

Magnetohydrodynamic (MHD) Convective Flow through a Porous Medium with Magnetic and Chemical Reaction Characteristics

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ABSTRACT

In this analysis, MHD convective flow in a porous medium with magnetic and chemical reaction characteristics were examined. We modeled the governing Partial Differential Equations (PDEs) in dimensional form viz: continuity, momentum, energy and mass. Furthermore, using suitable dimensionless quantities they were transformed and Finite Difference Method (FDM) was employed to deduce approximations for the velocity, temperature and concentration. Numerical experiments were conducted to study and explain the influence of parameters of physical interest associated with the fluid flow. It is found that the concentration and velocity of the fluid rise with increase in negative values of chemical reaction and an opposite trend was seen when increased with positive values. It is also exhibited that the momentum boundary layer becomes lower as the Hartman number becomes significant.

Keywords: MHD, Free Convection, Chemical reaction, Heat and mass transfer.

1.0 INTRODUCTION

The Magnetohydrodynamics flow plays a vital role in engineering fields such as heat exchanger devices, petroleum reservoirs, chemical catalytic reactors and processes, geothermal and geophysical engineering, aerodynamic engineering and others. Effect of chemical reaction also occurs in many branches of science and engineering. Chemical processes have numerous industrial applications such as manufacturing of glassware, food processing, filtration and purification process in chemical engineering, etc., The effect of heat and mass transfer in the presence of MHD flow with chemical reaction has many applications in design of chemical processing equipment's, formation and dispersion of flog, food processing and cooling towers (Kavitha, 2021). Magnetohydrodynamics (MHD) is concerned with how magnetic fields in electrically conducting fluids change over time. MHD flow has applications in solar physics, astrophysics, geophysics, plasma physics, missile technology, and many other fields. So, many scientists and engineers are interested in its applications (Bordoloi *et al.*, 2023).

In modern metallurgical and physical procedures, the research of the magnetohydrodynamic (MHD) flow of electrically conductive fluid is actually of great significance as a result of the effect of the magnetic field on the regulation of the boundary layer flow control as well as the effectiveness of numerous systems utilizing electrically conductive fluids. its application in many engineering problems, this kind of flow has attracted the focus of several researchers (Reddy *et al.*, 2021). Further

studies on MHD can be found in (Omokhuale and Jabaka, 2020a; Omokhuale and Jabaka, 2020b).

Magnetic field is utilized for several purposes in our daily lives such as semiconductor crystal development and molding improvements to reduce fluid mass transit vibrations (Waqas *et al.*, 2021). It is well known that the magnetic field and the effects of chemical reactions have an impact on flow and heat transfer rates. They are used in a wide range of industrial, medical, and environmental applications. It is also acknowledged that they alter the way boundary layer flow behaves. Because of the addition of these features, studying fluid movement becomes more interesting and realistic (Reddappa & Geetha, 2024).

The study of heat and mass transfer with chemical reaction is of great practical importance to engineers and scientists because of its almost universal occurrence in many branches of science and engineering. Possible applications of this type of flow can be found in many industries like power industry and chemical process industries (Raghunath, 2023). Saikia *et al.* (2023) explored the natural convective magnetohydrodynamics (MHD) mass transfer flow past an infinite vertical porous plate implanted in a porous medium with thermal diffusion and chemical reaction. An analytical solution for momentum, energy, and concentration equations is achieved by implementing the perturbation method. A uniform magnetic field is installed orthogonally with the plate and the fluid undergoes a normal suction velocity with the consideration that heat flux at the plate is constant. In contemplation of recording the influence of

different nondimensional parameters and deliberating the flow characteristics, the computational aftermath for fluid velocity, temperature, and species concentration is portrayed graphically. Investigations divulge the fact that the increase in thermal diffusivity causes hefty falls in the temperature field and improves the concentration of the fluid. Again, it is also noted that the fluid velocity and species concentration dwindle as a result of a high rate of consumption of species. Thermal and solutal convection studies in the realm of science and engineering technology are heavily influenced by chemical reactions. The Chemical reaction is caused due to the presence of multicomponent species in a system. Chemical reaction and MHD flow have recently piqued the curiosity of a large number of researchers (Bordoloi *et al.*, 2023).

