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Magnetohydrodynamic Flow in a Rotating System Over Horizontal Parallel Plates WithMass Transfer In A Porous Media

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Abstract: *This study investigated magnetohydrodynamic (MHD) flow in a rotating system between stationary horizontal parallel plates with mass transfer through a porous medium. The equations governing the flow were non-dimensionalised and solved using Finite Difference (FD) methods in MATLAB. The effect on non-dimensional parameters on velocity and concentration profiles were analysed and presented graphically. The study revealed that an increase in the magnetic parameter and Grashof number led to a decrease in velocity. The findings have practical applications in engineering and industries such as polymer processing, glass fibre production, metallurgy, and paper production*

Key Word*: MHD, Mass transfer, Porous medium*

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I. Introduction

Fluid refers to substances such as gases, liquids, or other materials that disFigureure 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 categorised as steady or unsteady. A flow is said to be steady if the fluid's velocity at a specific set position is constant. Magnetohydrodynamics 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 (8) 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 void spaces. 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. [20] 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 thermo 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. [11] examined a bi-diffusion of a Maxwell MHD fluid with chemical reaction, thermal and generation of heat. The objective of the study was obtain numerical solutions for now-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 [2] 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 [10]. For effective analysis two different types of Nanofluids were pondered. Analysing 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. [7] 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. [16] 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. [1] 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. [5] conducted a study investigating the flow of Magnetohydrodynamic 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. [17] 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. [23] 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. [25] 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 stabilised by sunction. 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 [9] in an unstable condition, and the study showed that different quantities exhibited various variations that are regarded as random with time and space. [6] brought up accurate solutions numerically for a two-dimensional steady fluid at rest in a stretching plane. Since then, several writers have contemplated different situations of this mathematical task, and the results that have come out show similarities. An investigation was carried out by [3] 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. [18] analysed the effects of Hall currents simultaneously on mass diffusion and thermal effects 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. [12] 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. [14] 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. [21] 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. [24] investigated the diffusion-thermo 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. [13] 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. [15] studied Magnetohydrodynamic flow of fluids that do 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. A similar method of solution was employed by [4] where the steady movement of magnetohydrodynamic through a permeable medium with quadratic velocity over a stretching sheet was carried out. [19] 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 a rise in parameter pranditl 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 horizontal parallel plates with mass transfer in a porous medium.

II. Methods

This study Considers a viscous, incomprehensible MHD fluid flow in a porous medium over horizontal parallel plates rotating with mass transfer. The plates are assumed to be stationary and at the same time are permeable so that it allows for suction or any possible blowing.

The induced magnetic field is perpendicular to the Z-axis. The fluid is at rest at time t=0. Along the Z-axis, the plate is infinite.

The whole system rotates at fixed angular velocity (Ω) about the Z-axis. Corolis force is considered because of rotation. The magnetic field B have the components (Bx, By, Bz) whereas velocity vector have components (u, v, w) along the x, y and z-axis respectively. The flow of the fluid is steady, incompressible, and viscous

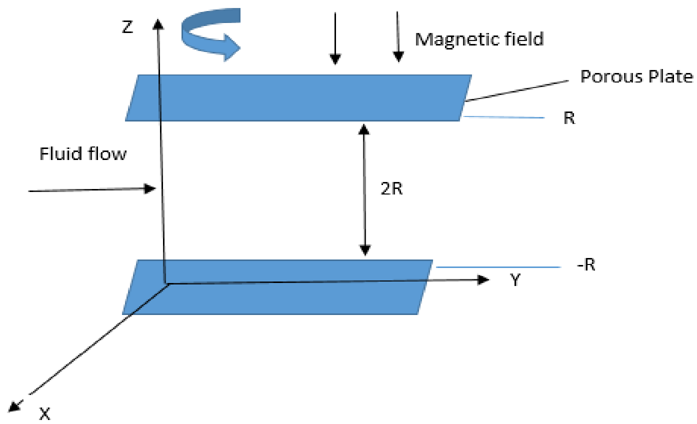

Figure 1 Flow geometry

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

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \ldots\ldots\ldots (1)$$

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

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}-2\text{fi} = \frac{1}{\rho}\frac{\partial p}{\partial y}-\frac{\sigma B_o U^2}{\rho}-\frac{v}{k}v-gB^*(C-C_\infty)\ldots\ldots..(3)$$

The boundary conditions are given as
v=0 when t=0 and -R ≤ x ≤ R at $C=0$
v=0 when t>0 and x=-R at $C=C_\infty$
v=v when t>0 and x=R at $C=C_\infty$
The non dimensionless parameters are defined below

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

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

$$\frac{U^* \partial v^*}{\partial x^*}+ \frac{U^* \partial v^*}{\partial y^*} - 2\Omega \frac{V^*}{U_\infty} = \frac{\partial P^*}{\partial y^*} - \frac{V^*U^*V^*R}{K} - \frac{\sigma RU^*B_O^2}{pU_\infty} + \frac{B^*gR(C - C\infty)}{U_\infty^2} \dots\dots\dots (4)$$

