

## MHD in a Porous Medium across Parallel Plates with Mass Transfer in a Rotating System

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### Abstract

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*This study investigated MHD flow in a porous medium across parallel plates with mass transfer in a rotating system. The governing equation of momentum were non-dimensionalised on velocity and concentration gradient. The resulting equations were then transformed using FD to fit some algebraic matrices solved by computer software (MATLAB). The end equations were analysed for velocity and concentration profile. The numerical data on concentration and velocity profile were recorded and presented graphically for interpretation and discussed. Some of the results revealed that velocity decreases when magnetic parameter and Grashof number increases. The knowledge obtained from this study can be applied in real life situations such as engineering and industries such as polymer processing.*

**Keywords:** MHD, mass transfer, Porous medium

### Introduction

Fluid refers to substances such as gases, liquids, or other materials that disfigure continuously under an applied outer force or shear stress and can run or flow easily. These substances have no definite shape but easily yield externally to pressure. These substances contain particles in a continuous and random state of motion. In addition, these substances move and swap their respective location minus any detachment of mass and simply relent to a physical force called pressure. Flow can be categorized as steady or unsteady. A flow is said to be steady if the fluid's velocity at a specific set position is constant. MHD is the study of fluids conducting electricity influenced by an electromagnetic field. Some examples of these fluids include water, ionised gases, salt, and liquid metals. Application areas of this field include; targeting a magnetic drug, controlling the flow of blood during surgery, cell separation in magnetic devices, and treatment of intestinal diseases. According to Giterere and Kinyanjui (2011), a porous medium is as a permeable solid linked with a system of pores occupied with the fluid. Examples of substances possessing pores are bones, soils, rocks and cement. Porosity is the estimate of the number of voidspaces. Permeable materials have a range of applications in day-to-day life, such as sound absorption in buildings that can be applied in subways, highways, and bridges for sound control. In addition, it is used in liquid and gas filtration. Sarma and Ahmed (2022) carried out investigation of MHD unsteady flow whereby the vertical sheet was embedded in a permeable media boosted with temperature. The aim of the work was to exclusively study the effects of chemical reaction, radiation and thermos-diffusion effect. The results of the study pointed that concentration, temperature and velocity profiles accelerate with time. Besides, the fluid becomes thinner swiftly as the Schmidt number and parameter reaction increases. Sudarmozhi et al. (2023) examined a bi-diffusion

of a Maxwell MHD fluid with chemical reaction, thermal and generation of heat. The objective of the study was to obtain numerical solutions for non-Newtonian fluid through the slanted permeable sheet. The findings showed that as concentration profile reduces the value of the chemical reaction increases. This also implied that a rise in the chemical reaction leads to increase in the concentration. A study conducted by Arif et al. (2023) on heat mass transfer for MHD non-Newtonian fluid through a porous medium with a boundary depicted that velocity decreases as the porosity parameter grows. The reduction in velocity was caused by increase in the coefficient of Inertia. Radiation, chemical, and Soret effect of MHD unsteady Nanofluid via a permeable plate vertically embedded with mass and heat transfer was studied by Raghunath (2023). For effective analysis two different types of Nanofluids were pondered. Analyzing the results revealed that velocity reduces as the Hartman number increases while it increases when the values of mass Grashof numbers and thermal are increased. Danwood and Hmood (2006) investigated the effects of unvarying and free convective flow across a permeable media all over an isothermal body. The results proved that the Nu number is a powerful function of the so-called modified Rayleigh number. Malaque and Sattar (2005) investigated the effects of varying fluid characteristics that is viscosity, density, and thermal conductivity to a porous rotating plate disk to the flow. The study concluded that the momentum boundary layer increases when the Pr number is kept constant together with sanction parameter values. Ahmed et al. (2020) conducted an analytical study on unstable free convective and two-dimensional flow for an MHD fluid across a porous plate submerged inside a permeable medium, accompanied by a heat source, hall currents, and thermal diffusion. The effect of parameters' flow on species' concentration, temperature, shear stress, and velocity was studied at the plate. Christian and Louis (2002) conducted a study investigating the flow of Magneto hydrodynamic in a porous media. They found out that electric current and mass flow are described by a coupled equation that has relations linearly to a macroscopic gradient of electric potential and pressure. Myers et al. (2020) studied the transfer of mass in a porous fluid media in motion. They applied the study to carbon capture in a packed column. A case study was carried out whose main intention was to get rid of carbon (IV) oxide gas from a mixture of gases. The gas mixture was passed over particles of activated carbon. The findings showed that the quantity of the available sabotage determines the material concentration to be eliminated.