Free convection flow in a boundary layer region is a motion that results from the interaction of gravity with density differences within a fluid. These differences occur due to temperature or concentration gradients or due to their composition. Studies pertaining free convection flows of incompressible viscous fluids have received much attention in recent years both theoretically (exact or approximate solutions) and experimentally (Zullkiflee *et al.*, 2019). The numerical observation of the convective motion of chemically active magnetohydrodynamic (MHD) fluid through a vertically oriented permeable medium, incorporating variations in mass and heat transfer. The fluid type is assumed to be incompressible, chemically strongly ionized and viscous with some mass infusibility. The model associated with this problem is solved by a highly stable Implicit Finite Difference Method (IFDM). The method is used for small and large deflection of the physical parameters, which results in a noticeable fluid flow behavior. Numerical configuration is graphically depicted to scrutinize the fluid behavior. The momentum, energy, concentration diffusion, skin friction, Nusselt number and Sherwood number are investigated for numerous factors such as magnetic field, permeability and chemical reaction rate was investigated by (Rath *et al.*, 2024). Goud & Nandeppanavar (2022) discussed chemical reaction and MHD flow for magnetic field effect on heat and mass transfer of fluid flow through a porous medium onto a moving vertical plate. Abd-Alla *et al.* (2023) studied Heat and mass transfer in a peristaltic rotating frame Jeffrey fluid via porous medium with chemical reaction and wall properties. Ramanjaneyulu & Hari Krishna (2023) analysed chemical reaction and magnetohydrodynamics effects on heat absorbing fluid past an inclined porous plate. Recently, Vinodkumar *et al.* (2024) researched on the stagnation point flow of non-Newtonian fluids has several engineering and industrial applications. In their study, they considered the investigation of the magnetohydrodynamic stagnation

point flow of Williamson hybrid nanofluid with chemical reaction and energy generation effects over a porous extending sheet. Similarly, the characteristics of radiation and convective boundary conditions are also taken. Mishra *et al.* (2024) examined the effects of heat radiation and chemical reactions on naturally occurring convective MHD flow that conducts electricity when there is an induced magnetic field present between two vertical walls having a porous medium between them. An analytical method is adopted to investigate the impacts of all pertinent parameters concerning the presented multi-physics problem. With the aid of relevant conversions, the nonlinear PDEs are remodeled into nonlinear ODEs. The effects of radiation parameters, Hartmann number, Hall current, chemical reaction and porosity parameters are scrutinized on velocity components, induced magnetic field, and current density.

The finite difference method (FDM) stands as one of the most commonly employed numerical techniques, particularly in the context of fluid flow problems. FDM replaces derivatives in the governing equations with discrete difference approximations, utilizing the values of the solution at discrete mesh points within the study domain, a process known as discretization. This discretized representation is systematically utilized to formulate algebraic systems of equations, relying on unknown values at mesh points. However, a notable limitation of this approach arises when dealing with complex domains, as it may lead to inaccuracies, although such challenges can be mitigated through the utilization of coordinate transformation techniques (Khan *et al.*, 2024). Some researches using FDM can be seen in (Omokhuale and Dange, 2023a; Omokhuale and Dange, 2023).

The aim of this current study is to examine MHD convective flow with magnetic and chemical reaction characteristics through a porous medium. The equations governing the flow of the fluid are: momentum, energy and diffusion. FDM was used to obtain approximate solutions for the velocity, temperature and concentration. Numerical experiments were performed to gain insight on physical parameters controlling the fluid's velocity, temperature, concentration which were explained and depicted through graphs.

2.0 MATHEMATICAL FORMULATION

An unsteady flow of an incompressible, viscous, electrically conducting and heat-absorbing fluid through a semi-infinite vertical plate is considered. A uniform transverse magnetic field of magnitude B_0 is applied in the presence of temperature and concentration buoyancy effects in the direction of the y^* – axis. The transversely applied magnetic field and magnetic Reynolds number is

assumed to be very small so that the induced magnetic field is negligible. We assumed that there is no applied voltage which implies the absence of an electric field. The physical variables are independent of the x^* -axis.

We further assume that there exist a homogeneous first order chemical reaction between the diffusing species and the fluid. The presence of constant injection/suction, magnetic field, variable pressure are taken into account.

The governing equations under the usual Boussinesq's and boundary layer approximations are:

Continuity equation:

$$\frac{\partial v^*}{\partial y^*} = 0 \quad (1)$$

Momentum equation:

$$\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + g\beta(T^* - T_\infty^*) + g\beta^*(C^* - C_\infty^*) + \nu \frac{\partial^2 u^*}{\partial y^{*2}} - \frac{\nu}{K^*} u^* - \frac{\sigma B_0^2}{\rho} u^* \quad (2)$$

Energy equation:

$$\frac{\partial T^*}{\partial t^*} + v^* \frac{\partial T^*}{\partial y^*} = \frac{k}{\rho c_p} \frac{\partial^2 T^*}{\partial y^{*2}} - \frac{Q}{\rho c_p} (T^* - T_\infty^*) \quad (3)$$

Mass Equation:

$$\frac{\partial C^*}{\partial t^*} + v^* \frac{\partial C^*}{\partial y^*} = Dc \frac{\partial^2 C^*}{\partial y^{*2}} - R_c^* (C^* - C_\infty^*) \quad (4)$$

