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# NUMERICAL ANALYSIS OF BRINKMAN FLUID FLOW PASSING OVER A HORIZONTAL CIRCULAR CYLINDER WITH MAGNETOHYDRODYNAMIC EFFECTS

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**Abstract:** *Brinkman model is often exploited for fluid flow and heat transfer through porous materials because of its being able to account for viscous effects. The purpose of this work is to study the heat transfer behavior of Brinkman fluid flow with magnetohydrodynamic (MHD) effects over a horizontal circular cylinder in a porous medium with a convective boundary condition (CBC). Non-dimensional variables and non-similarity transformations are employed at the lower stagnation point to convert the governing equations of continuity, momentum and energy into a set of non-linear ordinary differential equations. The Boundary Value Problem 4th-Order Solver (bvp4c) solver in MATLAB is used to numerically solve the transformed equations. The effect of Brinkman parameter (Γ), mixed convection parameter (λ), magnetic parameter (M), and convective parameter (γ) on the velocity and temperature profile are analysed. From the numerical results, it is observed that the velocity profile is improved with the increase in the mixed convection parameter, while the Brinkman parameter decreases the velocity profile and increases the temperature profile. The magnetic and convective parameters also have great significance on the flow and thermal behavior of the fluid. The bvp4c solver generally gives an efficient and reliable numerical solution to the nonlinear boundary value problems arising from MHD Brinkman fluid flow and the results help the understanding of the heat transfer behaviour in porous media for future thermal engineering applications.*

**Keywords:** *Brinkman fluid, Magnetohydrodynamic, Horizontal Circular cylinder, Convective boundary condition, bvp4c*

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## Introduction

The transfer of heat is one of the most vital processes that take place in engineering and industry, and it refers to the transfer of thermal energy across a system and its environment. Heat is pivotal when it comes to improving energy efficiency and performance in areas such as power generation, cooling systems, and chemical processing. In these systems there exists a temperature differential through a material or across two surfaces which cause thermal energy to conduct. These differentials also produce changes in thermal energy that are dependent on various interaction mechanisms involving both heat and fluid mechanics.

Among of the mechanisms of heat transfer, convection is especially significant because it involves the conduction of heat in flowing fluids. Convection occurs when a fluid in motion carries out heat from one location and redistributes the temperature in the fluid flow. Convection may be described as forced, free (natural), or mixed convection by identifying the principal driving force. As noted by Abderrahmane et al. (2022), convection is very important when applied to prepare heat exchangers, cooling electronics, and processing materials. Mixed convection flow occurs when buoyancy forces and externally forced flow induce fluid motion simultaneously.

In the past few years, the subject of mixed convection flow on horizontal circular cylinders has viewed much attention from researchers and often found in heat ex changing tubes, in pipelines and reactors. Characterizing flow and temperature fields is important in relation to performance. According to Kanafiah et al. (2021), in their investigation the lower stagnation point flow occurred when an upward or downward flowing stream created the lower stagnation point, it is causing the thermal boundary layer to become complex by including the effects of buoyancy, viscous forces, and surface conditions with mixed convection.

Furthermore, Straughan (2022) has found boundary condition is important for modelling thermal systems like cooling a heated pipe, reactor walls or other heat re leasing components in order to provide more accurate representation of the thermal interactions in real systems. A convective boundary condition is not fixed surface temperature or heat flow conditions because it represents a realistic circumstance where the one cylinder's surface exchanges heat with an ambient fluid. Adding a convective boundary condition makes the study more realistic and applicable for real-world systems.

The addition of a porous medium modifies the flow and heat transfer characteristics. Porous materials (foams, fibrous metals, packed beds) are often employed in industrial systems to augment heat exchange. The fluid flow in these materials is more complicated because it experiences viscous effects as well as resistance to flow from the porous material. Multiple theoretical models have been developed to model the fluid flow behavior in porous media. The Brinkman model is one of the most complete of these models.

According to Khan et al. (2019), Brinkman is the model utilized for a porous medium that is applicable to a high-porosity incompressible surface. Brinkman model describes the movement of fluid through (dominantly) porous media, and has shown considerable success in heat transfer analysis for cases involving nanofluids, microchannels, and mixed convection.

Furthermore, the Brinkman parameter quantifies the impact of viscous resistance, and higher values indicate stronger viscous resistance (shear) effects, which significantly impacts convective heat transfer in the porous region. Furthermore, when an external magnetic field is considered, the research branches into studies of magnetohydrodynamics (MHD). There are

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Lorentz forces generated by the interaction of the magnetic field and electrically conducting fluid within the MHD flow which cause velocity and temperature distributions to change. Al-Kaby et al. (2025) also define that combination of MHD and the Brinkman Model also generalizes what is understood using the magnetic forces to control heat transfer and enhance fluid stability. Combination is relevant for engineering fields such as nuclear cooling reactors, MHD pumps, and geothermal energy systems.

Mathematical modelling of the heat transfer problem usually translates to nonlinear partial differential equations (PDEs). The alternative way of getting a sufficiently accurate solution is using numerical methods. There are many options available, but the bvp4c method in MATLAB is among those that have been demonstrated to be successful for solving two-point boundary value problems with one or more coupled nonlinear ordinary differential equations (ODEs).

