Frontiers in Heat and Mass Transfer

Tech Science Press

DOI: 10.32604/fhmt.2024.050929

ARTICLE

Finite Difference Approach on Magnetohydrodynamic Stratified Fluid Flow Past Vertically Accelerated Plate in Porous Media with Viscous Dissipation

M. Sridevi[1], B. Shankar Goud[2], Ali Hassan[3,4,*] and D. Mahendar[5]

[1]Department of Mathematics, Koneru Lakshmaiah Education Foundation Hyderabad, Telangana, 500043, India

[2]Department of Mathematics, JNTUH University College of Engineering, Science & Technology, Hyderabad (TS), 500085, India

[3]Department of Mathematics, University of Gujrat, Gujrat, 50700, Pakistan

[4]Department of Mechanics and Aerospace Engineering, Southern University of Science and Technology, Shenzhen, China

[5]B V Raju Institute of Technology, Narsapur, Medak, India

*Corresponding Author: Ali Hassan. Email: muhammadali0544@gmail.com

Received: 23 February 2024 Accepted: 25 April 2024 Published: 11 July 2024

ABSTRACT

This study intends to evaluate the influence of temperature stratification on an unsteady fluid flow past an accelerated vertical plate in the existence of viscous dissipation. It is assumed that the medium under study is a grey, non-scattered fluid that both fascinates and transmits radiation. The leading equations are discretized using the finite difference method (FDM). Using MATLAB software, the impacts of flow factors on flow fields are revealed with particular examples in graphs and a table. In this regard, FDM results show that the velocity and temperature gradients increase with an increase of Eckert number. Furthermore, tables of the data indicate the influence of flow-contributing factors on the skin friction coefficients, and Nusselt numbers. When comparing constant and variable flow regimes, the constant flow regime has greater values for the nondimensional skin friction coefficient. This research is both innovative and fascinating since it has the potential to expand our understanding of fluid dynamics and to improve many different sectors.

KEYWORDS

MHD; FDM; stratified fluid; porous media; unsteady flow

Nomenclature

u_0	Characteristic velocity
ρ	Density of the fluid (kgm^{-3})
M	Magnetic field parameter
D	Molecular diffusivity
u	Non-dimensional velocity (ms^{-1})
S	Non-dimensional stratification parameter
θ	Non-dimensional temperature
Pr	Prandtl number
τ	Skin friction

T'_w	Temperature of plate (K)
T'_∞	Fluid Temperature at infinity (K)
T'	Temperature of the fluid (K)
u'	Velocity factor along the z-axis (ms^{-1})
K'_p	Permeability of the medium
υ	Kinematic coefficient of viscosity
σ	Electrical conductivity of the fluid ($\Omega^{-1}m^{-1}$)
k	Thermal diffusivity ($kgms^{-3}$)
Nu	Nusselt number
t'	Time
Gr	Grashof number for heat transfer
C_p	Specific heat at constant pressure ($Jkg^{-1}K^{-1}$)
K	Porosity parameter (m^2)
α	Thermal diffusivity (m^2s^{-1})
B_0	Magnetic field component along y' ($kgs^{-2}A^{-1}$)
g	Acceleration due to gravity (ms^{-2})
t	Non-dimensional time (s)
β	Heat transfer volumetric coefficient (K^{-1})
γ	Thermal stratification parameter

1 Introduction

Almost every branch of engineering, as well as biology, astronomy, biomedicine, meteorology, physical chemistry, and many of other fields. Heat transmission and hydromagnetic flows in porous media are analyzed. Several technological applications assist in understanding the moment of an electrically conducting fluid in a magnetic field. The study of MHD flow is of significant use to anyone interested in metallurgy and metalworking. Over the last several decades, researchers have learned about Magnetohydrodynamic phenomena. By observing the flow of a porous vertical plate, the pioneering study of transient free convection of an electrically conducting fluid away from a vertical plate in the occurrence of a magnetic field was conducted by Gupta [1]. Helmy [2] investigated the dynamics of MHD unsteady free convection. A solution to the problem of unsteady natural convection in porous media has been proposed analytically by Magyari et al. [3]. Using the finite difference approach, Raptis et al. [4] explored the flow through an impulsively started vertical plate on a porous surface. Deka et al. [5] considered transient free convection flow over a vertically accelerated plate embedded in a viscous thermally stratified fluid. Abdullah [6] looked into the transient free convection MHD flow that occurs through an accelerating vertical plate with periodic temperature. Over a thermally stratified medium, Mukhopadhyay [7] investigated the flow and heat transport of an MHD boundary layer in a sheet that was exponentially extending.

There are several scientific and engineering uses for the radiative effects, space technology, and high-temperature operations rely heavily on the impact of radiation heat transfer on various flows. Regarding the impact of radiation on the boundary layer, however, very little is known. In the polymer processing business, where the effectiveness of the heat-controlling factors is a significant factor in determining the quality of the final product. The impacts of thermal radiation may play a significant role in heat transfer. Radiative MHD convective flow across an impulsively initiated vertical plate with a constant heat and mass flux was studied by Prasad et al. [8]. Free convective flow past from a horizontally inclined plate in a medium with thermal stratification was analyzed by Sambath et al. [9].

The hydromantic natural convective that occurs from an isothermal inclined surface that is near a thermally stratified permeable medium was investigated by Chamkha [10].