The initial and boundary conditions associated with the flow are given as:

$$u^* = 0, T^* = T_w^*, C^* = C_w^* \text{ at } y^* = 0 \quad (5)$$

$$u^* \rightarrow 0, T^* \rightarrow T_\infty^*, C^* \rightarrow C_\infty^* \text{ as } y^* \rightarrow \infty \quad (6)$$

where x, y are the distances along and perpendicular to the plate, respectively, u, v are the components of velocities along the perpendicular plates, respectively, ν is the kinematic viscosity, g is the acceleration due to gravity, ρ is density, β is the coefficient of volume expansion with temperature, β^* is the volumetric coefficient of expansion with concentration, T^*, T_w^*, T_∞^* are the temperature of the fluid inside the thermal boundary layer, the plate temperature and the fluid temperature in the free stream, respectively, C^*, C_w^*, C_∞^* are the corresponding concentrations, K^* is the Darcy permeability, σ is electric conductivity, c_p is the specific heat at constant pressure, k is the thermal diffusion ratio, c_s is the concentration susceptibility, $Q(T^* - T_\infty^*)$ is assumed to be the amount of heat generated or absorbed per unit volume, Q is a constant which may take either positive or negative values, Dc is the coefficient of mass diffusivity.

where $v^* = \pm v_0$ from equation (1) and $-\frac{1}{\rho} \frac{\partial p}{\partial x} = Ae^{i\omega t}$.

$v_0 > 0$ signifies suction and $v_0 < 0$ explains injection.

In order to derive dimensionless form of the governing equations and the boundary condition. The following dimensionless quantities in equation (7) are introduced into equations (1) to (4).

$$y = \frac{U_0 y^*}{\nu}, u = \frac{u^*}{U_0}, t = \frac{t^* U_0^2}{\nu}, \varphi = \frac{T^* - T_\infty^*}{T_w^* - T_\infty^*}, \phi = \frac{C^* - C_\infty^*}{C_w^* - C_\infty^*} \quad (7)$$

Therefore, equations (1) to (4) become:

$$\frac{\partial u}{\partial t} \pm \gamma \frac{\partial u}{\partial y} = Ae^{i\omega t} + G_t \varphi + G_c \phi + \frac{\partial^2 u}{\partial y^2} - \frac{1}{D_a} u - \chi u \quad (8)$$

$$\frac{\partial \varphi}{\partial t} \pm \gamma \frac{\partial \varphi}{\partial y} = \frac{1}{Pr} \frac{\partial^2 \varphi}{\partial y^2} - \lambda \varphi \quad (9)$$

$$\frac{\partial \phi}{\partial t} \pm \gamma \frac{\partial \phi}{\partial y} = \frac{1}{Sc} \frac{\partial^2 \phi}{\partial y^2} - \delta \phi \quad (10)$$

The corresponding boundary conditions (5) and (6) in dimensionless form are:

$$u = 0, \varphi = 1, \phi = 1 \text{ at } y = 0 \quad (11)$$

$$u = 0, \varphi = 0, \phi = 0 \text{ as } y \rightarrow \infty \quad (12)$$

Here G_t is the Grashof number for heat transfer, G_c is the Grashof number for mass transfer, λ is the heat absorption, χ is the pressure term, D_a is the Darcy permeability parameter, χ is the Magnetic field parameter, Pr is the Prandtl number, Sc is the Schmidt number, δ is the chemical reaction parameter, γ is suction or injection parameter, u, φ, ϕ, t are the dimensionless velocity, temperature, concentration and time, respectively.

$$\text{where } \delta = \frac{R_c^* v}{U_0^2}, \gamma = \frac{v_0}{U_0}, Pr = \frac{\mu C_p}{k_T}, \lambda = \frac{Q_0 v}{\rho C_p U_0^2}, Gt = \frac{g \beta v (T_w^* - T_\infty^*)}{U_0^3},$$

$$Gc = \frac{g \beta v (C_w^* - C_\infty^*)}{U_0^3}, Da = \frac{K^* U_0^2}{v^2}, \chi = \frac{\sigma B_0^2 v}{\rho U_0^3}$$

3.0 NUMERICAL SOLUTION

The unsteady, nonlinear coupled equations (8) to (10) with conditions (11) and (12) are solved by an explicit finite difference scheme. Consider a rectangular region with y varying from 0 to $y_{max} = 5$, where y_{max} corresponds to $y = \infty$ at which lies well outside the boundary layers. The region to be studied in (y, t) space is covered by a rectilinear grid with sides parallel to axes with Δy and Δt , the grid spacing in y and t directions, respectively. The grid points (y, t) are given by