Therefore, this study proposed a mathematical formulation to reduce the complex partial differential equations (PDEs) of Brinkman with MHD model to the simplest form of equations. The equations are solved with MATLAB bvp4c method since it is computationally inexpensive approach to addressing complex boundary value problems

**Literature Review**

Increasing interest is being shown to the areas of heat transfer and fluid flow around cylindrical shapes because of their application to energy systems as an example pumps and turbines, chemicals like mixing and reactors, cooling technologies. Many different approaches have been investigated in studies of heat transfer and fluid flow in porous media including, among others, the effects of non-Newtonian fluids, the effects of MHD and mixed convection.

Ashraf et al. (2021) conducted a study on analysis of the physical of the periodic mixed-convection flow around a nonconducting horizontal circular cylinder embedded in a porous medium. This study predicted the mechanism of heat and fluid flow around different angles of a nonconducting horizontal circular cylinder embedded in a porous medium. It is well established that the transient convective heat transfer, skin friction, and current density depend on amplitude and phase angle.

Reddy and Chamkha (2018) researched about heat and mass transfer characteristics of nanofluid over horizontal circular cylinder. The method of The Finite- element (FEM) is used for this study. The result of this study is Brownian motion and thermophoresis noticeably increase the temperature and concentration inside boundary layer. However, there is insufficient numerical investigation of how these nanofluid parameters simultaneously influence momentum, heat, and mass trans-fer around a horizontal circular cylinder inside porous media.

Furthermore, Kanafiah et al. (2022) have conducted combined convective transport of Brinkman-viscoelastic fluid across circular cylinder with convective boundary condition. This study used Runge -Kutta-Fehlberg to solve the governing equations with the help of maple software. The numerical result showed that the fluid velocity increased by improving conjugate and combined convection parameter but decreased with increasing Brinkman and viscoelastic parameters. It is also discovered that there is a reverse trend on temperature profiles. Swalmeh et al. (2019) analyzed numerical study of mixed convection heat transfer in methanol based micropolar nanofluid about a horizontal circular cylinder using Keller-box method to transform the governing equations.

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Next, Yasin et al. (2021) examined the MHD effects in mixed convection of ferrofluid flow at lower stagnation point on horizontal circular cylinder. The results showed that viscosity depends on the ferroparticle volume fraction and ferrofluid temperature. The gap is that while this study explores MHD mixed convection of ferrofluid at a cylinder, it does not address more complex fluids, additional transport phenomena, porous media effects, or advanced boundary conditions, leaving room for more comprehensive models.

By the next research, Mahat et al. (2022) conducted a study on magnetohydrodynamic mixed convection of viscoelastic nanofluid past a circular cylinder with constant heat flux. The result discovered that the viscoelastic nanofluid's velocity, temperature, skin friction, and heat transfer coefficients heavily depend on the viscosity and thermal conductivity combined with the magnetic field and nanoparticles volume fraction. Although this study develops a viscoelastic nanofluid model with MHD effects over a horizontal circular cylinder, it only focuses on constant heat flux and does not examine several other important physical effects, boundary conditions, or flow mechanisms that commonly influence nanofluid behavior.

In addition, Akram et al. (2022) conducted a study on evaluation of MHD of natural convective heat flow over circular cylinder saturated by nanofluid with thermal radiation and heat generation effect. They discovered that velocity and temperature profiles change significantly when magnetic force, radiation, heat generation and Joule heating increase. Next, the research study from Mirzaei et al. (2023) analyzed convection heat transfer of MHD fluid flow in the circular cavity with various obstacles. The result showed variations in Raileigh (Ra) and Hartmann (Ha) numbers significantly influence flow structure, temperature distribution, and mass transfer patterns. However, Current MHD cavity studies do not consider porous media, nanofluid effects, convective bound- ary conditions, or external mixed-convection flow over cylinders, leaving a gap for more general and realistic heat–mass transfer modelling. Ullah et al. (2024) analyzed numerical computations of MHD mixed convection flow of Bingham fluid in a porous square chamber with a wavy cylinder. According to the result, larger Bingham number values promote thermal stratification and decrease flow mobility, which results in dominating conductive heat transmission.

In another study, Fauzi et al. (2025) investigated the mixed convection of a Brinkman–viscoelastic nanofluid at the lower stagnation point of a horizontal circular cylinder. Their findings revealed that increasing the Brinkman parameter, viscoelastic parameter, and nanoparticle volume fraction enhances the temperature profile, indicating their significant influence on the heat transfer characteristics. However, Rafique et al. (2025) investigated the effects of MHD, thermal radiation, viscous dissipation, Brownian motion, and thermophoresis on bioconvection nanofluid flow over an inclined cylinder. They found that these parameters significantly influence the velocity, temperature, and concentration profiles.

By the next research, Alam (2025) investigated the biomagnetic fluid flow and heat transfer of blood containing magnetic particles over cylindrical surfaces under the influence of MHD and ferrohydrodynamic (FHD) effects. Their numerical results showed that the applied magnetic field significantly influences the flow and heat transfer characteristics, and the governing equations were solved using numerical techniques including the MATLAB-based bvp4c solver.

Moreover, Aich and Bhargavi (2026) investigated the heat transfer enhancement in magnetohydrodynamic Darcy–Brinkman flow through anisotropic porous media with viscous dissipation effects. They found that the magnetic field, anisotropy, and viscous dissipation

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significantly affect the flow and heat transfer characteristics, with an increase in the Hartmann number enhancing heat transfer under the investigated conditions.