Viscous dissipation effects are an essential component of free convection, used in various techniques that are subject to significant fluctuations in gravitational energy or that work at high velocities. Israel-Cookey et al. [11] explored on natural convection flow of MHD across an infinite vertical plate in a permeable medium with suction and dissipation. Soundalgekar [12] investigated viscous dissipation in unsteady free convection across an infinite plate with constant suction and heat. Palani et al. [13] evaluated the joint impact of dissipation and MHD on MHD-free convective across the vertical plate with varying surface temperatures. Aydın et al. [14] investigated the phenomenon of mixed convective a viscous liquid that was dissipating around a vertical plate. The Impact of Heat Generation/Absorption on the Nonlinear Convective flow of a Casson fluid through a horizontal Plate. Impact of viscous dissipation on natural convective in a non-Darcy porous media saturated with non-Newtonian fluid of variable viscosity. Unconfined flow of a non-Newtonian fluid through a non-Darcy porous media that is thermally stratified. An analysis of the consequences of solutal dispersion and dissipation on non-Darcy free convection across a cone in power-law fluids. A non-Newtonian nanofluid saturated in a permeable medium: the impact of melting on mixed convection heat and mass transmission. was studied by Kairi et al. [15,16]. The significance of nanofluid aggregation in an unstable rotating flow, the consequences of slip circumstances, and the role of varying viscosity were investigated by Khan et al. [17]. Koriko et al. [18] examined the use of thermal conductivity models in the non-Darcian flow analysis of micropolarfluid over a vertical surface. Kishan et al. [19] inspected the importance Viscous dissipation's effects on MHD flow with mass and heat transfer across a stretched surface with thermal stratification, and chemical reaction. In a thermally stratified medium using a second order slip model, Hakeem et al. [20] investigated the heat transfer of a non-Darcy MHD flow of nanofluid across a surface that was stretching and shrinking.

The impact of double stratification on the transfer of heat and mass in unsteady MHD nanofluid flow across a flat surface was investigated by Mutuku et al. [21]. Computational investigation of a semi-infinite porous media with thermal radiation, heat transfer in MHD system was conducted by Beg et al. [22]. Joule heating impacts multi-homogeneous convective fluid flow across a semi-infinite angled vertical plate in the presence of a chemical reaction also thermal radioactivity affects MHD-free convection flow over an absorbent vertical surface with temperature was investigated by Goud et al. [23,24]. The flow of the MHD boundary layer in a medium with two stratifications was studied by Ismail et al. [25]. The impacts of the mass and heat transfer on the movement of non-Newtonian fluids immersed in a thermally stratified permeable medium were investigated by Tharapala et al. [26]. The impact of a thermally stratified surrounding fluid on MHD convection over a non-isothermal vertical plate in motion was investigated by Singh et al. [27]. Thermal stratification impacts on MHD radiative flow of nanofluid passed across a nonlinear stretching sheet with changing thickness were investigated by Daniel et al. [28].

The purpose of this research is to examine free convective MHD flow in a thermally stratified fluid over an accelerating vertical plate in the existence of viscous dissipation. Converted nondimensional governing equations are solved numerically using finite difference. The numerical finite difference approach solves dimensionless flow field equations for various flow variables. A graph shows velocity and temperature gradients. Finally, the numerical findings of this work have been compared with the study that was published before this one.

2 Formulation

In a thermally stratified medium with a magnetic field, a transient laminar, unstable, free convection flow of a viscous and incompressible fluid across an infinite vertical plate has been investigated. When taking the dimensions of a plate, and $x-$axis is positioned horizontally across, whereas $y-$axis is positioned erect to the plate. The plate is subjected to a homogeneous magnetic field of intensity B0 in the y-direction. In this scenario, the induced magnetic field from the fluid motion is thought to be negligible since the applied magnetic field is so powerful. In the beginning, at the time $t^* \leq 0$, it is assumed that both the fluid and the plate have a temperature of T^*_∞. The plate's temperature is then increased to T_w at some time $t > 0$. The flow geometry (Fig. 1) and modal are represented, and taking into account the aforementioned assumptions and the standard governing equations [5] are:

$$\frac{\partial u^*}{\partial t^*} = \upsilon \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta\left(T^* - T^*_\infty\right) - \left(\frac{\sigma B_0^2}{\rho}\right) u^* - \frac{\upsilon}{K^*} u^* \tag{1}$$

$$\frac{\partial T^*}{\partial t^*} = \alpha \frac{\partial^2 T^*}{\partial y^{*2}} - \gamma u^* + \frac{\mu}{\rho C_p}\left(\frac{\partial u^*}{\partial y^*}\right)^2 \tag{2}$$

where $\gamma = \frac{dT_\infty}{dz} + \frac{g}{C_p}$, here, thermal stratification is $\frac{dT_\infty}{dz}$, the term pressure work is $\frac{g}{C_p}$.

Under appropriate circumstances are:

$$\left.\begin{array}{l} u^* = 0, T^* = T^*_\infty, \forall y^*, when\, t^* \leq 0 \\ u^* = At^*, T^* = T^*_w, at\, y^* = 0, when\, t^* > 0 \\ u^* \to 0, T^* \to T^*_\infty, as\, y^* \to \infty \end{array}\right\} \tag{3}$$

where T^*_w is wall temperature, t^* is time, and A (> 0) is constant acceleration.

It is proposed to use the following nondimensional quantities:

$$\left.\begin{array}{l} y = \sqrt{\frac{A}{\upsilon}} y^*, u = u^*, t = At^*, K = \frac{K^* A}{\upsilon}, M = \frac{\sigma B_0^2}{\rho A}, Gr = \frac{g\beta\left(T^*_w - T^*_\infty\right)}{A} \\ S = \frac{\gamma\upsilon}{A\left(T^*_w - T^*_\infty\right)}, \theta = \frac{T^* - T^*_\infty}{T^*_w - T^*_\infty}, Pr = \frac{\mu C_p}{k}, Ec = \frac{A\upsilon}{C_p\left(T^*_w - T^*_\infty\right)}, \mu = \rho\upsilon \end{array}\right\} \tag{4}$$

It is possible to simplify Eqs. (1) and (2) using nondimensional values.