Sigey et al. (2013) investigated MHD flow free convective over limitless vertical permeable plate accompanied by joule heating. The study found that increasing the joule parameter number increases velocity. In addition to this, the temperature near the sheet is distributed in a uniform manner, whereas keeping away from the plate, both the temperature profile and velocity profiles are distributed constantly. Tania and Samad (2010) studied the effects of radiation, Heat dissipation, together with production on unconfined convective motion of MHD across a stretching plate. The findings noted from the study are; that tremendous values of upthrust parameters/floatability may be in control of boundary layer concentration and temperature if used. In addition, the growth of the boundary layer can be stabilized by suction. Another conclusion derived from the study was that a magnetic field could also be applied in controlling flow properties and has essential effects on transferring heat and mass. Unsteady/Turbulent motion of fluid was studied by Hinze (1959) in an unstable condition, and the study showed that different quantities exhibited various variations that are regarded as random with time and space. Crane (1970) brought up accurate solutions numerically for a two-dimensional steady fluid at rest in a stretching plane. Since then, several authors have contemplated different situations of this mathematical task, and the results that have come out show similarities. An investigation was carried out by Bathaiah and Venkataramana (1986) on buoyance effects caused by parallel flow enclosed by a fixed porous plate that is

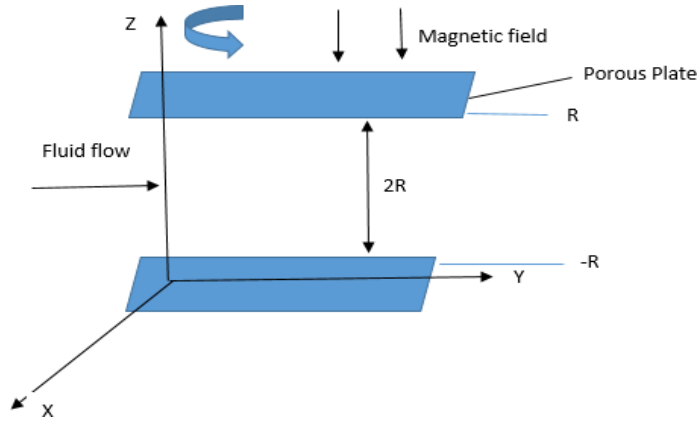
permeable. For the solution to be discussed, the section was partitioned into two, whereby the first was made of Lamar fluid flow, and Navier Stokes' equations governed it while Darcy's law controlled the second one. The deduced findings of the study revealed that velocity decreases as the magnetic parameter increases in the first region while velocity increases in the dual-zone in the scenario of Pouseullie flow. Ram and Mishira (1997) analysed the effects of Hall currents simultaneously on mass diffusion and thermaleffects via a rotating permeable media embedded by a sheet erected uprightly, a scenario where the strength of the magnetic field constrained in a surface is high, making several angles normal to the plate. Raghunath et al. (2020) considered the MHD of an incomprehensible fluid conducting electricity over a porous material accompanied by mass and heat transfer directed by a vertical magnetic field that is homogeneous and normal to the plate. The model of Brinkman guided the flow. This model is for the equation of momentum. The numerical results emanating from equations governing fluid flow were drawn for temperature, concentration profile, and velocity using a perturbation technique. Joystina and Cheran (2017) investigated MHD convective free flow, mass, and heat transport accelerated exponentially in an inclined sheet bound in a permeable media, saturated, and the temperature varied. Shankar et al. (2019) investigated the flow of MHD through porous media and material exchange effects along significantly hastened and inclined sheets whose thermal radiation and temperature were treated as variables. The inclination angle of the fluid flow situation with heat sink or source together with damaging reaction were analysed. Decelerating velocity was observed with an inclined angle and source of heat. Suresh and Baluguri (2020) investigated the thermos-diffusion effect on a free combined MHD fluid flow with temperature variation and mass diffusion on an oscillating and inclined plate. The Duffer effect (diffusion thermo) was numerically studied. Dwivwdi et al. (2018) carried out a study on MHD through a vertical channel with porous media. The fluid was assumed to flow under the influence of a pressure gradient that was non-dimensionalised, and it was presumed to be oscillating towards the horizontal x-axis. The graph between layer distance and velocity of fluid for various angles of inclination with the plate, which is associated with the magnetic field, was plotted for physical interpretation. The results concluded that both the inclination and the magnetic field control the velocity of the fluid.