The research highlighted in the literature has as its fundamental plan to analyze heat transfer with magnetohydrodynamic (MHD) Brinkman fluid flow past a horizontal circular cylinder which is subjected to a convective boundary condition (CBC). Although several researchers have succeeded in overcoming numerical limitations through the application of techniques like the Runge-Kutta method, Keller-Box method, and MATLAB bvp4c to resolve transformed boundary layer equations, there is still no such single framework in which the effects of porous media, magnetic field, and realistic thermal boundary conditions can be accounted for at the same time. It is for this reason that the present study proposes to apply the MATLAB bvp4c solver for treating the nonlinear equations as it is excellent for boundary value problems, to be able to visualize the velocity and temperature fields of a viscous, electrically conducting Brinkman fluid under the effect of magnetic field and convective surface heating.

## Research Methodology

The flowchart in Figure 1 summarizes the key step of the methodology, beginning with problem formulation leading to the numerical method and result of this study.

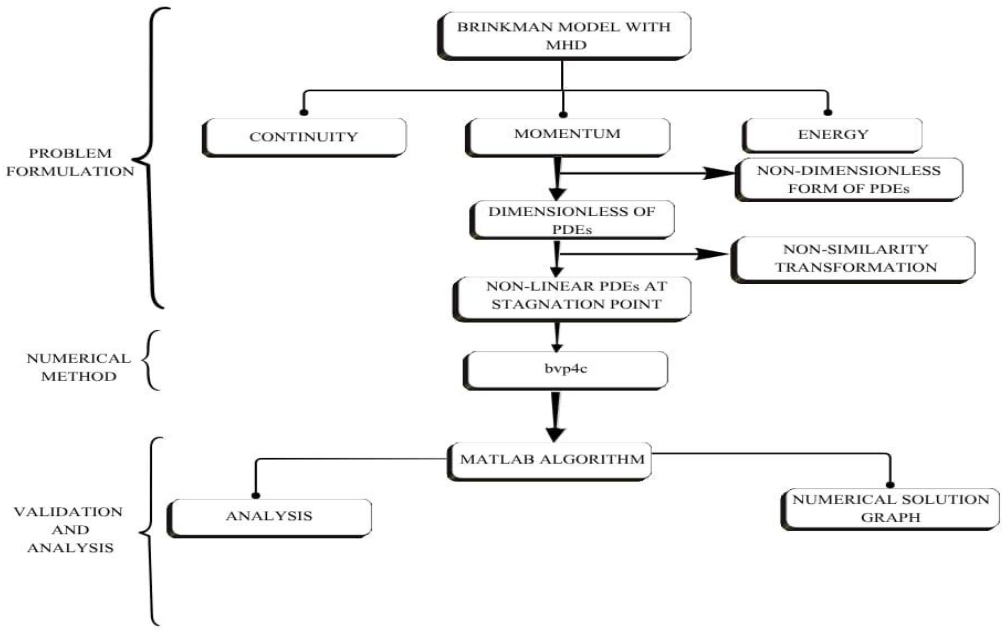


**Figure 1: Methodology Flowchart**

### Mathematical Formulation

This section presents the mathematical formulation of the mixed convection heat transfer problem for Brinkman fluid flow with magnetohydrodynamic (MHD) effects passing over a horizontal circular cylinder embedded in a porous medium under a convective boundary condition (CBC). The governing equations are established based on the principles of conservation of continuity, momentum, and energy together with the corresponding boundary conditions. The resulting partial differential equations are subsequently transformed into a system of nonlinear ordinary differential equations using appropriate non-dimensional variables and non-similarity transformations. The transformed equations are then solved numerically using the MATLAB Boundary Value Problem 4th Order (bvp4c) solver to analyse the effects of the governing parameters on the fluid flow and heat transfer characteristics. Figure 2 shows the physical model of this problem. The radius of the cylinder submerged in a saturated porous

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media. The values $\bar{x}$ and $\bar{y}$ are evaluated from lowest stagnation and perpendicular to the surface of the cylinder. The ambient temperature is denoted as $T_\infty$. The convection heats up the surface of the cylinder at temperature, $T_f$ that results in a heat transfer coefficient, $h_f$. The acceleration of gravity is denoted as $g$. It is formed from free stream velocity which $\frac{1}{2}U_\infty$.

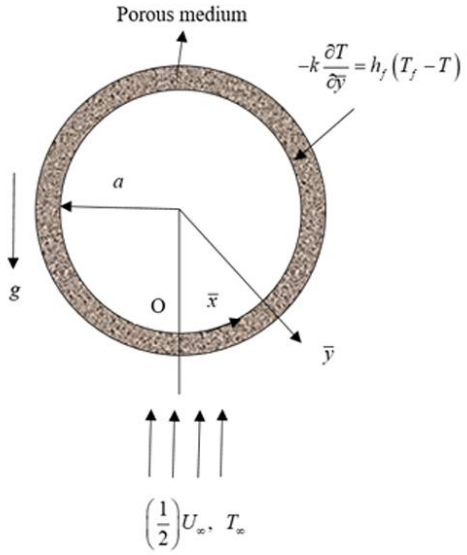


**Figure 2: Geometry model of the flow**

According to Kanafiah et al. (2021) and Yasin et al. (2021), the governing equations for Brinkman flow with MHD effects are

