suction. It is also assumed that an exponential variation with time is imposed to temperature. Jha *et al.* (2018) studied the combined effect of suction/injection MHD free-convection flow in a vertical channel with thermal radiation.

In science and in many engineering applications such as in condensation, evaporation, and chemical process, many transport processes are influenced by the combined action of the buoyancy forces from both heat and mass diffusion. Heat and mass transfer

combined effects are studied extensively due to their significant role in chemical processing equipment, oceanic circulation, emergency cooling system of advanced nuclear reactors, cooling process of plastic sheets, formation and dissipation of the fog, processing and drying the food, temperature distribution and moisture of agriculture fields, and production of polymer. Anwar *et al.* (2021) studied unsteady MHD natural convection flow of casson fluid incorporating thermal radiative flux and heat injection/suction mechanism under variable wall conditions. The analysis of bio-convective MHD Blasius and Sakiadis flow with Cattaneo-Christov heat flux model and chemical reaction was analyzed by Ali *et al.* (2022).

In recent years, a lot of practical applications attracted many scientists and engineers to pay a considerable amount of focus to learn the heat and mass effects either analytically or numerically. In industrial and engineering processes, most fluids are non-Newtonian, Goud (2020) and Krishna (2021). Since the non-Newtonian fluids deal more complexities due to the rheological behavior than Newtonian fluids, distinct models were proposed. Some research scholars committed to the study of MHD through a porous medium in the presence of rotation effect includes Vijayalakshmi and Ravikumar (2016), Khan and Mustafa (2019), Mythrey and Hyderabad (2023), Hamza and Abdusalam (2023), Emanuel and Jabaka (2022), Krishna (2022) among others. The influence of heat and mass transfer in the non-Newtonian fluid is an important subject from the theoretical as well as practical point of view due to its abundant applications in industry and engineering. Common examples include polymer extrusion, the emergency cooling system of nuclear reactors, food processing, thermal welding, to name a few. Convective flow is a self-sustained flow with the effect of the temperature gradient was analysed by Noor *et al.* (2020). In literature, different theories are made to see the occurrence of heat and mass transfer in convective flows of different fluids. Thermal radiation is an important factor in the thermodynamic analysis of many high temperature systems like solar collectors, boilers and furnaces. The simultaneous effect of heat and mass transfer in the presence of thermal radiation plays an important role in manufacturing industries for the design of fins, steel rolling, nuclear power plants, cooling of towers, gas turbines and various propulsion device for aircraft, materials processing, energy utilization, temperature measurements, remote sensing for astronomy and space exploration, food processing and cryogenic engineering, as well as numerous agricultural, health and military applications.

Magneto-hydro-dynamics plays an important role in agriculture, petroleum industries, geophysics and in

astrophysics. MHD flow has application in metrology, solar physics and in motion of earth's core. Krishna (2021) also considered applications in the field of stellar and planetary magnetospheres, aeronautics, chemical engineering and electronics. In the field of power generation, MHD is receiving considerable attention due to the possibilities it offers for much higher thermal efficiencies in power plants. It is also found useful in magnetic control of molten iron flow in the steel industry, liquid metal cooling in nuclear reactors, magnetic suppression of molten semi-conducting materials and meteorology. It is being observed that the radiation effects on MHD convective flows with heat transfer has got remarkable importance in every concern field. In related development the effect of chemical reaction on unsteady MHD free convective flows past a vertical porous plate embedded in a porous medium with variable suction was conducted by Mythrey and Hyderabad (2023). So many scientists and technologists are taking keen interesting the study of MHD convective flows so that their results so obtained may be applied with great accuracy in respective fields.

The main objective of this work is to investigate the significant influence of time dependent MHD natural convection flow, isothermally vertical plates in a porous medium with radiation effect.

## 2.0 MATHEMATICAL FORMULATION

Initially, it is considered that the fluid particles and the plate are at rest at the same temperature  $\bar{T}$  ( $= T_\infty$ ) with the same species concentration level  $\bar{C}$  ( $= C_\infty$ ) at all points, where  $T_\infty$  and  $C_\infty$  are fluid temperature and concentration of uniform flow respectively. The physical configuration and coordinate system of this study is presented in fig. 2.

In addition the analysis is based on the following assumptions;

- i. The viscous dissipation and joule heating terms in the energy equation have been considered for high speed flow as well as a constant heat source is used for heat generation. A time dependent free convective MHD heat and mass transfer flow of electrically conducting incompressible viscous micropolar fluid through an electrically non conducting infinite vertical porous medium with constant suction velocity is considered here. The flow is assumed to be in the x- direction, which is chosen along the medium in upward direction and y-axis is normal to it. A transverse field B is applied normal to the flow region.