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + Gr\theta - Mu - \frac{1}{K} u \tag{5}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} - Su + Ec\left(\frac{\partial u}{\partial y}\right)^2 \tag{6}$$

The boundary constraints in the nondimensional form are as follows:

$$\left.\begin{array}{l} u = 0, \theta = 0, \forall y, when\, t \leq 0 \\ u = t, \theta = 1, at\, y = 0, when\, t > 0 \\ u \to 0, \theta \to 0, as\, y \to \infty \end{array}\right\} \tag{7}$$

Now, let's analyze the velocity field for skin friction. We represent it dimensionless as [29]:

$$\tau = -\left(\frac{\partial u}{\partial y}\right)_{y=0}.$$

The nondimensional representation of the Nusselt number resultant from the temperature profile is $Nu = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0}$

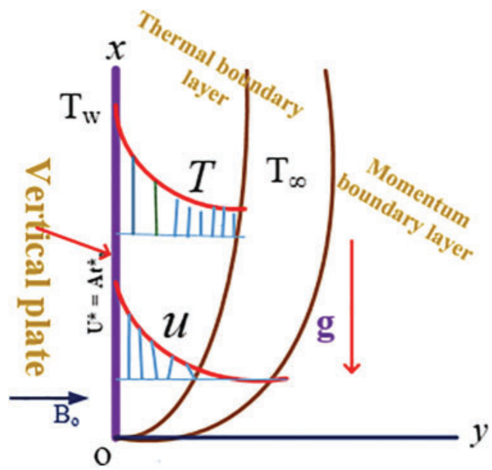

Figure 1: Flow geometry of the present study

3 Problem Solution

Using the implicit finite difference process of the Crank-Nicolson process, the momentum & energy Eqs. (5) and (6) may be solved once the initial and boundary constraints (7) have been established, and the geometry of the finite difference scheme can be seen in Fig. 2.

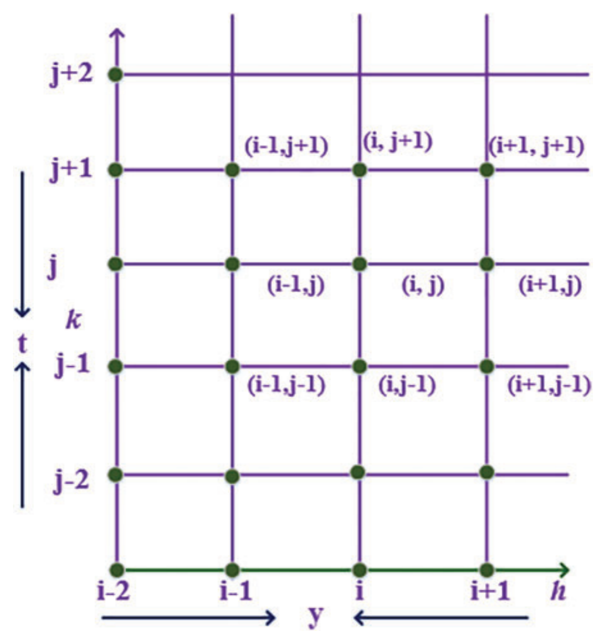

Figure 2: Geometry of finite-difference system

After determining the necessary starting and boundary constraints (7), we can use the implicit finite difference method, often known as the Crank-Nicolson model, to solve the momentum and energy Eqs. (5) and (6). We discretize the necessary finite difference equations in (5) and (6) by using the Nicolson method, as shown below:

$$\frac{u_i^{j+1}-u_i^j}{\Delta t}=\left[\frac{u_{i-1}^{j+1}+u_{i+1}^{j+1}+u_{i-1}^j-2\left(u_i^{j+1}+u_i^j\right)+u_{i+1}^j}{2\left(\Delta y\right)^2}\right]-\left(M+\frac{1}{K}\right)u_i^j+Gr\theta_i^j$$

$$u_i^{j+1}-u_i^{j+1}=\frac{\Delta t}{(\Delta y)^2}\left[u_{i-1}^{j+1}+u_{i+1}^{j+1}+u_{i-1}^j-2\left(u_i^{j+1}+u_i^j\right)+u_{i+1}^j\right]-\left(M+\frac{1}{K}\right)\Delta t u_i^j+Gr\Delta t\theta_i^j$$

$$-\frac{r}{2}\left(u_{i-1}^{j+1}+u_{i+1}^{j+1}\right)+(1+r)\,u_i^{j+1}=\frac{r}{2}\left(u_{i-1}^j+u_{i+1}^j\right)+\left(1-r-\left(M+\frac{1}{K}\right)\right)u_i^j+Gr\mathrm{k}\theta_i^j$$

$$-Au_{i-1}^{j+1}+Bu_i^{j+1}-Au_{i+1}^{j+1}=Au_{i-1}^j+Cu_i^j+Au_{i+1}^j+Gr\mathrm{k}\theta_i^j$$

$$Bu\,(i)-A\,(u\,(i+1)+u\,(i-1))=A\,(u\,(i+1)+u\,(i-1))+Cu\,(i)+Gr\mathrm{k}\theta\,(i)$$

$$u\,(i)=\frac{D\,(i)+A\,(u\,(i-1)+u\,(i+1))}{B} \tag{8}$$

where $A\,(u\,(i+1)+u\,(i-1))+Cu\,(i)+Gr\mathrm{k}\theta\,(i)=D\,(i)$

$(1+r)=B, A=\frac{r}{2}, C=\left(-\left(M+\frac{1}{K}\right)+1-r\right)$

$$\frac{\theta_i^{j+1}-\theta_i^j}{\Delta t}=\frac{1}{Pr}\left[\frac{\theta_{i-1}^{j+1}-2\theta_i^{j+1}+\theta_{i+1}^{j+1}+\theta_{i-1}^j-2\theta_i^j+\theta_{i+1}^j}{2\left(\Delta y\right)^2}\right]-Su_i^j+Ec\left(\frac{u_{i+1}^{j+1}-u_i^j}{\Delta y}\right)^2$$