$(i\Delta y, k\Delta t)$. The finite difference equations corresponding to equations (8) to (10) are as follows:

equations (8) to (10) are non-linear and coupled PDEs. In order to obtain solutions for the velocity, temperature and concentration of the fluid, we assume solution of the form:

$$\frac{u_i^{k+1} - u_i^k}{\Delta t} - \gamma \frac{u_i - u_{i-1}}{\Delta y} = \lambda + G_t \phi_i + G_c \phi_i + \frac{u_{i+1} - 2u_i + u_{i-1}}{\Delta y^2} - \frac{1}{Da} u_i - \chi u_i \quad (13)$$

$$\frac{\phi_i^{k+1} - \phi_i^k}{\Delta t} - \gamma \frac{\phi_i - \phi_{i-1}}{\Delta y} = \frac{1}{Pr} \frac{\phi_{i+1} - 2\phi_i + \phi_{i-1}}{\Delta y^2} - \gamma \phi_i \quad (14)$$

$$\frac{\phi_i^{k+1} - \phi_i^k}{\Delta t} - \gamma \frac{\phi_i - \phi_{i-1}}{\Delta y} = \frac{1}{Sc} \frac{\phi_{i+1} - 2\phi_i + \phi_{i-1}}{\Delta y^2} - \delta \phi_i \quad (15)$$

The corresponding initial and boundary conditions (11) and (12) become:

$$u_i = 0, \phi_i = 1, \phi_i = 1 \text{ at } y = 0 \quad (16)$$

$$u_i = 0, \phi_i = 0, \phi_i = 0 \text{ as } y \rightarrow \infty \quad (17)$$

The coefficient appearing in difference equations are treated as constants. The finite-difference equations at every internal nodal point on a particular n -level constitute a tri-diagonal system of equations. These equations are solved by using the Thomas Algorithm. Computations are carried out until the steady-state solution is reached when the absolute difference between the values of velocity, temperature and concentration at three consecutive time steps are less than 10^{-8} at all grid points.

4.0 DISCUSSION OF RESULTS

A numerical approach using FDM is employed to analyze MHD Convection flow in a porous medium with magnetic and chemical reaction characteristics. Numerical experiments were performed to study the influence of physical parameters embedded in the flow and transport properties. The results are demonstrated from Figures 4.1 to 4.12.

Figures 4.1 and 4.2 show the influence of positive and negative values of chemical reaction parameter on the concentration profiles, respectively. The influence of Schmidt number on the concentration profiles is as illustrated in Figure 4.3. It is observed that the concentration of the fluid reduces with increasing values of Schmidt number.

Figures 4.4 and 4.5 display the influence of Prandtl number and heat generation on the temperature profiles, respectively. From this figure it is observed that, the

temperature decreases with the increasing Prandtl parameter. This is because, at small values of the Prandtl number, the thermal conductivity is increasing and the heat is able to diffuse away from the plate more rapidly than for large values of Prandtl number. The thickness of the thermal boundary layer decreases if the Prandtl number increases. A similar trend is seen when the heat generation becomes significant.

Magnetic parameter leads to a decrease in the velocity profile as shown in Figure 4.6. It is due to Lorentz force. Lorentz force works in the opposite direction of the fluid which makes a decreasing effect on velocity. Furthermore, increasing value of Magnetic parameter increases resistive forces which resist the fluid flow and thus decreasing the fluid velocity.

Figures 4.7 and 4.8 present the influence of positive and negative values of the chemical reaction parameters on the velocity profiles, respectively. Elevating the chemical reaction on the fluid flow leads to an observed enhancement in the velocity profile. The physical mechanism behind the increase in the velocity profile due to an elevated chemical reaction parameter on a vertical plate involves several factors related to the chemical reactions occurring within the fluid. Chemical reactions often involve the release or absorption of energy. This change in power can affect the temperature and, consequently, the fluid's viscosity. In some cases, an increase in chemical reaction can result in a decrease in density, facilitating faster flow and, hence, an increased

velocity profile. Chemical reactions may involve species transport or generation, altering the mass transport properties of the fluid. This could lead to changes in density or composition, impacting the fluid's flow behaviour and influencing the velocity profile. Chemical reactions can modify the rheological properties of the liquid, such as viscosity and elasticity. Alterations in these properties affect how the fluid responds to applied forces, potentially leading to changes in velocity profiles. Reactions that generate or consume heat can influence the temperature distribution within the fluid. Temperature changes can, in turn, affect the fluid's viscosity and flow characteristics, controlling the velocity outline. Overall, the interaction between chemical reactions and fluid properties such as viscosity, density, temperature, and rheology directly impact the flow behaviour and subsequently influences the velocity profile on the vertical plate.

Figure 4.9 and 4.10 connote the influence of temperature and concentration Grashof numbers, respectively. The

velocity of the fluid is seen to be enhanced as both parameters are increased respectively.

Figure 4.11 explains the influence of Schmidt number on the velocity profiles. Growth in Schmidt number declines the concentration boundary layer thickness. As Schmidt number is the ratio between viscous forces and mass diffusivity, therefore, it reduced the concentration as well as velocity profile. Physically, if the increase occurs in viscous forces, it leads to a decrease in the velocity of the fluid.

