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RESEARCH ARTICLE

A numerical study of unsteady MHD free convection flow with heat and mass transfer across an inclined porous plate, taking hall current and dufour effects by FDM

G. Pavani[1*], M. Changal Raju[2], Mopuri Obulesu[3]

Abstract

This current study focuses on time-dependent natural convection magnetohydrodynamic (MHD) flow as an incompressible, along with viscous flow around an inclined plate immersed within a porous medium, subject to heat absorption and thermal radiation effects. This flow is impacted by chemical reactions, variable temperature, Hall current, and mass diffusion. Equally, the Dufour and Soret effects have been included in the model, which describes the interaction of heat and species diffusion. The basic equations regulating fluid dynamics, namely continuity, momentum, energy, and species concentration, are discretized into numerical representations through the use of the finite difference method, which makes it possible to solve them effectively and systematically. The impact of a number of physical factors, including heat absorption, chemical reaction, Hall current, magnetic field intensity, inclination angle, and thermal radiation on the momentum, diffusion, and temperature gradient profiles is investigated and graphically depicted. EMF interactions cause Hall currents to increase the speed of the flow on the cooled plate while decreasing them on the heated plate. The fluid becomes cooler when a heat source or sink (Q) is present, indicating its cooling effect. By enhancing the internal energy flux, the Dufour factor elevates the fluid's temperature. A larger Soret factor diminishes concentration by thermal propagation, whereas a bigger Schmidt number suppresses mass dissemination and minimizes concentration.

Keywords: MHD, Hall current, Dufour, Soret, Heat source/sink, Chemical reaction, FDM.

Introduction

In many fields of engineering solutions, research, and scientific applications, including petroleum engineering, agricultural irrigation systems, chemical engineering, mechanical engineering, biomechanics, biomedical sciences, and spacecraft engineering, the MHD flow challenges are crucial. The influence of magnetic fields is crucial for applications including petroleum purification, magnetic materials manufacture, and glassmaking process control on viscous, incompressible, and electrically conducting fluids.

Khatun examines a 2-D unsteady magnetohydrodynamics (MHD) natural convection motion. Moving viscous, incompressible fluid, electrically conducting, across a horizontal plate when Schmidt Number, Dufour effects, Grashof Number, Prandtl Number, and Modified Grashof Number are present. The equations used for modeling a problem are resolved mathematically by the explicit finite difference approach. Mahtarin *et al.* have studied thermal diffusion's effect on mass transfer flow and irregular MHD natural convection of heat flow along an inclination with heat production. The discrete difference approach is utilized to solve the governing structure of dimensionless equations numerically. Shanmugam employs a number of mathematical methods to investigate magnetohydrodynamics (MHD) fluids, including the energy equation, the Maxwell equations

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of electromagnetism, the Navier-Stokes equations, and the continuity equation. Electrically conducting fluids' mechanical, magnetic, and behavioral characteristics are examined in this work using mathematical applications of magnetohydrodynamics (MHD).

In many scientific and industrial processes, including extreme temperatures, sculpting and thermonuclear reaction, flotation, glass fabrication, solar thermal technology, combustion chamber design, etc., Heat radiation's effect on hydromagnetic free convection fluid flow is crucial. Numerous scholars have been interested in studying MHD in radiative fields with coupled mass diffusion and heat because of its many potential uses. It is crucial to investigate MHD flow in conjunction with chemical reactions, which involves a number of scientific along with engineering domains. When a plate is in motion, the operating fluid and a foreign mass undergo many physical and chemical engineering activities, including reactions with chemicals. These operations occur in many industrial applications, including polymerization processes, ceramics, glass manufacturing, and food engineering.

Sharma *et al*. examined how radiation and chemical interactions affect time-dependent MHD natural convection, including mass transfer whenever it is mixed, incompressible, viscous fluid passes by to permeable plate that is vertical alongside has been heated and submerged in a porous solution. A homogenous magnetic field, fluctuating free-stream velocity, heat generation, & the effect of viscosity were all taken into account in their analysis. Balla *et al*. explored the time-dependent over an impulsively initiated semi-infinite vertical plate, a natural convection exchange between Newtonian, viscous, and incompressible fluids with mass transfer and changing temperature is influenced by radiation, chemical processes, and applied magnetic fields, including viscous dissipation.