$$\frac{\theta_i^{j+1}-\theta_i^{j+1}}{\Delta t}=\frac{1}{Pr}\left[\frac{\theta_{i-1}^{j+1}-2\theta_i^{j+1}+\theta_{i+1}^{j+1}+\theta_{i-1}^j-2\theta_i^j+\theta_{i+1}^j}{2\left(\Delta y\right)^2}\right]-Su_i^j+Ec\left(\frac{u_{i+1}^{j+1}-u_i^j}{\Delta y}\right)^2$$

$$\theta_i^{j+1}-\theta_i^{j+1}=\frac{\Pr k}{(\Delta y)^2}\left[\theta_{i-1}^{j+1}-2\theta_i^{j+1}+\theta_{i+1}^{j+1}+\theta_{i-1}^j-2\theta_i^j+\theta_{i+1}^j\right]+k\left(Ec\left(\frac{u_{i+1}^{j+1}-u_i^j}{\Delta y}\right)^2-Su_i^j\right)$$

$$-\frac{rPr}{2}\left(\theta_{i-1}^{j+1}+\theta_{i+1}^{j+1}\right)+rPr\theta_i^{j+1}=\frac{rPr}{2}\theta_{i-1}^j+(1+rPr)\,\theta_i^j+\frac{rPr}{2}\theta_{i+1}^j+k\left(Ec\left(\frac{u_{i+1}^{j+1}-u_i^j}{\Delta y}\right)^2-Su_i^j\right)$$

$$-C_1\theta_{i-1}^{j+1}+C_2\theta_i^{j+1}-C_1\theta_{i+1}^{j+1}=C_1\theta_{i-1}^j+C_3\theta_i^j+C_1\theta_{i+1}^j+k\left(Ec\left(\frac{u_{i+1}^{j+1}-u_i^j}{\Delta y}\right)^2-Su_i^j\right)$$

$$C_2\theta_i^{j+1}-C_1\left(\theta_{i-1}^{j+1}+\theta_{i+1}^{j+1}\right)=C_1\left(\theta_{i-1}^j+\theta_{i+1}^j\right)+C_3\theta_i^j+k\left(Ec\left(\frac{u_{i+1}^{j+1}-u_i^j}{\Delta y}\right)^2-Su_i^j\right)$$

$$C_2\theta\,(i)-C_1\,(\theta\,(i+1)+\theta\,(i-1))=C_1\,(\theta\,(i+1)+\theta\,(i-1))+C_3\theta\,(i)$$

$$\theta\,(i)=\frac{C\,(i)+C_1\,(\theta\,(i-1)+\theta\,(i+1))}{C_2} \tag{9}$$

where $C\,(i)=C_1\,(\theta\,(i-1)+\theta\,(i+1))+C_3\theta\,(i)+k\left(Ec\left(\frac{u_{i+1}^{j+1}-u_i^j}{\Delta y}\right)^2-Su_i^j\right)C_1=\frac{rPr}{2}, C_2=rPr, C_3=(1+rPr)$, Initial and boundary limits that are suitable are as follows:

$$\left.\begin{array}{r} u\left(i,0\right)=t,\theta\left(i,0\right)=1 \\ u\left(i_{max},0\right)\rightarrow 0,\theta\left(i_{max},0\right)\rightarrow 0,\text{for any } i \text{ value} \end{array}\right\}. \tag{10}$$

As an initial stage in solving differential equations, the movement domain is split into a network by shapes parallel to t and y axes. An off-grid test is undertaken to determine which approach is the most exact. This is performed by conducting trials with various grid dimensions. The difference equations are obtained using this grid or mesh, as shown in Fig. 2.

For each node in a particular n-stage, there exists a tridiagonal matrix representation of the finite difference equations. Through the use of the boundary circumstances (10) and Eqs. (8) and (9), respectively, we achieve the set of equations for the tridiagonal matrix form.

4 Results and Discussion

The numerical findings of this investigation are existing in the form of profiles of velocity, temperature, and concentration, in addition to distributions of several other factors that are significant; the physicochemical parameters M (magnetic parameter), Ec (Eckert number), Pr (Prandtl number), S (heat source parameter), t (time), and K (permeability parameter). These simulations involve plotting the graphs and conducting a thorough investigation of the obtained results.

The magnetic field role is seen in the velocity in addition to temperature curves in Figs. 3 and 4, respectively. According to the findings, a rise in M causes a drop in velocity while simultaneously leading to an increase in temperature. The Lorentz forces produced by the transverse magnetic field account for this finding. These Lorentz forces function as resistive forces, much like drag forces, and slow down the flow. Therefore, a higher value for M slows the flow. The transverse magnetic flux, which causes the Lorentz forces, is responsible for this occurrence.

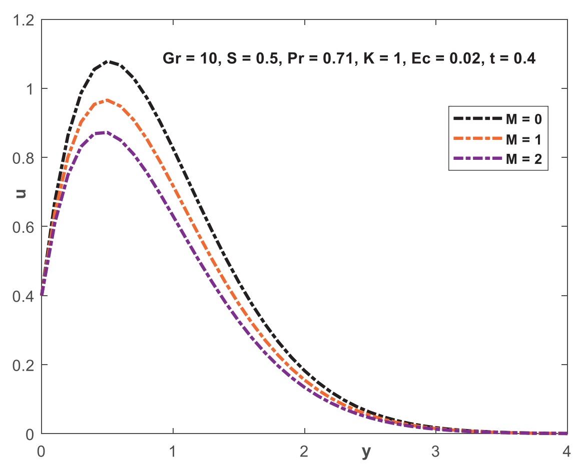

Figure 3: Plot velocity against M

Different values of the Grashof number are shown in the velocity field in Figs. 5 and 6. When Gr improves, the velocity field is thought to increase while the temperature field declines. The Grashof number provides an approximation of the ratio between the thermal buoyancy and viscous force acting on a fluid; changes in Gr have the effect of both increasing and lowering the buoyancy force. As the viscosity reduces, the fluid's internal resistance also lowers, which increases the fluid's velocity.