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

$$\frac{\mu}{K}\bar{u} = \frac{\mu}{\emptyset}\left(\frac{\partial^2 \bar{u}}{\partial \bar{y}^2}\right) - \frac{\partial p}{\partial \bar{x}} + \rho g \beta (T - T_\infty)\, sin\left(\frac{\bar{x}}{a}\right) - \frac{\sigma {B_0}^2}{\rho}(\bar{u} - \bar{u}_e) \tag{2}$$

$$\bar{u}\frac{\partial T}{\partial \bar{x}} + \bar{v}\frac{\partial T}{\partial \bar{y}} = a_m\left(\frac{\partial^2 T}{\partial \bar{x}^2} + \frac{\partial^2 T}{\partial \bar{y}^2}\right) \tag{3}$$

Depending on the boundary conditions,

$$\bar{v} = 0, \bar{u} = 0, -k\frac{\partial T}{\partial \bar{y}} = h_f(T_f - T),\ at\ \bar{y} = 0,$$
$$\bar{u} \to \bar{u}_e(\bar{x}), T \to T_\infty\ as\ \bar{y} \to \infty \tag{4}$$

where $\bar{u}$ and $\bar{v}$ are the velocity component along the $\bar{x}$ and $\bar{y}$ directions. For clarity, the physical quantities and parameters used in mathematical formulation are defined as follows. $T$ represents the fluid temperature, while $p$ denotes the pressure. The thermal conductivity and dynamic viscosity of the fluid are represented by $K$ and $\mu$. The fluid density is denoted by $\rho$ and $\phi$ represents the porosity of the porous medium. The effective thermal diffusivity of the porous medium is given by $a_m$ while $\beta$ denotes the thermal expansion coefficient. Finally, $B_0$ represents the intensity of the applied magnetic field. Velocity is prescribed as $\bar{u} \to \bar{u}_\infty \sin\left(\frac{\bar{x}}{a}\right)$.

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Subsequently, Equations (1)-(4) are transformed into their dimensionless form by introducing the non-dimensional variables following Kanafiah et al. (2021)

$$x = \frac{\bar{x}}{a},\ y = Pe^{\frac{1}{2}}\left(\frac{\bar{y}}{a}\right),\ u = \frac{\bar{u}}{U_\infty},\ v = Pe^{\frac{1}{2}}\left(\frac{\bar{v}}{U_\infty}\right), \theta = \frac{T-T_\infty}{T_f-T_\infty},\ u_e(\bar{x}) = \frac{\bar{u}_e(x)}{U_\infty} \tag{5}$$

The Péclet number for the porous region is defined as $Pe = U_\infty\left(\frac{a}{a_m}\right)$. Equation (5) is employed to transform Equations (1)-(4) into their corresponding dimensionless form. Hence, the resulting dimensionless governing equations are expressed as follows

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{6}$$

$$\frac{\partial u}{\partial y} = \Gamma\frac{\partial^3 u}{\partial y^3} + \lambda\frac{\partial \theta}{\partial y}\sin x - M\big(u - u_e(x)\big) \tag{7}$$

$$u\frac{\partial \theta}{\partial x} + v\frac{\partial \theta}{\partial y} = \frac{\partial^2 \theta}{\partial y^2} \tag{8}$$

Subjected to the transformed boundary condition:

$$u = 0,\ v = 0,\ \frac{\partial \theta}{\partial y} = -\gamma(1-\theta)\ at\ \ y = 0$$
$$u \to u_e,\ \ \theta \to 0\ \ as\ y \to \infty \tag{9}$$

Here, $\Gamma, \theta, \lambda\ and\ M$ denote the Brinkman parameter, dimensionless fluid temperature, mixed convection parameter and magnetic parameter, respectively. The non-similarity transformation in Equation (10) is applied to Equations (6)-(9) as follows

$$\psi = xf(x,y), \theta = \theta(x,y) \tag{10}$$

where $\psi$ is the stream function, defined such that $u = \frac{\partial \psi}{\partial y}$ and $v = -\frac{\partial \psi}{\partial x}$, while $\theta$ represent the fluid temperature. Then, the equations will be formed as follows

$$\frac{\partial f}{\partial y} = \Gamma\frac{\partial^3 f}{\partial y^3} + \frac{(1+\lambda\theta)\sin x}{x} - \frac{M}{x}\left(x\frac{\partial f}{\partial y} - \sin x\right) \tag{11}$$

$$\frac{\partial^2 \theta}{\partial y^2} + f\frac{\partial \theta}{\partial y} = x\left(\frac{\partial f}{\partial y}\frac{\partial \theta}{\partial x} - \frac{\partial f}{\partial x}\frac{\partial \theta}{\partial y}\right) \tag{12}$$

Depending on boundary condition

$$f = 0,\ \frac{\partial f}{\partial y} = 0,\ \frac{\partial \theta}{\partial y} = 0,\ \ at\ y = 0$$
$$\frac{\partial f}{\partial y} \to \sin x,\ \ \theta \to 0,\ \ as\ y \to \infty \tag{13}$$

At the lower stagnation points, where $x \cong 0$, Equations (11)-(13) are reduced to the following ordinary differential equations

$$f' - \Gamma f''' - (1 + \lambda\theta) + M(f' - 1) \tag{14}$$

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$$\theta'' + f\theta' = 0 \tag{15}$$

where boundary conditions:

$$f(0) = 0\,,\ f'(0) = 0,\ \theta'(0) = -\gamma\big(1 - \theta(0)\big),$$
$$f'(\infty) \to 1,\ \theta(\infty) \to 0 \tag{16}$$

Here, Primes depict the differentiation with respect to $y$, $\Gamma = \frac{Da}{\phi} Pe$ is Brinkman parameter $Da = \frac{K}{a^2}$ is Darcy number, $\lambda = \frac{Ra}{pe}$ mixed convection parameter, $Ra = \frac{gk\beta(T_f - T_\infty)a}{a_m v}$ is Rayleigh number and $\gamma$ is the conjugate parameter.