The influence of Prandtl number on the velocity fields is shown in Figure 4.12. It is clear that, the increase of Pr leads to falling in velocity. The low rate of thermal diffusion causes arising in velocity boundary layer thickness. Pr controls the relative thickness of the thermal and momentum boundary layers in the problems of heat transfer. Consequently, Pr can be utilized to expand the percentage of cooling.

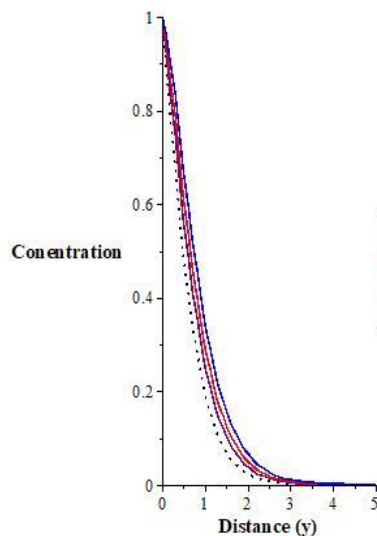


Figure 4.1: Influence of δ on the concentration profiles.

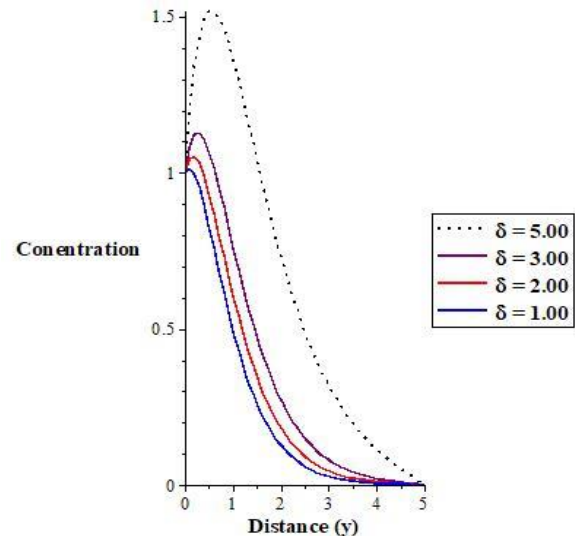


Figure 4. 2: Influence of δ on the concentration profiles.

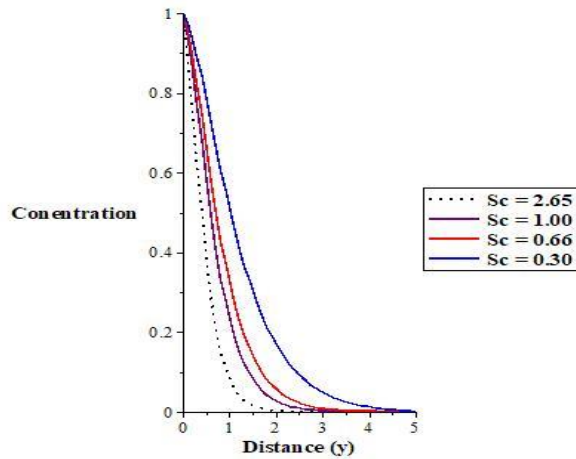


Figure 4. 3: Concentration profiles for different values of Sc

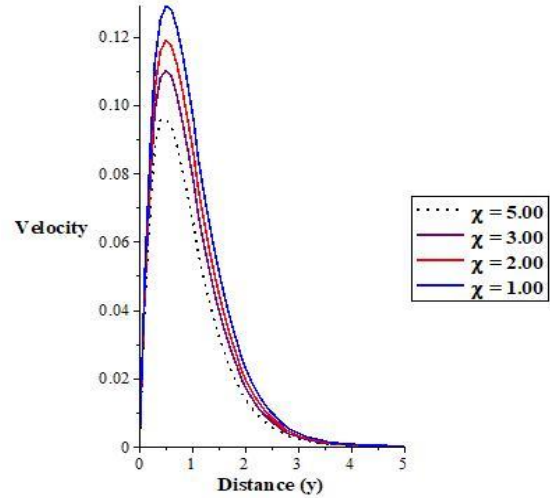


Figure 4.6: Influence of χ on the velocity profiles.

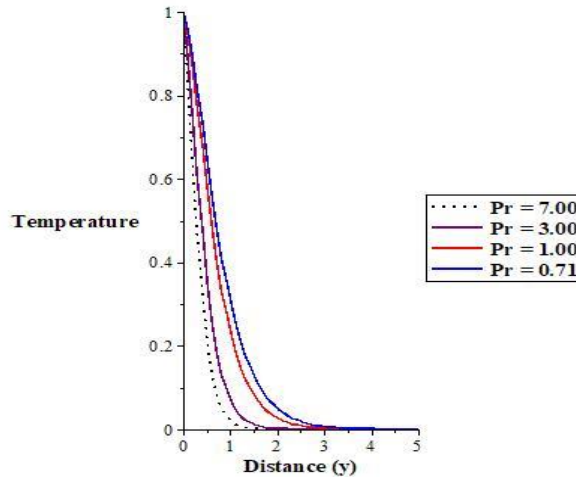


Figure 4. 4: Influence of Pr on the temperature profiles.