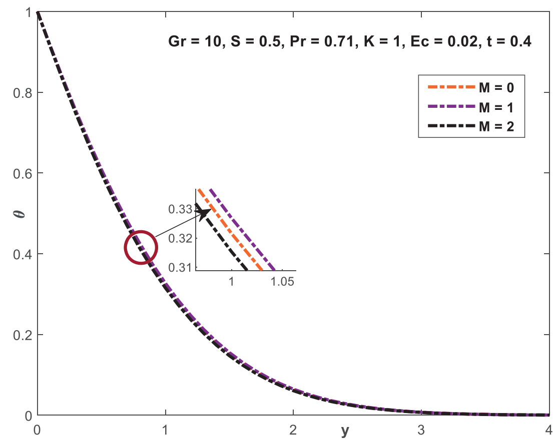

Figure 4: Plot temperature against *M*

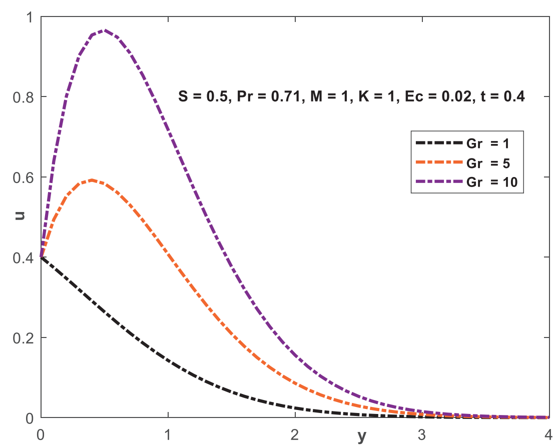

Figure 5: Plot velocity against *Gr*

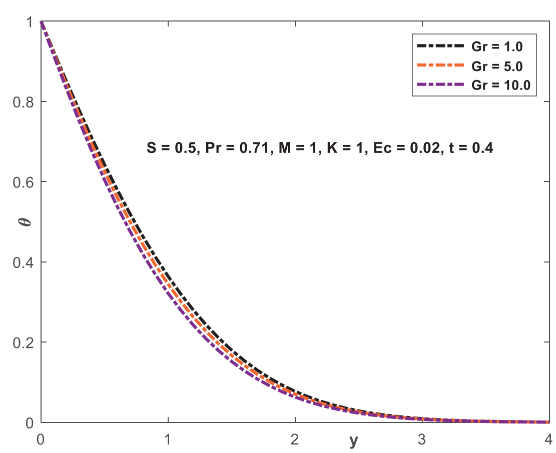

Figure 6: Plot temperature against *Gr*

Figs. 7 and 8 show the velocity and temperature profiles for various values of the permeability parameter (K). As K is enhanced, fluid velocity increases while temperature drops.

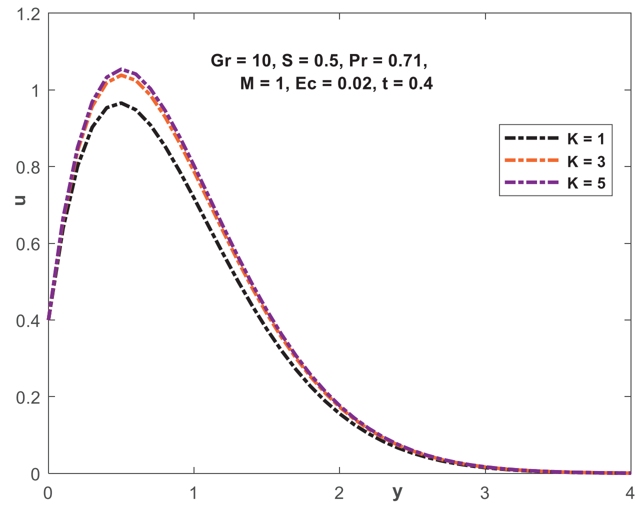

Figure 7: Plot velocity against K

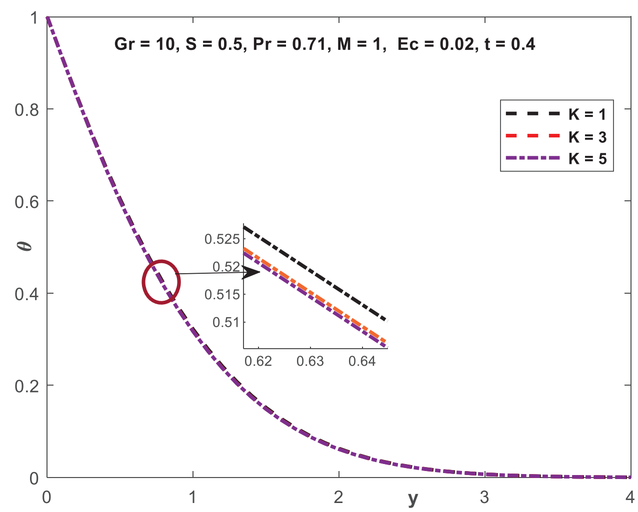

Figure 8: Plot velocity against K

The impact of time on the velocity curves is seen in Fig. 9. There is a clear improvement in the velocity profiles of the fluid over time.

Changing the stratification parameter (S) leads to different results in terms of velocity and temperature, as illustrated in Figs. 10 and 11, respectively. Velocity and temperature drop as the stratification factor increases.

The influence of the Prandtl number on the temperature distributions is seen in Fig. 12. According to this diagram, the fluid temperature drops as Pr rises. It is possible that the Pr values, like the ratio of the kinematic viscosity and the thermal diffusivity, are static. This phenomenon holds as a lower Prandtl number signifies a reduced capacity of the fluid to conduct heat. However, when the

Prandtl number increases, there is a little enhancement in the heat transfer rate near the plate. This phenomenon may be attributed to the escalating disparity in temperature between the plate and the surrounding atmospheric conditions.