- ii. The physical properties of fluid are considered to be constant, the variation of the influence of density with temperature is assumed only in the body force term, in accordance with the Boussinesq's approximation.
- iii. Since the fluid motion is unsteady and the plate is infinite extent then all the flow variables will depend only on  $y$  and time ( $\tau$ ).
- iv. Micro rotational vector is of the form  $\vec{G}=(0,0,\bar{\Gamma})$  where  $\bar{\Gamma}$  is the micro-rotational component.
- v. The magnetic Reynolds number of the flow is taken to be small enough so that the induced magnetic field is negligible in comparison with the applied transverse magnetic field.

With the frame work of stated above, the equation relevant to unsteady free convective heat and mass transfer problem of micropolar fluid are governed by the following system of non-linear partial differential equations under the boundary layer approximations,

Governing Equations

Under the foregoing assumptions and using the model proposed.

$$\frac{\partial u^1}{\partial t^1} = g\beta(T^1 - T_\infty^1) + g\beta^*(C^1 - C_\infty^1) + V \frac{\partial^2 u^1}{\partial y^2} - \frac{\sigma\beta_0^2 U^1 V_0^1}{\rho V} - V \frac{U^1 V_0^2}{KV} \quad (1)$$

$$\rho c_p \frac{\partial T^1}{\partial t^1} = K \frac{\partial^2 T^1}{\partial y^2} - \frac{\partial q^r}{\partial y} \quad (2)$$

$$\frac{\partial C^1}{\partial t^1} = D \frac{\partial^2 C^1}{\partial y^2} - \alpha(C - C_\infty) \quad (3)$$

where  $y$  is Cartesian coordinate;  $u, v$  are velocity components;  $g$  is the local acceleration due to gravity,  $\beta$  is thermal expansion coefficient,  $\beta^*$  is concentration expansion coefficient,  $U$  kinematic viscosity,  $\rho$  is the density,  $\chi$  is the vortex viscosity,  $\sigma$  is electrical conductivity,  $K$  is the permeability,  $j$  is microinertia per unit mass,  $\gamma$  is spin-gradient viscosity,  $k$  is thermal conductivity,  $c_p$  is the specific heat at constant pressure,  $c_s$  is a concentration susceptibility,  $Q$  is constant heat flux per unit area,  $s$  is a micro rotational constant,  $D_m$  is the coefficient of mass diffusivity,  $k_T$  is the thermal diffusion ratio.

The appropriate initial and boundary conditions for the problem are given by,  $\tau \leq 0, u = 0, \bar{\Gamma} = 0, \bar{T} \rightarrow T_\infty, \bar{C} \rightarrow C_\infty$  every where

$$\tau > 0, u = 0, \bar{\Gamma} = -s$$

$$\frac{\partial u}{\partial y}, \frac{\partial \bar{T}}{\partial y} = -\frac{Q}{k}, \frac{\partial \bar{C}}{\partial y} = -\frac{m}{D_m} \text{ at } y = 0$$

$$u = 0, \bar{\Gamma} = 0, \bar{T} \rightarrow T_\infty, \bar{C} \rightarrow C_\infty \text{ as } y \rightarrow \infty$$

The non-dimensionless quantities are given as:

$$U = \frac{U_1}{U_0} \Rightarrow U^1 = Uu_0, \partial u^1 = \partial Uu_0, \partial^2 u^1 = \partial^2 Uu_0$$

$$t = \frac{t^1 U_0^2}{V} \Rightarrow t^1 U_0^2 = tv, \quad t^1 = \frac{tv}{U_0^2}, \quad \partial t^1 = \frac{\partial tv}{U_0^2}$$

$$Y = \frac{yU_0}{V} \Rightarrow yU_0 = YV, \quad y = \frac{YV}{U_0}, \quad \partial y^2 = \frac{\partial Y^2 V^2}{U_0^2}$$

$$\theta = \frac{T^1 - T_\infty^1}{T_\omega^1 - T_\infty^1} \Rightarrow T^1 - T_\infty^1 = \theta(T_\omega^1 - T_\infty^1), T^1 = T_\infty^1 + \theta(T_\omega^1 - T_\infty^1) = \partial T^1 = \partial \theta(T_\omega^1 - T_\infty^1) + \partial T_\infty^1 = \partial^2 T^1 = \partial^2 \theta(T_\omega^1 - T_\infty^1) + \partial^2 T_\infty^1$$