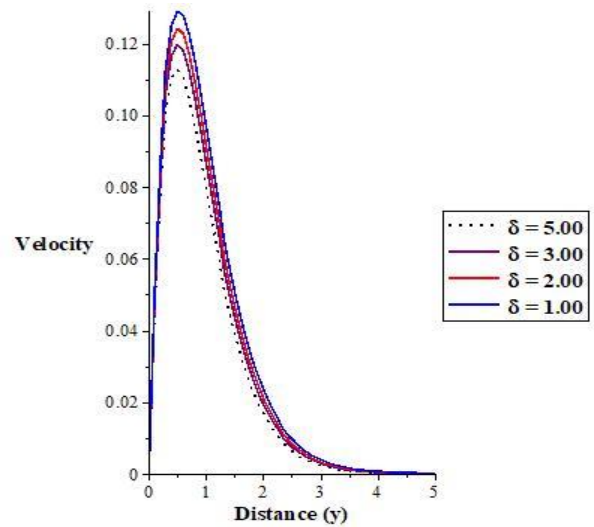


Figure 4.7: Influence of δ on the velocity profiles.

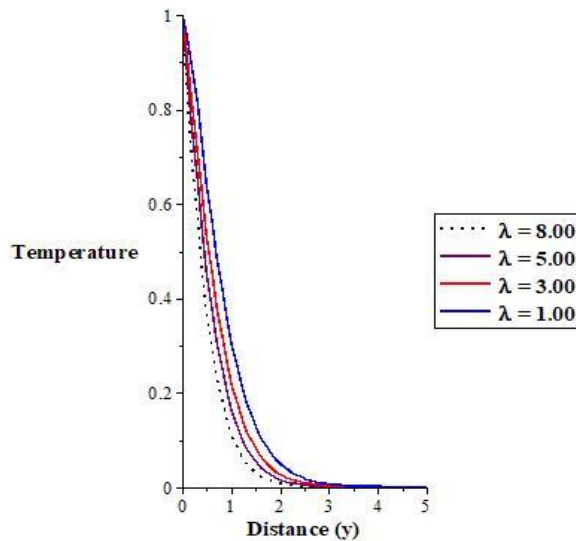


Figure 4. 5: Influence of λ on the temperature profiles.

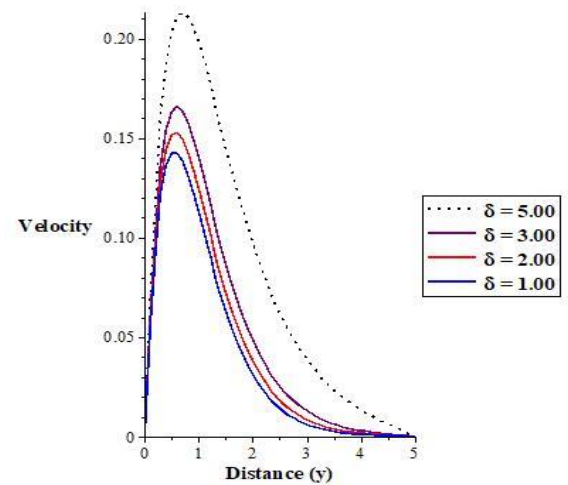
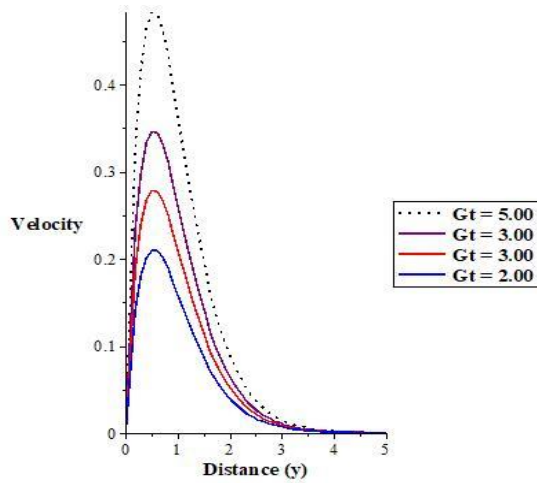
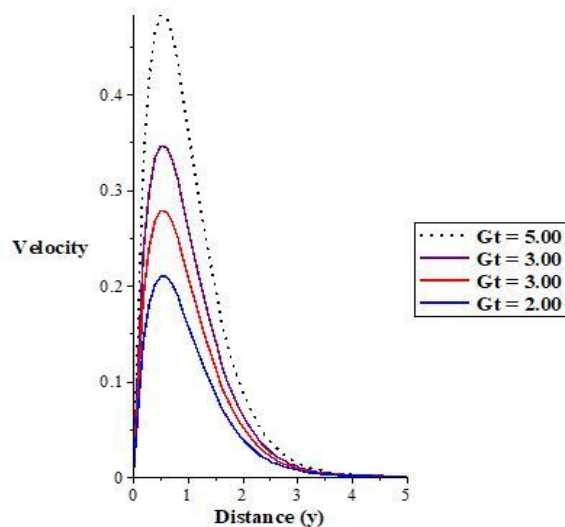