**Results and Discussion**

The numerical calculations on system of Equations (14) and (15) with respect to boundary conditions (16) were solved utilising the built in "bvp4c" function in MATLAB software. The results of the analyses are displayed graphically to study the mixed convection parameter (λ), magnetic parameter ($M$) , Brinkman parameter (Γ) and conjugate parameter (γ). In this study, the assisting flow (heated cylinder), λ > 0, is considered. According to Nazar et al. (2003) and Kanafiah et al. (2021), a large value of the Brinkman parameter implies the dominance of the no-slip condition which is limited to the viscous layer only. Γ ≠ 0 is used to define the Brinkman factor. In the present results, the boundary conditions were asymptotically reached by taking an adequate thickness of the boundary layer.

To verify, the comparison values between the outcomes of the numerical result of Nazar et al. (2003) and exact equation of Harris et. al (2009) are shown in Table 1. The boundary layer thickness was chosen to be sufficiently large for the boundary conditions to be satisfied as a limit. The effect of mixed convection parameter (λ), magnetic parameter ($M$), Brinkman parameter (Γ) and conjugate parameter (γ) on velocity and temperature profiles were examined. The comparison of $f"(0)$ in Table 1 shows excellent agreement, confirming the accuracy and reliability of the numerical method.

**Table 1. Comparison values of $f"(0)$ near stagnation point for different Γ, $\gamma \to \infty$ and $M = 0$**

| Γ | Harris et al. (2009) | Nazar et al. (2003) | Current |
|---|---|---|---|
| 0.1 | 3.1622 | 3.1623 (0.0001) | 3.1622 (0.0000) |
| 0.2 | 2.2360 | 2.2361 (0.0001) | 2.2360 (0.0000) |
| 0.3 | 1.8257 | 1.8257 (0.0000) | 1.8257 (0.0000) |
| 0.4 | 1.5811 | - | 1.5813 (0.0002) |

Figures 3 and 4 show the velocity and temperature profiles when the value of the Brinkman parameter Γ is varied. As increases of Γ the velocity profile decreases throughout the boundary layer region. An increase in Γ results in a greater resistance to fluid flow, which means that the fluids will move slowly, and will approach the free stream velocity slower. The temperature profile is rising with the increase of Γ. The thermal boundary layer thickness is increased due to the fluid staying at a higher temperature throughout the boundary layer.

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The rise and fall of the velocity profile and temperature profile with the change of the mixed convection parameter λ is shown in Figures 5 and 6, respectively. The result shows that velocity profile will increase with increasing λ. This is because a higher mixed convection parameter increases the buoyancy force that aids the fluid to flow faster and hence boosts the velocity in the boundary layer. Temperature profile decreases as value of λ increases. This is because the buoyancy force is also increased with an increase in (λ), thus increasing the convective heat transfer from the surface of the cylinder to the surrounding fluid.

The magnetic parameter $(M)$ on velocity profile and magnetic parameter $(M)$ on temperature profile are shown in Figures 7 and 8 respectively. The result indicates that the velocity profile gets greater with increase in the value of $M$. This shows that by increasing magnetic parameter the fluid motion within the boundary layer improves, and the fluid attains the free-stream velocity quicker. The temperature profile falls as the result of increase of $M$. This means that with the increase of the magnetic parameter the thickness of the thermal boundary layer decreased.

Figures 9 and 10 shows the velocity and temperature profile for conjugate parameter, (γ). As shown in Figure 9, the velocity profiles increases with increasing γ. This indicates that the higher the value of γ, the more fluid flows through it and the thicker the boundary layer is slightly. As shown in Figure 10, it is possible to find higher temperature profiles, as γ is increased. This means that the higher γ the more heat will be transferred from the surface to the fluid, resulting in higher temperatures within the boundary layer.