Mahabaleshwar et al. (2021) studied Magneto hydrodynamic flow of fluids that obey Newton's law of viscosity, blend motion of Nanofluid, together with exchange of mass caused by a stretching plate superlatively linear. The primary lunar boundary surface for mass transfer, together with the momentum equation, was converted to the non-linear ordinary differential equation by use of similarity transformation method. Shakhikala and Lavanya (2020) studied oscillatory, electrically conducting fluid moving via a permeable medium of a non-Newtonian fluid in the company of radiation with Hall currents and chemical diffusion. The conclusion from the study showed that oscillatory MHD flow of non-Newtonian fluid of radiation parameter and thermal diffusivity. The dimensionless governing equations were solved analytically because; temperature fall with rise in parameter prandtl number when it increases with time, the concentration decreases with an increment in Schmidt number, and the increase in velocity with a decrease in parameters of the plate under heat. This study focuses MHD flow in a rotating system through a rotating system embedded in parallel plates with mass transfer in a porous medium.

### ***Governing equations***

The study considered a steady, incomprehensible and viscous fluid flow in a porous medium across parallel sheets with mass transfer in a rotating system. The plates are stationary and permeable. The induced magnetic field is perpendicular to the Z-axis. The fluid is at rest at

$t=0$ . The plate is infinite along the  $z$ -direction. The whole system rotates at fixed angular velocity ( $\Omega$ ) about the  $Z$ -axis. Coriolis force is considered because of rotation. The magnetic field  $B$  has components in three dimensions.



**Figure 1. Flow geometry**

Considering the study assumptions, the continuity, concentration and momentum equation is given as;

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

$$u \frac{\partial c}{\partial x} + v \frac{\partial c}{\partial y} = D \left( \frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} \right) \tag{2}$$

$$u \frac{\partial v}{\partial x} + \frac{v \partial v}{\partial y} - 2\Omega v = \frac{1}{\rho} \frac{\partial p}{\partial y} - \frac{\sigma B_0^2 u}{\rho} - \frac{v}{k} - gB^*(C - C_\infty). \tag{3}$$

The boundary conditions are given as

$$v = 0 \quad \text{when } t = 0 \text{ and } -R \leq x \leq R \text{ at } C = 0$$

$$v = 0 \quad \text{when } t > 0 \text{ and } x = -R \text{ at } C = C_\infty$$

$$v = v \quad \text{when } t > 0 \text{ and } x = R \text{ at } C = C_\infty$$

**Methodology**

The non dimensionless parameters are defined below

$$U^* = \frac{U}{U_\infty} \quad V^* = \frac{V}{U_\infty} \quad W^* = \frac{w}{U_\infty} \quad t^* = \frac{U_\infty t}{R} \quad y^* = \frac{y}{R} \quad x^* = \frac{x}{R} \quad z^* = \frac{z}{R} \quad P^* = \frac{p}{\rho U_\infty^2}$$