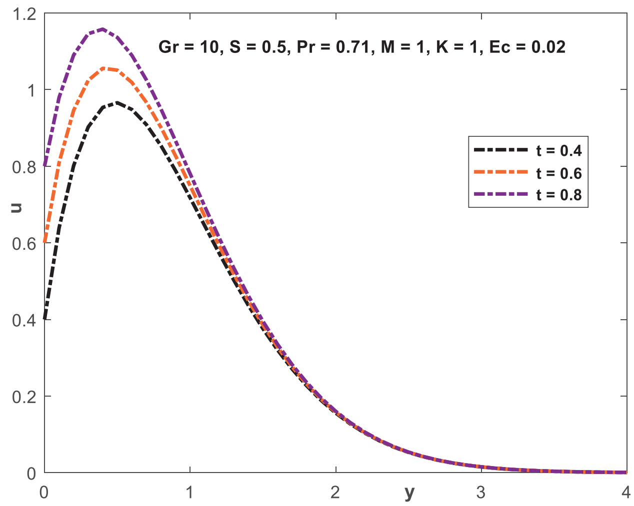

Figure 9: Plot velocity against t

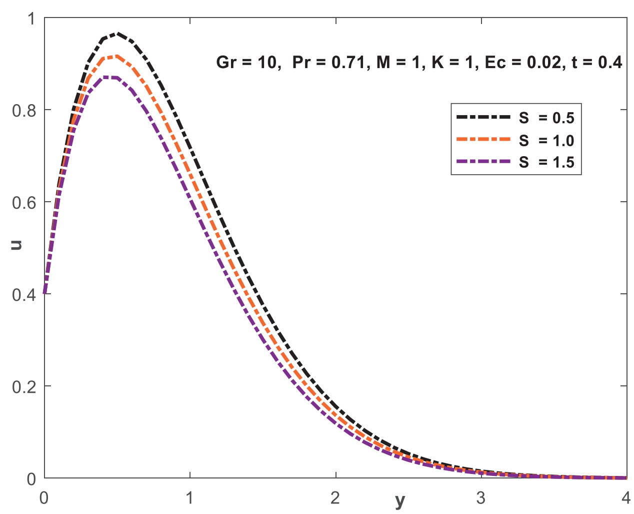

Figure 10: Plot velocity against S

Various transverse velocity field variations for different Eckert numbers Ec are shown in Fig. 13. There is a correlation between an enhancement in Ec and a rise in the significance of the variables measuring velocity, indicating that the enhanced buoyancy force is liable for this correlation. When Eckert's number increases, the ability of friction & heating compression to dissipate heat makes it the major source of the thermal boundary layer fluid. See the influence of Ec on temperature in Fig. 14. Friction heating adds to Ec-caused wall temperature increases because of the heat it generates.

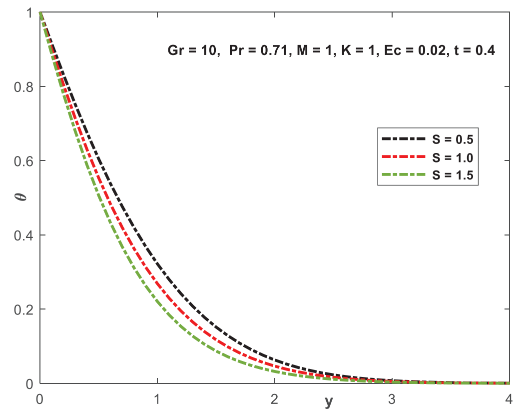

Figure 11: Plot temperature against *S*

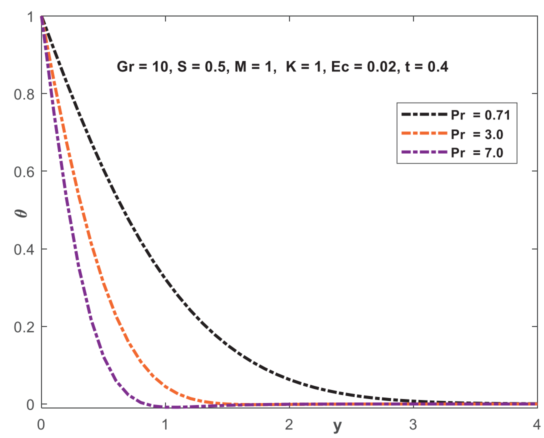

Figure 12: Plot temperature against *Pr*

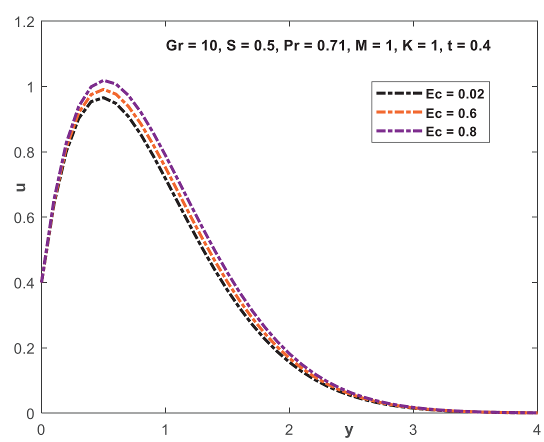

Figure 13: Plot velocity against *Ec*

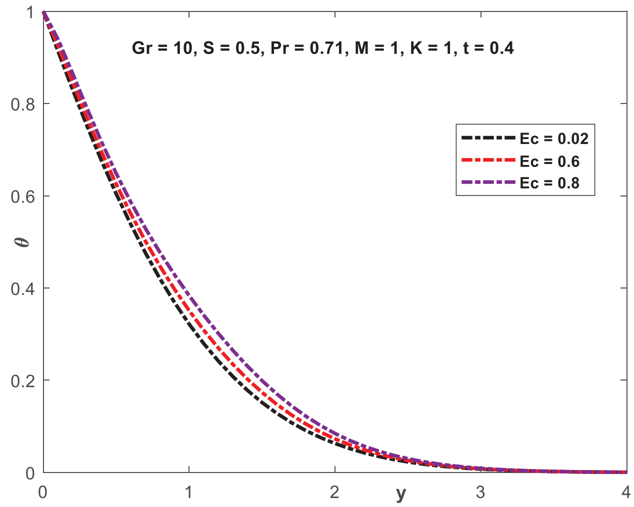

Figure 14: Plot temperature against *Ec*

The values of the friction factor and Nusselt number are shown in Table 1. Skin friction values grow as the quantities of components M, Pr, S, and t increase. Skin friction is reduced when Gr, K, and Ec levels rise. However, when $M$and Ec grow, the Nusselt number falls, whereas Gr, K, S, Pr, and t grow.