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

$$\frac{U^* 6v^*}{6x^*} + \frac{U^* 6v^*}{6y^*} - 2R_o V^* = \frac{6P^*}{6y^*} - X_i V^* - MU^* + Gr_c C^* \cdots\cdots\cdots\cdots\cdots (5)$$

While the non-dimensional Boundary conditions given as

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

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

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

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

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

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

The dimensionless numbers obtained are; modified Grashof number, Magnetic permeability, Rotational parameter and Permeability parameter which are defined as

$Gr_c = \frac{B^* gR(C_\omega - C_\infty)}{U_\infty^2}$ $\qquad M = \frac{\sigma B_{oR}^2}{pU_\infty}$ $\qquad Ro = \frac{R\Omega}{U_\infty}$ $\qquad X_i = \frac{R}{K} V$

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

$$U^* \left(\frac{v_j^{k+1} - v_{j-1}^{k+1} + v_j^k - v_{j-1}^k}{2\Delta x}\right) + U^* \left(\frac{v_j^{k+1} - v_{j-1}^{k+1} + v_j^k - v_{j-1}^k}{2\Delta y}\right) - 2R_O V^* = \frac{p_j^{k+1} - p_{j-1}^{k+1} + p_j^k - p_{j-1}^k}{2\Delta y} - X_i v^* - MU^* - Gr_c c^* \dots\dots\dots (6)$$

III. Result

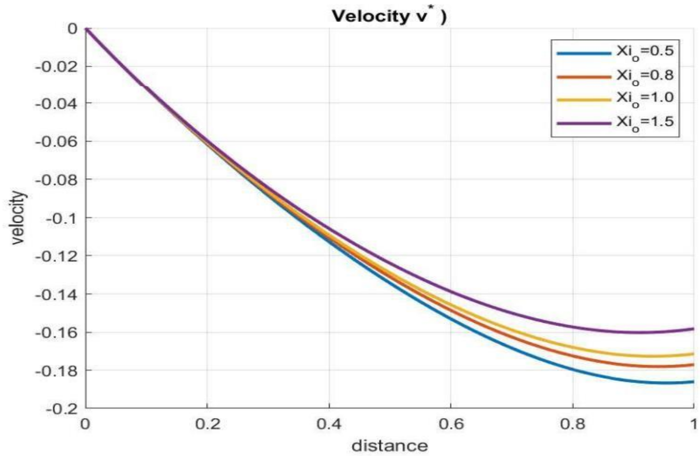

Figure 3.0 Velocity profile for different values of Permeability Xi

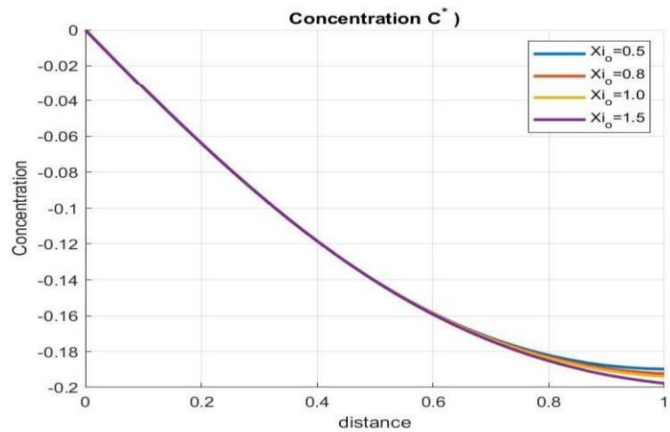

Figure 4.0 Concentration profile for different values of Permeability parameter Xi