By using the above definition, equation 3 is given as;

$$\frac{U^* \partial v^*}{\partial x^*} + \frac{U^* \partial v^*}{\partial y^*} - 2\Omega \frac{V^*}{U_\infty} = \frac{\partial P^*}{\partial y^*} - \frac{V^* U^* V^* R}{K} - \frac{\sigma R U^* B_0^2}{\rho U_\infty} + \frac{B^* g R (C - C_\infty)}{U_\infty^2} \tag{4}$$

And, when the non-dimensional numbers are introduced, the equation becomes

$$\frac{U^* \partial v^*}{\partial x^*} + \frac{U^* \partial v^*}{\partial y^*} - 2R_0 V^* = \frac{\partial P^*}{\partial y^*} - X_1 V^* - MU^* + Gr_c C^* \tag{5}$$

While the non-dimensional Boundary conditions given as

For  $t \leq 0 \quad t^* = \frac{U_\infty t}{R} = 0$  and when  $t > 0 \quad t^* > 0$

For  $v = 0 \quad v^* = \frac{V}{U_\infty}$  and  $v > U_\infty, \frac{V}{U_\infty} = v^* = 1$

At  $x = -R, x^* = \frac{x}{R} = \frac{-R}{R} = -1$  and  $x = R, x^* = \frac{R}{R} = 1$

$t^* = 0 \quad v^* = 0 \quad C^* = 0 \quad \text{at } -1 \leq x^* \leq 1$

$t^* > 0 \quad v^* = 0 \quad C^* = 1 \quad \text{at } x^* = -1$

$t^* > 0 \quad v^* = 1 \quad C^* = 1 \quad \text{at } x^* = 1$

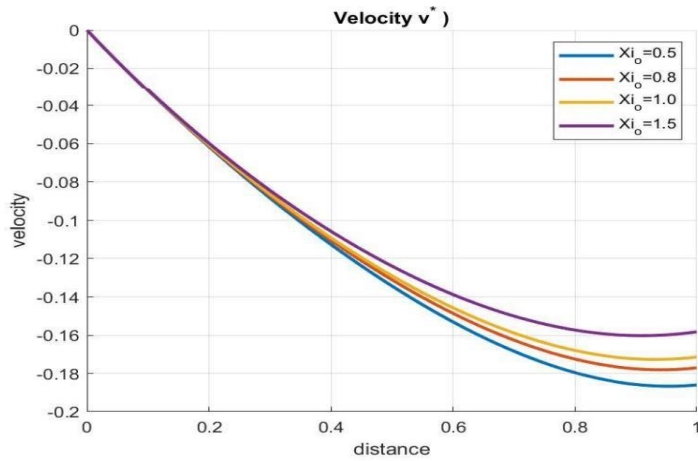
The dimensionless numbers obtained are defined as ;

$$Gr_c = \frac{B^* g R (C_\omega - C_\infty)}{U_\infty^2} \quad M = \frac{\sigma B_0^2 R}{\rho U_\infty} \quad R_0 = \frac{R \Omega}{U_\infty} \quad X_1 = \frac{R}{K} V$$

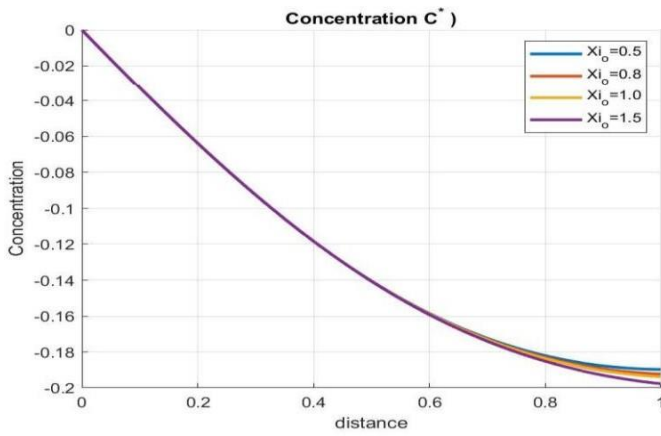
Using finite difference method, Equation 5 can be written as;