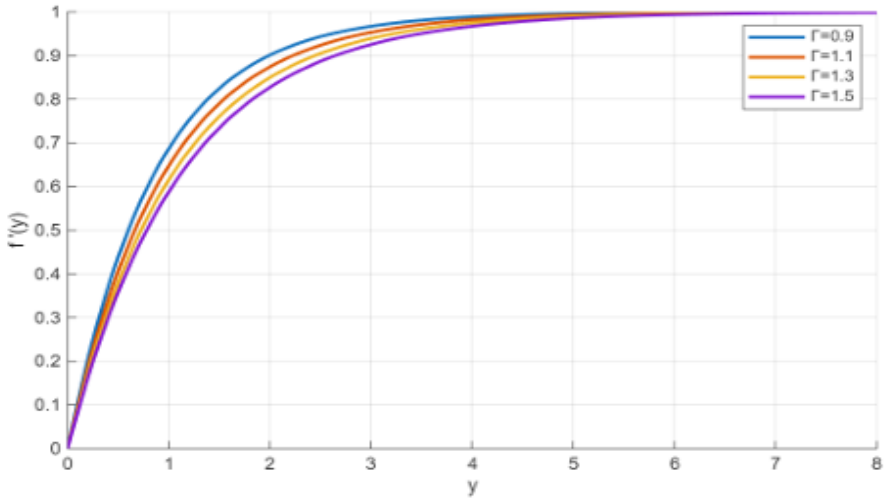


**Figure 3: Velocity profile for varies $\Gamma$ when $\lambda$=1, $M = 0, \gamma \to \infty$**

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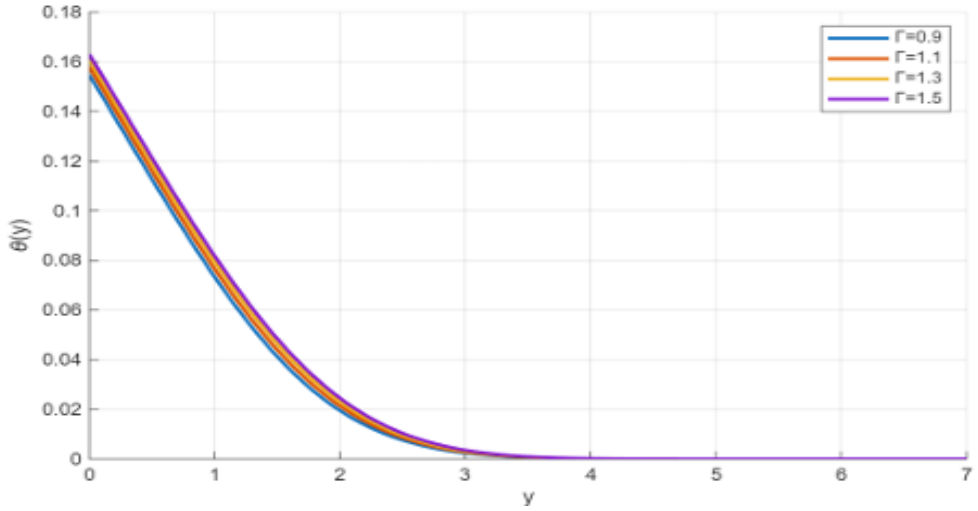