Table 1: Impacts of friction factor &Nusselt number for dissimilar values of flow factors

M	Gr	K	S	Pr	Ec	t	τ	Nu
0	10	1	0.5	0.71	0.02	0.4	−2.722409	0.867706
1							−2.388396	0.856109
2							−2.102349	0.845887
1	3						−0.341848	0.784025
	5						−0.935455	0.80585
	10	2					−2.548688	0.861723
		3					−2.605023	0.863676
		1	1				−2.266274	1.001940
			1.5				−2.150945	1.138232
			0.5	3			−1.353048	1.672471
				7			−0.778255	2.488849
				0.71	0.6		−2.490382	0.671971
					0.8		−2.527616	0.600553
					0.02	0.6	−2.091665	0.878100
						0.8	−1.795374	0.899540

Comparing our findings to those found in previously published publications [30] is something that interests us. Table 2 illustrates the comparison of the skin fibroblasts. We compare the findings from a few restricted examples with those that have been published before, and we find that there is a good agreement.

Table 2: Comparison of the friction factor for dissimilar values of flow factors with other factors are $K = 1,\ Gr = 10,\ S = 0.5,\ t = 0.4,\ Ec = 0$

M	Rajput et al. [30]	Present study
0	−2.7428	−2.7448
1	−2.32712	−2.3274

5 Conclusions

This study investigates the influence of a thermally stratified fluid with viscous dissipation as it flows over an accelerating vertical plate through a permeable material. The FDM is used to generate numerical solutions. The impact of various important factors on the flow distribution has been investigated, and the findings have been interpreted with the use of graphs and tables. This study revealed the following significant findings:

- The thickness of the momentum boundary layer decreases with enhancing M and S, while it increases with increasing $Gr,\ K,\ t$, and Ec.
- As the temperature increases with M and Ecincrease, while $K,\ Gr,\ Pr$, and S increase with enhancing temperature.
- Increasing the values of $Pr,\ S,\ t$ and M leads to higher skin friction values, though the opposed result can be perceived while $Gr,\ Ec$ and K are raised.
- Yet, Enhancing Ec and M results in a decline in Nu, although enhancing $Pr,\ S,\ Gr,\ t$ & K has the opposite impact.

Acknowledgement: The authors would like to thank the worthy reviewers and respected editor for their constructive remarks to enhance the over all presentation of this work.

Funding Statement: The authors received no specific funding for this study.

Author Contributions: Study conception and design: M. Sridevi, D. Mahendar; data collection: M. Sridevi, B. Shankar Goud; analysis and interpretation of results: B. Shankar Goud, Ali Hassan; draft manuscript preparation: Ali Hassan, D. Mahendar. All authors reviewed the results and approved the final version of the manuscript.

Availability of Data and Materials: This research has no unavailable data.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

1. Gupta, A. S. (1960). Steady and transient free convection of an electrically conducting fluid from a vertical plate in the presence of a magnetic field. *Applied Scientific Research, 9,* 319–333. https://doi.org/10.1007/BF00382210