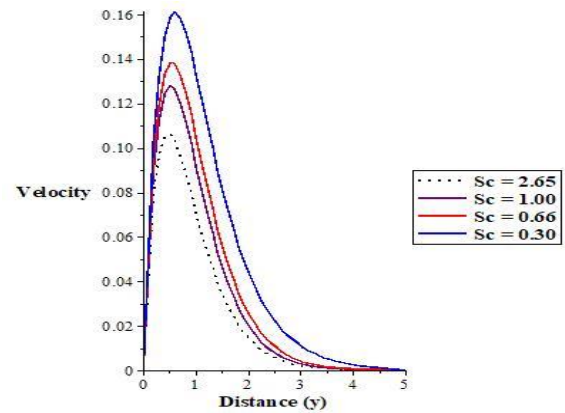
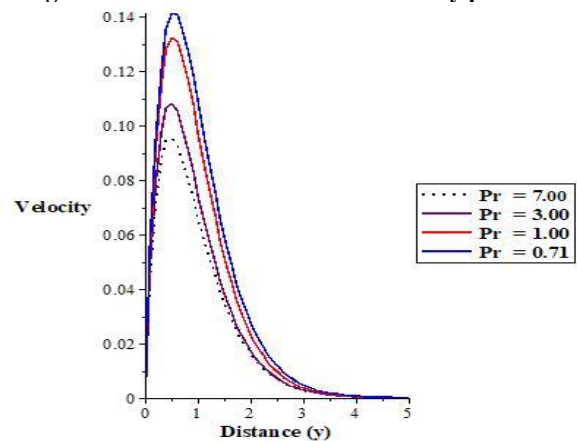
Figure 4.8: Influence of δ on the velocity profiles.

Figure 4.9: Influence of Gt on the velocity profiles.Figure 4.10: Influence of Gm on the velocity profiles.

5.0 CONCLUSION

A numerical analysis has been carried out to examine MHD convective flow through a porous medium with chemical reaction and magnetic characteristics by employing FDM. Numerical computations were performed using MAPLE. Results were displayed as Figures and explained for parameters of physical interest associated with the flow of the fluid. From the study, we conclude that:

- Increase in concentration and temperature Grashof numbers cause rise in the momentum boundary layer of the fluid.
- The velocity of the fluid becomes higher as the Magnetic effect becomes significant. The same principle operates in case of heat generation.
- The temperature and velocity of the fluid falls for higher values of both Prandtl and heat generation

Figure 4.11: Influence of Sc on the velocity profiles.Figure 4.12: Influence of Pr on the velocity profiles.

while a similar trend is also noticed as Schmidt number is increased.

- It is seen that increase in the chemical reaction positively and negatively lead lowering and rising of the mass and momentum boundary layers of the fluid, respectively.