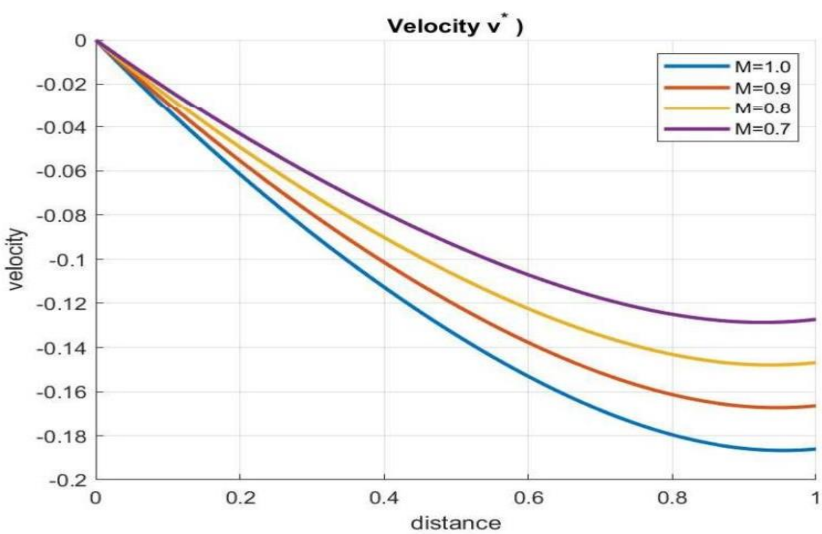

Figure 5.0 Velocity profile for different values of Magnetic Parameter,M

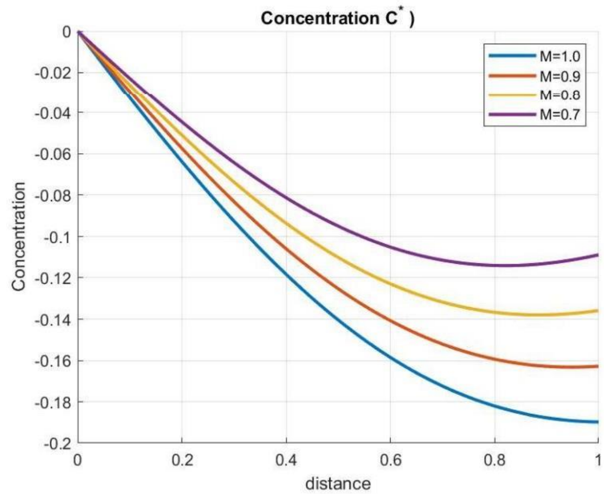

Figure 6.0 Concentration for different values of Magnetic parameter M

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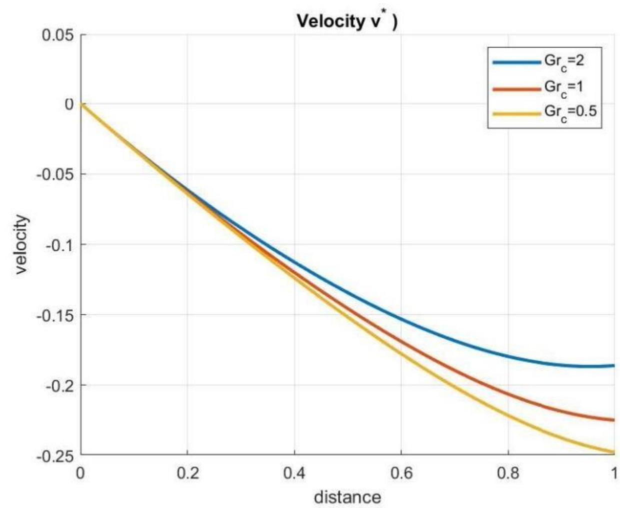

Figure 7.0 velocity profile for different values of Grashof number Grc

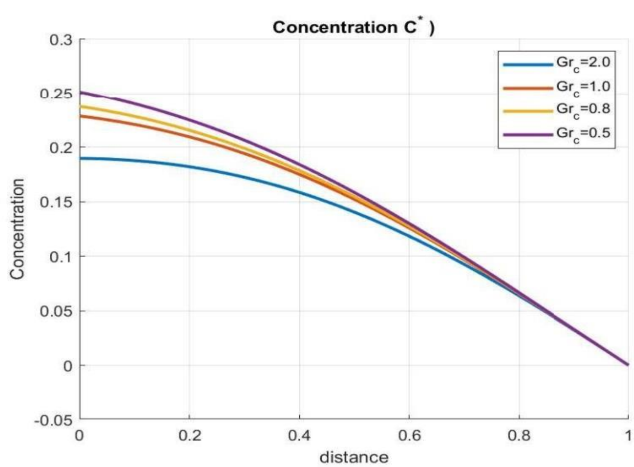

Figure 8.0 Concentration profile for different values of Modified Grashof, Grc

IV. Discussion

Figure 3.0 shows that increase in the Xi values leads to an increment in velocity profile. This parameter is a representative of the relative strength of the magnetic field. An increase in this means that the magnetic field is stronger.

Figure 4.0 points out that when the values of Xi are increased, the concentration also increases. The reason for this is, an increase in the values for Xi reduces the rate at which transportation of the species from the horizontal plate causing a rise in concentration profile. When porous medium and permeability is varied, then concentration and velocity can be controlled [8].

Figure 5.0 displays that when the values of M are increased, the velocity of the fluid decreases. It is evident that when the values for M increases, the proclivity of velocity slowing down the movement of fluid is high. 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 [25].

Figure 6.0 displays that increase in the values M causes the concentration to increase too. The increase in concentration is caused by magnetic diffusion. Magnetic field induce 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 7.0 shows that when Grc increases, the fluid's velocity decreases. This clearly points out that the buoyancy force dominates. This force opposes the motion of the fluid, hence reducing its velocity.

Figure 8.0 indicates that increase in the values of Grc leads to a drop 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 Grc means that the hydrodynamic viscous force has been reduced and this causes a reduction in viscous dissipation. According to [22], when species buoyancy force is increased, high quantity of species transportation is done.

V. Conclusion

Based on the study, the conclusions drawn are as follows: an increase in magnetic permeability was found to decrease velocity; higher values of the magnetic parameter (M) corresponded to a decrease in concentration; increasing the Grashof values resulted in a decrease in velocity and the permeability parameter influenced the concentration profile of the fluid, with higher values leading to an increase in concentration.

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