$$c = \frac{C^1 - C_\infty^1}{C_\omega^1 - C_\infty^1} \Rightarrow C^1 - C_\infty^1 = c(C_\omega^1 - C_\infty^1) = C^1 = C_\infty^1 + c(C_\omega^1 - C_\infty^1)$$

$$R = \frac{1ba^*V^2\sigma T_\infty^3}{KU_0^2}, \quad M = \frac{\sigma\beta_0^2 U}{\rho}, \quad Pr = \frac{NCP}{K},$$

$$Sc = \frac{V}{D}, \quad Gr = \frac{g\beta V(T_\omega - T_\infty)}{U_0^3}$$

Substituting the non-dimensional quantities into equation (1), (2) and (3) we get,

$$\frac{\partial U}{\partial t} = Gr\theta + GcC + \frac{\partial^2 U}{\partial Y^2} - MU - KU \quad (4)$$

$$\frac{\partial \theta}{\partial Y^2} = Pr \frac{\partial \theta}{\partial t} - R\theta \quad (5)$$

$$\frac{\partial \phi}{\partial t} = \frac{1}{Sc} \frac{\partial^2 \phi}{\partial Y^2} - \alpha\phi \quad (6)$$

### 3.0 SOLUTION TO THE PROBLEM

Using the method of implicit finite difference solution to obtained the result of velocity, concentration, and temperature equations:

$$r_1 U_i^j (M - K) + (Gr\theta_i^j + GcC_i^j)r_1 = U_1^{j+1}r_2(1 - 2) + U_{i-1}^j r_2 \quad (7)$$

$$R\theta_i^j r_1 - Pr\theta_1^j = (\theta_{i-1}^{j+1}r_2 + r_2\theta_1^{j+1}(1 - Pr + 2)) \quad (8)$$

$$+r_1(1 - \alpha) = \frac{1}{Sc}(1 - 2)\phi_1^{j+1}r_2 - \phi_{i-1}^{j+1}r_2 \quad (9)$$

Solving equations (7-8) with the boundary conditions, using 3point formula for velocity, temperature and concentration equations, we get,

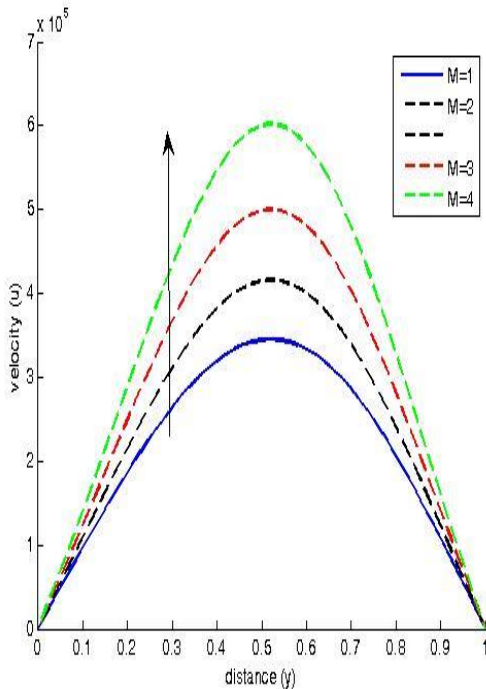
$$r_2 \frac{(2U_1^{j+1} - U_2^{j+1} + 2\Delta Y)}{3} + U_0^j r_2 = r_1 U_1^j (M - K) + (Gr\theta_1^j + GcC_1^j)r_1 \quad (10)$$

$$\left(\frac{4r_2}{3} + 1 + Pr - 2r_2\right)\theta_1^{j+1} + \left(\frac{r_2}{3} - r_2\right)\theta_2^{j+1} - \frac{2}{S}\Delta Y = (R_1^r - Pr)\theta_1^j \quad (11)$$