2. Helmy, K. A. (1998). MHD unsteady free convection flow past a vertical porous plate. *ZAMM-Journal of Applied Mathematics and Mechanics/Zeitschrift für Angewandte Mathematik und Mechanik: Applied Mathematics and Mechanics, 78(4),* 255–270.
3. Magyari, E., Pop, I., Keller, B. (2004). Analytical solutions for unsteady free convection in porous media. *Journal of Engineering Mathematics, 48,* 93–104. https://doi.org/10.1023/B:ENGI.0000011914.16863.06
4. Raptis, A. A., Singh, A. K. (1985). Free-convection flow past an impulsively started vertical plate in a porous medium by finite difference method. *Astrophysics and Space Science, 112,* 259–265. https://doi.org/10.1007/BF00653508
5. Deka, R. K., Neog, B. C. (2009). Unsteady natural convection flow past an accelerated vertical plate in a thermally stratified fluid. *Theoretical and Applied Mechanics, 36(4),* 261–274. https://doi.org/10.2298/TAM0904261D
6. Abdullah, M. R. (2018). Transient free convection MHD flow past an accelerated vertical plate with periodic temperature. *Chemical Engineering Transactions, 66,* 331–336.
7. Mukhopadhyay, S. (2013). MHD boundary layer flow and heat transfer over an exponentially stretching sheet embedded in a thermally stratified medium. *Alexandria Engineering Journal, 52(3),* 259–265. https://doi.org/10.1016/j.aej.2013.02.003
8. Prasad, R. V., Reddy, B. N., Muthucumaraswamy, R. (2006). Transient radiative hydromagnetic free convection flow past an impulsively started vertical plate with uniform heat and mass flux. *Theoretical and Applied Mechanics, 33(1),* 31–63. https://doi.org/10.2298/TAM0601031P
9. Sambath, P., Kannan, R. M., Pullepu, B. (2017). Free convection flow past from horizontally inclined plate in thermally stratified medium. *International Journal of Pure and Applied Mathematics, 114(12),* 313–322.
10. Chamkha, A. J. (1997). Hydromagnetic natural convection from an isothermal inclined surface adjacent to a thermally stratified porous medium. *International Journal of Engineering Science, 35(10–11),* 975–986.
11. Israel-Cookey, C., Ogulu, A., Omubo-Pepple, V. B. (2003). Influence of viscous dissipation and radiation on unsteady MHD free-convection flow past an infinite heated vertical plate in a porous medium with time-dependent suction. *International Journal of Heat and Mass Transfer, 46(13),* 2305–2311. https://doi.org/10.1016/S0017-9310(02)00544-6
12. Soundalgekar, V. M. (1974). Viscous dissipation effects on unsteady free convective flow past an infinite vertical porous plate with variable suction. *International Journal of Heat and Mass Transfer, 17(1),* 85–92. https://doi.org/10.1016/0017-9310(74)90041-6
13. Palani, G., Srikanth, U., Kim, K. Y. (2017). Combined effects of viscous dissipation and MHD on free convection flow past a semi-infinite vertical plate with variable surface temperature in the presence of heat source. *Journal of Engineering Thermophysics, 26,* 113–124. https://doi.org/10.1134/S1810232817010131
14. Aydın, O., Kaya, A. (2007). Mixed convection of a viscous dissipating fluid about a vertical flat plate. *Applied Mathematical Modelling, 31(5),* 843–853. https://doi.org/10.1016/j.apm.2005.12.015
15. Kairi, R. R., Ramreddy, C., Roy, S. (2022). Influence of heat generation/absorption on the nonlinear convective flow of a casson fluid over a horizontal plate. *Discontinuity, Nonlinearity, and Complexity, 11(3),* 523–538. https://doi.org/10.5890/DNC.2022.09.013
16. Kairi, R. R., Murthy, P. V. S. N., Ng, C. O. (2011). Effect of viscous dissipation on natural convection in a non-Darcy porous medium saturated with non-Newtonian fluid of variable viscosity. *The Open Transport Phenomena Journal, 3,* 1–8. https://doi.org/10.2174/1877729501103010001
17. Khan, U., Rafique, K., Mahmood, Z. (2023). Significance of unsteady rotating flow of nanofluid with nanoparticles aggregation and impacts of slip conditions and variable viscosity. *Numerical Heat Transfer, Part A: Applications,* 1–28. https://doi.org/10.1080/10407782.2023.2299294
18. Koriko, O. K., Oreyeni, T., Omowaye, A. J., Animasaun, I. L. (2016). Homotopy analysis of MHD free convective micropolar fluid flow along a vertical surface embedded in non-darcian thermally-stratified medium. *Open Journal of Fluid Dynamics, 6(3),* 198–221. https://doi.org/10.4236/ojfd.2016.63016

19. Kishan, N., Amrutha, P. (2010). Effects of viscous dissipation on MHD flow with heat and mass transfer over a stretching surface with heat source, thermal stratification and chemical reaction. *Journal of Naval Architecture and Marine Engineering, 7(1),* 11–18.
20. Hakeem, A. A., Ganesh, N. V., Ganga, B. (2015). Heat transfer of non-Darcy MHD flow of nanofluid over a stretching/shrinking surface in a thermally stratified medium with second order slip model. *Scientia Iranica. Transaction F, Nanotechnology, 22(6),* 2766.
21. Mutuku, W. N., Makinde, O. D. (2017). Double stratification effects on heat and mass transfer in unsteady MHD nanofluid flow over a flat surface. *Asia Pacific Journal on Computational Engineering, 4,* 1–6.
22. Bég, O. A., Zueco, J., Ghosh, S. K., Heidari, A. (2011). Unsteady magnetohydrodynamic heat transfer in a semi-infinite porous medium with thermal radiation flux: Analytical and numerical study. *Advances in Numerical Analysis, 2011,* 1–17. https://doi.org/10.1155/2011/304124
23. Goud, B. S., Bindu, P., Srilatha, P., Krishna, Y. H. (2020). The Joule heating effect on MHD natural convective fluid flow in a permeable medium over a semi-infinite inclined vertical plate in the presence of the chemical reaction. *IOP Conference Series: Materials Science and Engineering, 993(1),* 12111. https://doi.org/10.1088/1757-899X/993/1/012111
24. Goud, B., Shankar, D. M., Shekar, M. N. (2020). Thermal radioactive influence on MHD free convection flow across a porous medium in a vertical surface with temperature. *AIP Conference Proceedings, 2246(1),* 020081.
25. Ismail, N. S. A., Aziz, A. S. A., Ilias, M. R., Soid, S. K. (2021). MHD boundary layer flow in double stratification medium. *Journal of Physics: Conference Series, 1770(1),* 012045.
26. Tharapatla, G., RajKumari, P., Ramana Reddy, G. V. (2021). Effects of heat and mass transfer on MHD nonlinear free convection non-Newtonian fluids flow embedded in a thermally stratified porous medium. *Heat Transfer, 50(4),* 3480–3500. https://doi.org/10.1002/htj.v50.4
27. Singh, G., Sharma, P. R., Chamkha, A. J. (2010). Effect of thermally stratified ambient fluid on MHD convective flow along a moving non-isothermal vertical plate. *International Journal of Physical Sciences, 5(3),* 208–215.
28. Daniel, Y. S., Aziz, Z. A., Ismail, Z., Salah, F. (2018). Thermal stratification effects on MHD radiative flow of nanofluid over nonlinear stretching sheet with variable thickness. *Journal of Computational Design and Engineering, 5(2),* 232–242. https://doi.org/10.1016/j.jcde.2017.09.001
29. Kishore, P. M., Rajesh, V., Verma, S. V. (2010). Thermal stratification and viscous dissipation effects on MHD unsteady radiative natural convection flow past an infinite vertical accelerated plate embedded in a porous medium with variable surface temperature. *International Journal of Applied Mathematics & Mechanics, 6(16),* 1–18.
30. Rajput, U. S., Kumar, S. (2016). Unsteady natural convection MHD flow through porous media past an accelerated vertical plate in a thermally stratified fluid. *International Journal of Mathematical Archive, 7(5),* 100–106.