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REFERENCES

- Abd-Alla, A. M., Abo-Dahab, S. M., Thabet, E. N., Bayones, F. S., & Abdelhafez, M. A. (2023). Heat and mass transfer in a peristaltic rotating frame Jeffrey fluid via porous medium with chemical reaction and wall properties. *Alexandria Engineering Journal*, 66, 405-420. <https://doi.org/10.1016/j.aej.2022.11.016>
- Bordoloi, R., Chamuah, K., & Ahmed, N. (2023). Free convective MHD radiative flow past a porous vertical plate in a porous medium with chemical reaction. *Biointerface Res. Appl. Chem*, 13, 1-15. <https://doi.org/10.33263/BRIAC133.259>
- Goud, B. S., & Nandeppanavar, M. M. (2022). Chemical reaction and MHD flow for magnetic field effect on heat and mass transfer of fluid flow through a porous medium onto a moving vertical plate. *International Journal of Applied Mechanics and Engineering*, 27(2), 226-244.
- Kavitha, R. (2021). Numerical Investigation on Heat and Mass transfer through a porous medium in the presence of MHD and Chemical Reaction. *Turkish Journal of Computer and Mathematics Education (TURCOMAT)*, 12(2), 1178-1182.
- Khan, I., Chinyoka, T., Ismail, E. A., Awwad, F. A., & Ahmad, Z. (2024). MHD flow of third-grade fluid through a vertical micro-channel filled with porous media using semi implicit finite difference method. *Alexandria Engineering Journal*, 86, 513-524.
- Mishra, M., Panda, J. P., & Sahoo, S. S. (2024). Investigations concerning the effects of thermal radiation, induced magnetic field, and chemical reaction on MHD flow through a permeable medium. *International Journal of Modern Physics B*.38(02), doi.org/10.1142/5021797922450030.
- Omokhuale, E. and Jabaka, M. L. (2020a). Effect of Radiation on Heat and Mass Transfer Magnetohydrodynamic Casson fluid flow in a vertical channel. *Caliphate Journal of Science and Technology (CaJoST)*, 2020, 2, 73 – 80. [Doi/10.4314/cajost.v2i2.43](https://doi.org/10.4314/cajost.v2i2.43).
- Omokhuale, E. and Jabaka, M. L. (2020b). Magnetohydrodynamic Casson fluid Flow Past a Vertical Plate in the Presence of Thermal Conductivity and Chemical Absorption. *International Journal of Science for Global Sustainability, IJSGS*, 6(2), 82 – 90. [Doi/10.57233/ijsgs.v6i2.111](https://doi.org/10.57233/ijsgs.v6i2.111).
- Omokhuale, E. and Dange, M. S. (2023a). Heat Absorption effect on Magnetohydrodynamic (MHD) Flow of Jeffery fluid in an infinite vertical plate. *FUDMA Journal of Sciences*, 7(2). [Doi.org/10.33003/fjs-2023-0702-1200](https://doi.org/10.33003/fjs-2023-0702-1200).
- Omokhuale E. and Dange M. S. (2023b). Radiation absorption and chemical reaction effects on magnetohydrodynamic (MHD) flow of Jeffery fluid in an infinite vertical plate. *Science Forum (Journal of Pure and Applied Sciences)*, 23, 417 – 428.
- Raghunath, K. (2023). Study of heat and mass transfer of an unsteady magnetohydrodynamic (MHD) nanofluid flow past a vertical porous plate in the presence of chemical reaction, radiation and Soret effects. *Journal of Nanofluids*, 12(3), 767-776. <https://doi.org/10.1166/jon.2023.1965>
- Ramanjaneyulu, T., & Hari Krishna, L. (2023). Chemical reaction and magnetohydrodynamics effects on heat absorbing fluid past an inclined porous plate. *Heat Transfer*, 52(5), 3595-3614. <https://doi.org/10.1002/htj.22842>
- Rath, A. K., Nayak, I., & Padhi, S. (2024). Transient magnetohydrodynamic heat and mass transfer analysis of chemically reacting fluid flow over oscillatory permeable media. *International Journal of Modern Physics B*, 2550031.
- Reddappa, B., & Geetha, R. (2024). Effects of second order chemical reaction on MHD forced convection Cu, Ag, and Fe₃O₄ nanoparticles of Jeffrey Nanofluid over a moving plate in a porous medium in the presence of heat source/sink. *Journal of Integrated Science and Technology*, 12(3), 762-762. <https://doi.org/10.62110/sciencein.jist.2024.v12.762>
- Reddy, N. N., Rao, V. S., & Reddy, B. R. (2021). Chemical reaction impact on MHD natural convection flow through porous medium past an exponentially stretching sheet in presence of heat source/sink and viscous dissipation. *Case studies in thermal engineering*, 25, 100879. <https://doi.org/10.1016/j.csite.2021.100879>
- Saikia, D. J., Ahmed, N., & Bordoloi, R. (2023). Natural convective MHD mass transfer flow past an infinite vertical porous plate embedded in a porous medium with thermal diffusion and chemical reaction. *Special Topics & Reviews in Porous Media: An International Journal*, 14(2). [Doi.10.1615/SpecialTopicsRevPorousMedia.2023045885](https://doi.org/10.1615/SpecialTopicsRevPorousMedia.2023045885)
- Vinodkumar Reddy M, Ajithkumar M, Zafar SSB, Faizan M, Ali F, Lakshminarayana P. (2024). Magnetohydrodynamic stagnation point flow of Williamson hybrid nanofluid via stretching sheet in a porous medium with heat source and chemical reaction. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*. [doi:10.1177/09544089241239583](https://doi.org/10.1177/09544089241239583)
- Waqas, H., Farooq, U., Bukhari, F. F., Alghamdi, M., & Muhammad, T. (2021). Chemically reactive transport of magnetized hybrid nanofluids through Darcian porous medium. *Case Studies in Thermal Engineering*, 28, <https://doi.org/10.1016/j.csite.2021.101431>



DOI: <https://doi.org/10.57233/ijsgs.v10i1.591>

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Zulkiflee F., Mohamad A. Q., Shafie S. and Khan A.
(2019). Unsteady Free Convection Flow between Two

Vertical Parallel Plates with Newtonian Heating,
MATEMATIKA: MJIAM, 35(2), 117–127.