**Figure 4: Temperature profile for varies $\Gamma$ when $\lambda = 1. M = 0, \gamma \to \infty$**

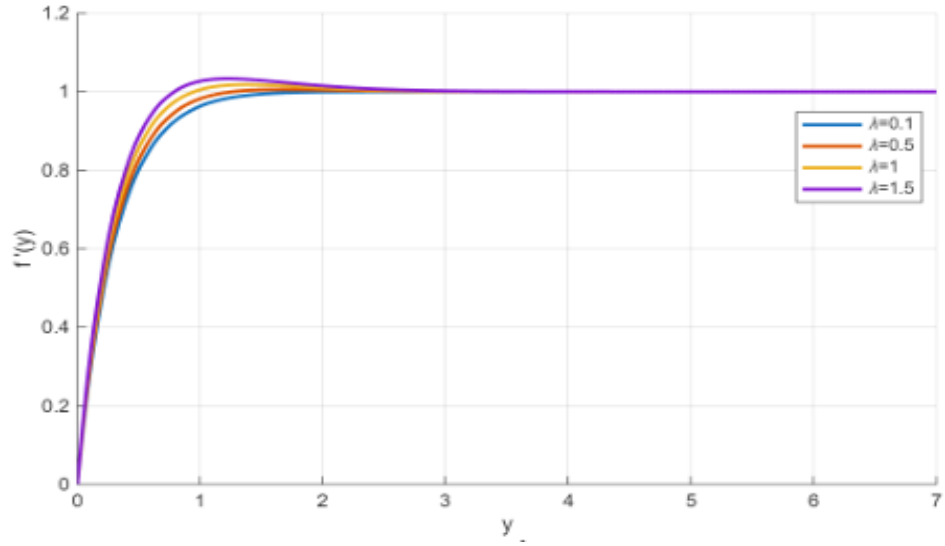


**Figure 5: Velocity profile for varies $\lambda$ when $\Gamma = 0.1. M = 0, \gamma \to \infty$**

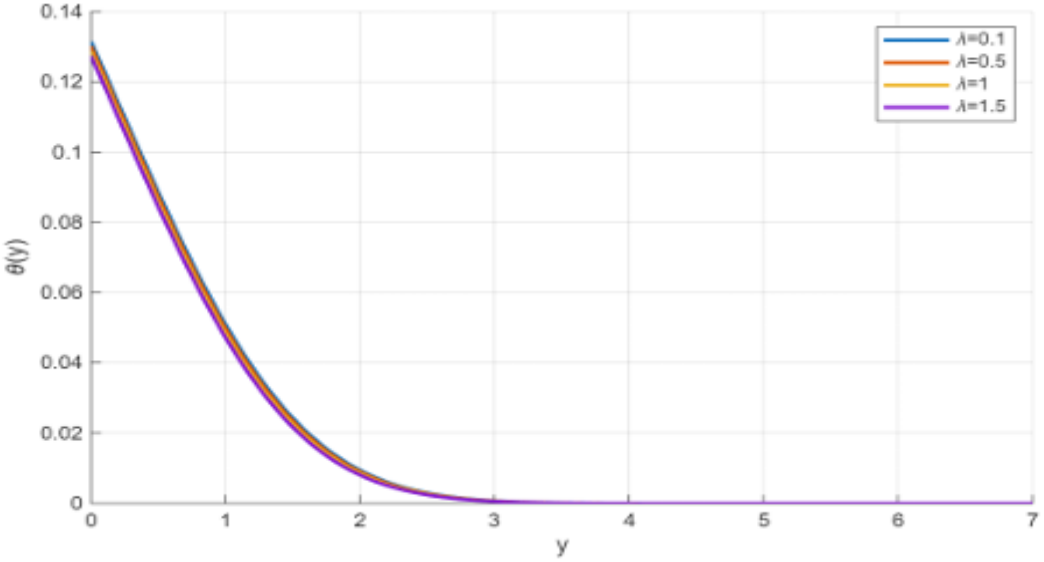


**Figure 6: Temperature profile for varies $\lambda$ when $\Gamma = 0.1. M = 0, \gamma \to \infty$**

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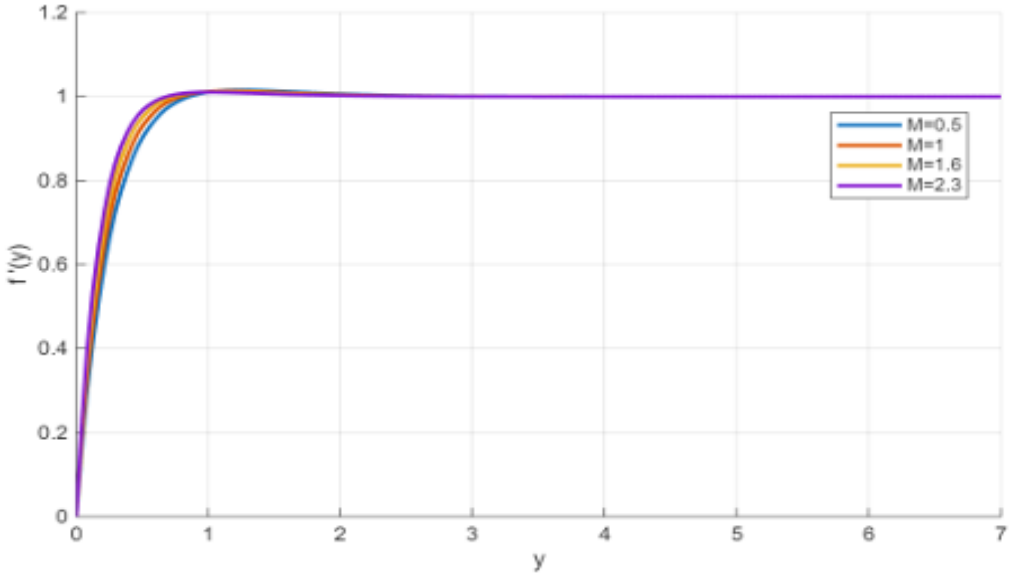