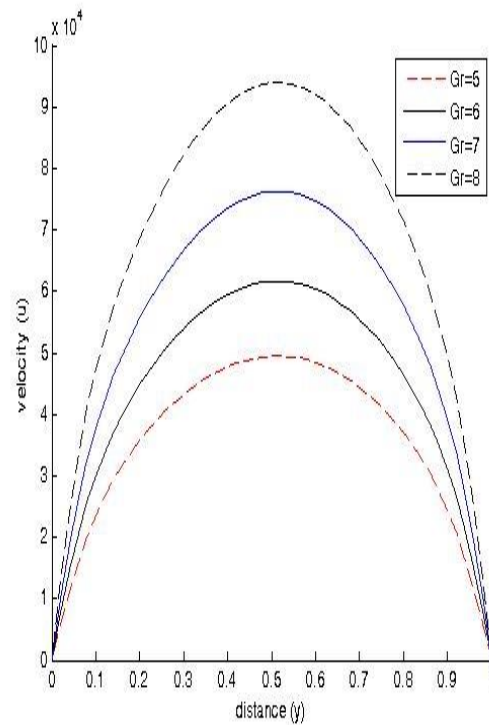
$$r_1(1 - \alpha)\phi_1^j = r_2 \frac{1}{Sc} (1 - 2) \frac{-4\phi_1^{j+1} + \phi_2^{j+1} - \frac{2\Delta Y}{S}}{3} - \frac{(2u_1^{j+1} - u_2^{j+1} + 2\Delta Y)}{3} r_2 \quad (12)$$

**4.0 RESULTS AND DISCUSSION**

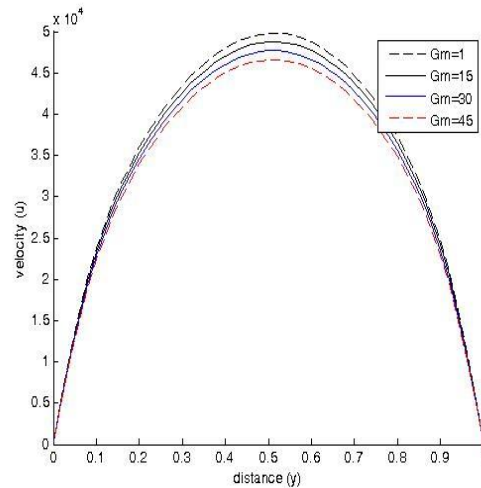
This study examined the MHD free convective heat generating micropolar fluid flow through a porous medium with thermal radiation, constant heat and mass fluxes. The system of governing equations is formulated, analyzed and solve using implicit finite difference scheme. To point out the effect of physical parameters namely Grashof number Gr, Mass Grashof number Gm, Prandtl number Pr, Schmidt number Sc, Time t, Radative parameter F, the investigation is performed using the basic dimensionless parameters that governed the flow, to be specific the following choices were made; Pr = 0.71 which correspond to air, Sc = 0.26, and Gr > 4.



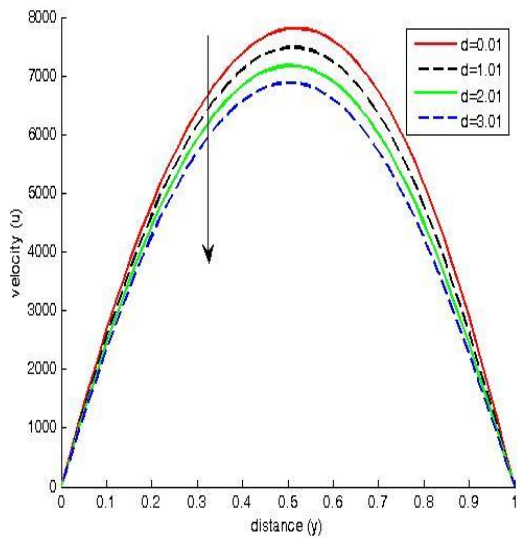
**Figure 4.1:** Velocity profile for difference value M. Effect of magnetic parameter on velocity when d =0.01, A =0.1, Pr =0.71, dt=0.002, dy = 1/m, y =0:dy:1, DY2=2.0\*dy, Ec = 0.001, Da = 0.02, Gr = 5, Gm = 5, and S =0.5.



**Figure 4.2:** Velocity profile for difference value Gr. Effect of Grashof number on velocity when dd=0.01, A =0.1, Pr =0.71, dt=0.002, dy = 1/m, y =0:dy:1, DY2=2.0\*dy, Ec = 0.001, Da = 0.02, M = 1, Gm = 5, and S =0.5.