$$U^* \left( \frac{v_j^{k+1} - v_{j-1}^{k+1} + v_j^k - v_{j-1}^k}{2\Delta x} \right) + U^* \left( \frac{v_j^{k+1} - v_{j-1}^{k+1} + v_j^k - v_{j-1}^k}{2\Delta y} \right) - 2R_0 V^* = \frac{p_j^{k+1} - p_{j-1}^{k+1} + p_j^k - p_{j-1}^k}{2\Delta y} - X_1 V^* - MU^* - Gr_c C^* \tag{6}$$

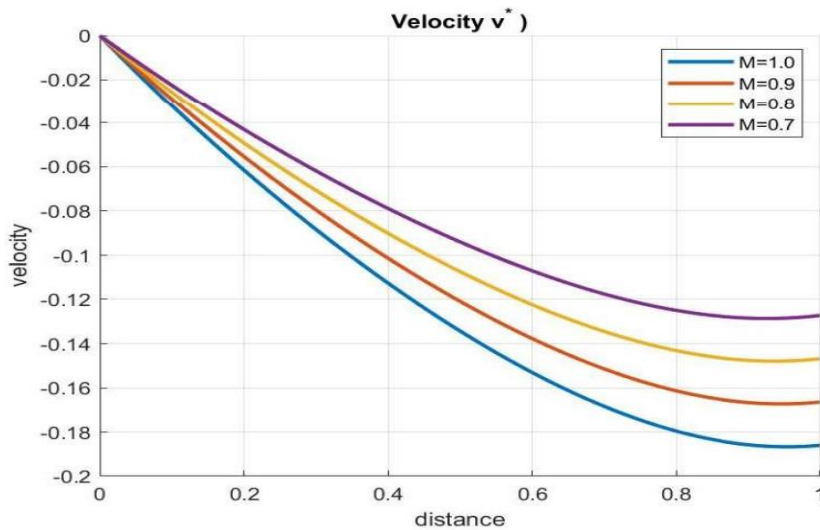
**Results**



**Figure 2. Velocity profile for different values of Permeability Xi**



**Figure 3. Concentration profile for different values of Permeability parameter Xi**



**Figure 4. Velocity profile for different values of Magnetic Parameter M**

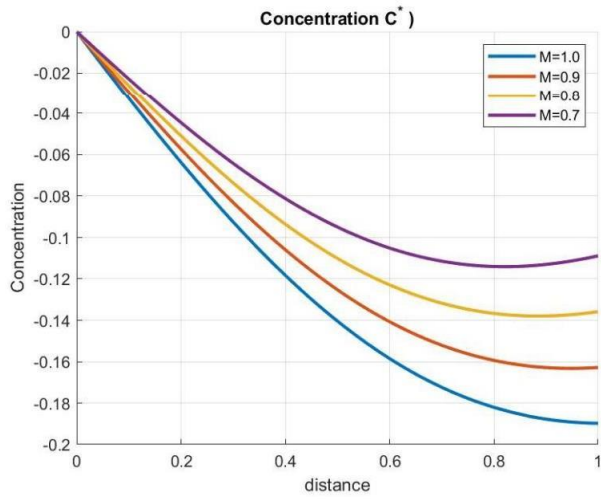


Figure 5. Concentration for different values of Magnetic parameter M

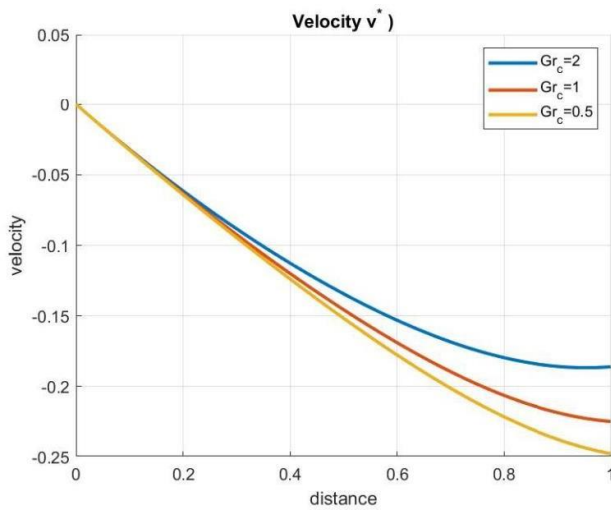


Figure 6. velocity profile for different values of Grashof number  $Gr_c$

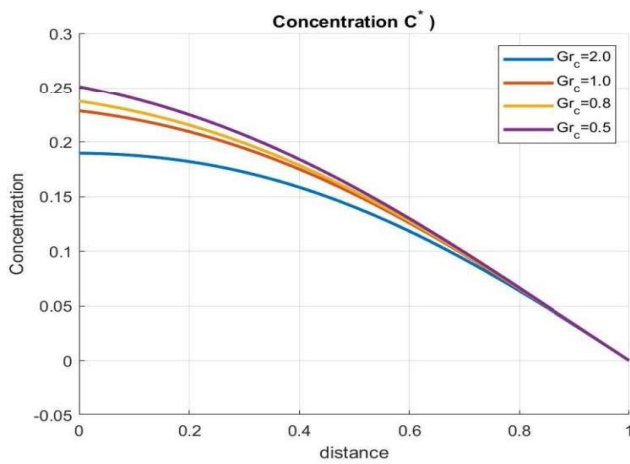


Figure 7. Concentration profile for different values of Modified Grashof,  $Grc$

## Discussion

Figure 2 shows that increase in the permeability parameter values leads to an increase in velocity profile which simply implies that the magnetic field is stronger.

Figure 3 points out that when the permeability parameters are increased, the concentration also increases. The higher values for permeability reduces the rate at which the mass or quantity of matter can be transported and for this reason the concentration increases. Both concentration and velocity can be controlled under the condition that porous medium and permeability are varied, Tanial et al. (2010).

Figure 4 displays that velocity decreases as the values of  $M$  are increased. An increase in the values of  $M$  increases the proclivity of velocity slowing down the movement of fluid. Reduction in velocity slows down the movement of the fluid's species. One of the types of forces that is resistive to a fluid that is electrically conductive is Lorentz force. This type of force renders the movement of the fluid. It reduces the movement of the fluid which in turn leads to increase in concentration, Shateyi (2008).

Figure 5 displays that increase in the values  $M$  causes the concentration to increase too. The increase in concentration is caused by magnetic diffusion. Magnetic field induces magnetic diffusion and this has an influence on the transportation of the species and the characteristic within the fluid.  $M$  enhances the diffusion of the species that are desired hence increasing the concentration.

Figure 6 shows that when  $G_{rc}$  increases, the velocity of the fluid also decreases. This means that the buoyancy force dominates which opposes the movement of the fluid, hence reduction in the velocity profile.

Figure 7 indicates that increase in the values of  $G_{rc}$  leads to a decrease in the concentration profile. This parameter expresses the ration of force of buoyance of the species to that of the hydrodynamic viscous force. Increment in values of  $G_{rc}$  means that the hydrodynamic viscous force has been reduced and this causes a reduction in viscous dissipation. According to Giterere et al. (2011), when species buoyancy force is increased, high quantity of species transportation is done.

## Conclusion

The following conclusions are drawn from the study; an increase in magnetic permeability leads to a decrease in velocity profile but leads to a decrease in concentration; increasing the Grashof values resulted in a decrease in velocity but increase in concentration and the permeability parameter influenced the concentration profile of the fluid, with higher values leading to an increase in concentration.

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