**Figure 7: Velocity profile for varies $M$ when $\Gamma = 0.1. \lambda = 1, \gamma \to \infty$**

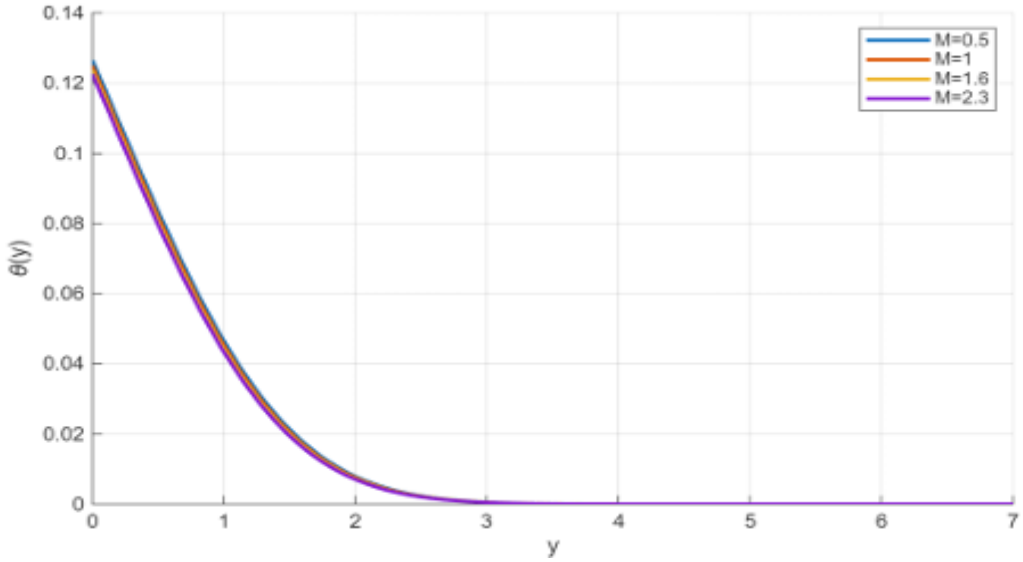


**Figure 8: Temperature profile for varies $M$ when $\Gamma = 0.1. \lambda = 1, \gamma \to \infty$**

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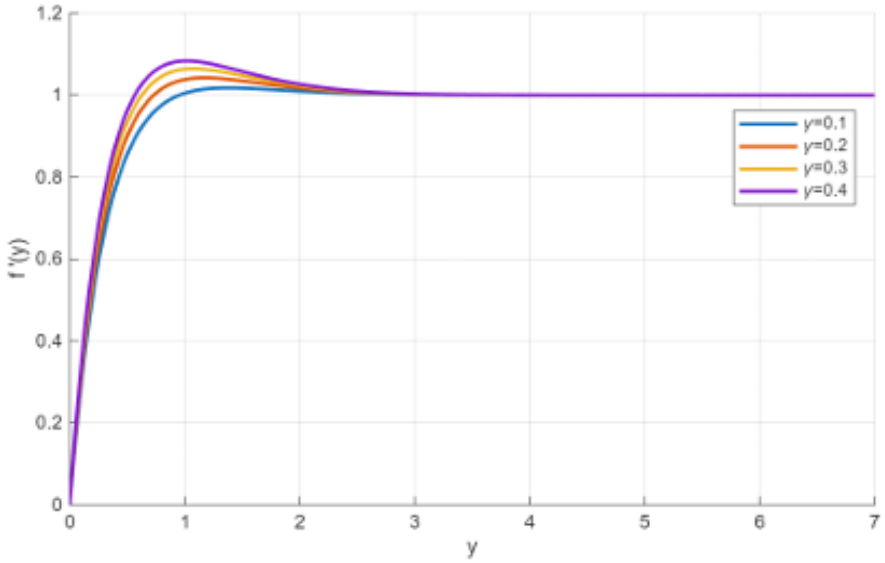


**Figure 9: Velocity profile for varies $\gamma$ when $\Gamma = 0.1, \lambda = 1, M = 0$**

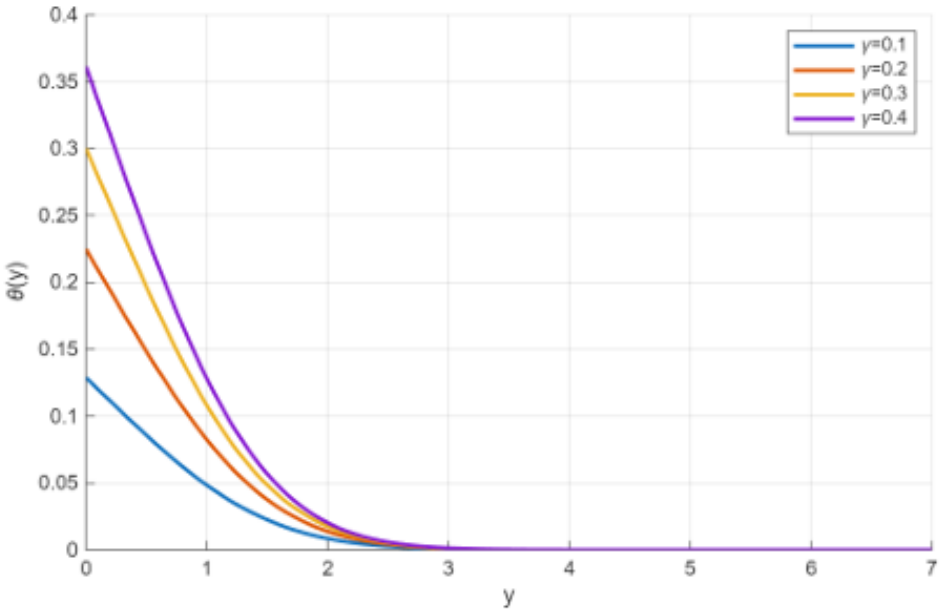


**Figure 10: Temperature profile for varies $\gamma$ when $\Gamma = 0.1, \lambda = 1, M = 0$**

## Conclusions

In the present study, the steady mixed convection flow of Brinkman with MHD effect over a horizontal circular cylinder placed inside a porous medium in presence of convective boundary conditions is studied. The flow and heat transfer characteristics are analysed for the influence of the mixed convection parameter (λ), magnetic parameter ($M$), Brinkman parameter (Γ) and conjugate parameter (γ). The conclusions for the current study are as follows:

i. Velocity profile is increasing with the increasing of the parameter of mixed convection (λ), the magnetic parameter ($M$), the conjugate parameter (γ) and decreasing with the increase of Brinkman parameter (Γ).

ii. The temperature profile decreases with increasing the mixed convection parameter (λ) and magnetic parameter ($M$), while it increases with increasing the Brinkman parameter (Γ) and the conjugate parameter (γ).

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iii. The thickness of thermal boundary layer decreases with increase of the mixed convection parameter,(λ) and magnetic parameter, ($M$) and increases with increase of the Brinkman parameter, (Γ) and conjugate parameter, (γ) respectively.
iv. Brinkman parameter (Γ) and mixed convection parameter (λ) have an inverse effect on velocity and temperature profiles.

Overall, the parameters in this investigation play an important role in analyzing the characteristics of fluid flow, especially for temperature and velocity distribution of the flow, which is crucial in the heat transfer process. Nevertheless, this current study has the potential to be expanded in several ways. It is suggested that to consider several physical effects such as viscous dissipation and chemical reaction. In addition, future research can also consider the nanofluid into this model owing to its widely application in industrial sectors.

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