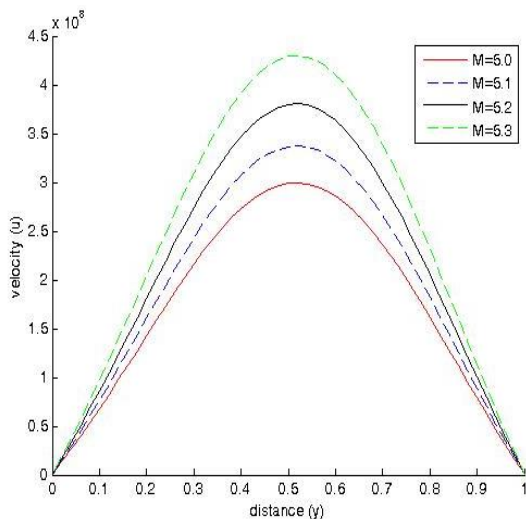


**Figure4.3:** Velocity profile for difference value Gm. Effect of modified Grashof Number on velocity when d =0.01, A =0.1, Pr =0.71, dt=0.002, dy = 1/m, y =0:dy:1, DY2=2.0\*dy, Ec = 0.001, Da = 0.02, Gr = 5, M = 1, and S =0.5.

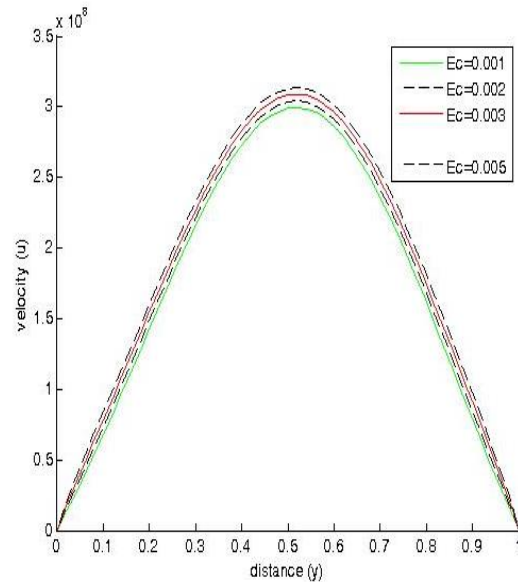


**Figure 4.4 :**Velocity profile for difference value d. Effect of micro-rotational number on velocity when  $A = 0.1$ ,  $Pr = 0.71$ ,  $dt=0.002$ ,  $dy = 1/m$ ,  $y = 0:dy:1$ ,  $DY2=2.0*dy$ ,  $Ec = 0.001$ ,  $Gm = 5$ ,  $Gr = 5$ ,  $M = 1$ , and  $S = 0.5$ .

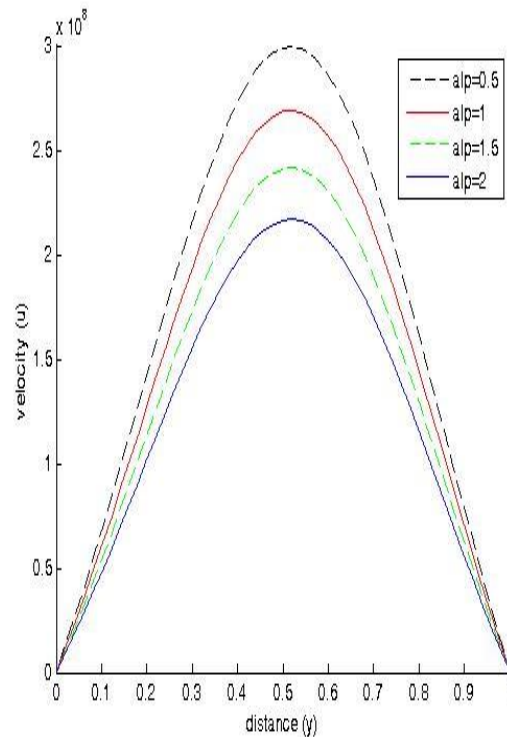
The result for the temperature profile were obtained and presented in figure 1 to 3. Figure 1 illustrate the effect of M in temperature, it is observed the temperature increases as M increase for fixed value of other parameters. This implies the as the external magnetic drag increases it makes the temperature of the fluid to go higher, the increase in magnetic parameter reduce the magnitude of velocity profile in the boundary layer and the temperature of the boundary layer will rise. Figure 4 we observed that as the value of (Ec) Eckert number increased the temperature also increased. In Figure 4.8 increase in heat source parameter ( $\alpha$ ) make the temperature to decrease as well. In Figure 5 we observed that temperature increase as  $\Delta = d$  decreases for fixed value of other parameters. Figure 6 illustrate the effect of Prandtl number on temperature profile the fluid temperature increases with decrease in Prandtl number Pr. Prandtl number controls the relative thickness of the momentum and thermal boundary, when the thermal boundary exceed the thickness in the velocity boundary layer then the temperature will be high



**Figure 4.5 :** Temperature profile for difference value M. Effect of magnetic parameter on temperature when  $d = 0.01$ ,  $A = 0.1$ ,  $Pr = 0.71$ ,  $alp = 2$ ,  $dt=0.002$ ,  $dy = 1/m$ ,  $y = 0:dy:1$ ,  $DY2=2.0*dy$ ,  $Ec = 0.001$ , and  $S = 0.5$ .

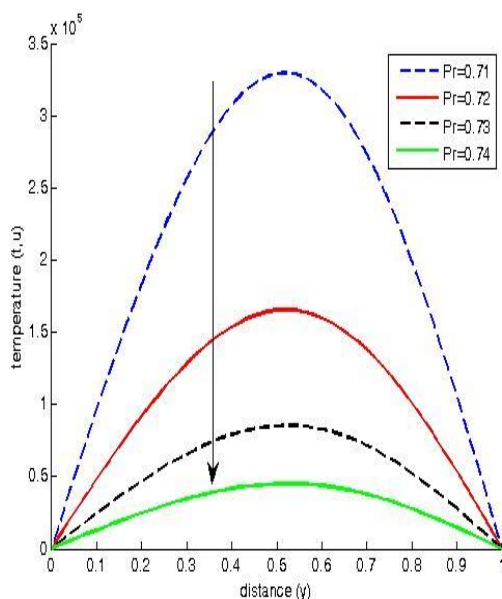


**Figure 4.6 :** Temperature profile for difference value Ec. Effect of Eckert Number on temperature when  $d = 0.01$ ,  $A = 0.1$ ,  $Pr = 0.71$ ,  $alp = 2$ ,  $dt=0.002$ ,  $dy = 1/m$ ,  $y = 0:dy:1$ ,  $DY2=2.0*dy$ ,  $M = 1$ , and  $S = 0.5$ .



**Figure 4.7 : Temperature profile for difference value  $\alpha$ . Effect of heat source number on temperature when  $d = 0.01$ ,  $A = 0.1$ ,  $Pr = 0.71$ ,  $Ec = 0.001$ ,  $dt = 0.002$ ,  $dy = 1/m$ ,  $y = 0:dy:1$ ,  $DY2 = 2.0 * dy$ ,  $M = 1$ , and  $S = 0.5$ .**

**Figure 4.8 : Temperature profile for difference value  $d$ . Effect of micro-rotational Number on temperature when  $\alpha p = 0.5$ ,  $A = 0.1$ ,  $Pr = 0.71$ ,  $Ec = 0.001$ ,  $dt = 0.002$ ,  $dy = 1/m$ ,  $y = 0:dy:1$ ,  $DY2 = 2.0 * dy$ ,  $M = 1$ , and  $S = 0.5$ .**



**Figure 4.9 : Temperature profile for difference value  $Pr$ . Effect of Prandtl Number on temperature when  $\alpha p = 0.5$ ,  $A = 0.1$ ,  $Pr = 0.71$ ,  $Ec = 0.001$ ,  $dt = 0.002$ ,  $dy = 1/m$ ,  $y = 0:dy:1$ ,  $DY2 = 2.0 * dy$ ,  $M = 1$ , and  $S = 0.5$ .**

## 5.0 CONCLUSION

Unsteady MHD free convective isothermal vertical plate in a porous medium with radiation effect have been studied numerically using implicit finite difference scheme, in the presence of radiative heat fluxes and constant heat source. The effects of different parameters such as prandtl number, modify Grashof of number, Mass Grashf number, Schmidt number and radiative effect were studied. The results for the flow of velocity, angular velocity, temperature and concentration were obtained and presented graphically.

This paper analysed the influence of magnetohydrodynamic free convective flows past a vertical porous plate in the presence of radiation effect. The following conclusion was summarized as follows.

- The effect of MHD investigates on the velocity profile shows that the velocity increases with a rise in MHD value ( $M$ ). It indicates that the hydromagnetic effect in the term  $MU^2$  of the momentum equation increases the velocity in the hot channel plates.
- The temperature profiles for the effect of radiative heat fluxes show that as the value of MHD increases so the velocity increases, this means that the external cooling of the channel plates which result in thickening the boundary layer and assist the velocity.
- It is also observed that as the Schmidt value  $Sc$  increase the concentration profile increases. A reverse flow is also noticed due to suction as demonstrated on concentration profile.

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