In a variety of applications, research in porous media containing continuous mass and heat transport via MHD free convection flow and non-porous media is essential. These include, among several other things, the cooling of nuclear reactors, the petroleum extraction from porous media, liquid metal filtration, heat transfer from radioactive materials, the boundary layer control, the avoidance of scaling in Heat regulators, and dermal penetration.

With a time-varying heat flux applied, Seth *et al*. explore the mass transfer flow and time-dependent heat-emitting fluid in hydromagnetic natural convection as viscous, incompressible, electrically conducting, and directly thick. It moves impulsively over an infinite vertical plate. This angled magnetic field is influencing a chemical reaction that is taking place in the medium. Mohamed examines how mass transfer and hydromagnetic convection of heat across heat radiation and uniform chemical reactions have an impact on semi-infinite, vertical permeable plate passing over porous substances.

Both heats, along with mass transport systems, the diffusion-thermo, or Soret effects, are frequently disregarded since their magnitudes are lower than those required by Fourier's laws. A temperature gradient causes a diffusion flow referred to as the thermodiffusion effect, while a chemical potential difference causes a heat flux referred to as the diffusion-thermo effect. These effects are beneficial to geology and ceramic engineering.

The influence of Dufour along with Soret is magnetohydrodynamics (MHD). The movement of a fluid around a stretched surface that is not Newtonian is examined by Hayat *et al*. Considering the thermal diffuse & diffusion thermo effects examined by Thangavelu *et al*. Numerical analysis is performed on the heat transfer parameters involved in a flat surface surrounded by natural convection in a saturated porous media that is sensitive to changes in viscosity. Habib *et al*. examined the Dufour and thermal emission sorting, as well as other important characteristics caused by the magnetic field. porosity and thermal diffusivity of media and surfaces.

However, the consequences of Hall currents are not included in any of these experiments. Because Hall current is what gives an ionized gas its charge, it cannot be totally disregarded even in cases in which the magnetic force is powerful and there are few density electrons. In addition, the influence of Hall current is amplified in an ionized flow with a strong magnetic field and possibly low density. Moreover, it tends to cause the flow field to experience secondary flow. Studying its impact on the flow field appears to be important as a consequence. Hall's impact on the movement of fluids is used in magnetometers, nuclear power reactors, MHD power producers, subsurface energy storage systems, Hall current sensors, Hall effect accelerators, spaceship propulsion, and other applications. Some of the researchers that have explored MHD flow models with Hall effect are included here.

Bafakeeh *et al*. examine the irregular; they also look into the effects of Soret, rotation, and the Hall effect. When chemical reactions and thermal radiation are present, MHD natural convection mass also heat transfer occurs when a sudden incompressible, viscous, electrically conducting fluid flows across an inclined plate embedded in a porous material. Matato *et al*. analyse unstable MHD convection flows through an impulsively launched vibrating plate that is vertical and contains Hall current, radiation, and chemical reactions. For the purpose of investigate the effect researchers Shanker Seth *et al*. employed a fatal incompressible, electrically conducting, time-dependent, viscous, heat-absorbing fluid the fact that flowed through. For the purpose of investigating the impact on Hall current is unstable hydromagnetic natural convection fluid flow, something spontaneously affecting straight plate over a permeable medium is used, together with mass quantity temperature transport without taking thermal diffusion into account. Dufour's outcome on erratic natural convection Rajput and associates. Examine MHD flow involving a fixed mass diffusion over a porous media across an exponentially accelerating plate and variable temperature in an angled magnetic field. Electrical conductivity is present in the fluid under consideration. The approach of Laplace transform was used to find the solutions. Seth *et al*., examine an incompressible, unstable movement over a vertical plate using a hydromagnetic natural convection fluid within an viscous, electrically conducting, physically dense, and heat-absorbing substance with a changing, increasing temperature that is traveling quickly. The modeling equations for a fluid's temperature and velocity can be solved fully using the Laplace transform method. According to Rajakumar *et al*., an unstable MHD mixed convective flow that fluid across Suddenly, a vibrating plate submerged in a permeable media near a magnetic flux, mass, and heat transfer is influenced by viscosity dissipation by a heat source. Rehman *et al*., explore the complex patterns of MHD Carreau fluid motion on a stretchy porous surface using Darcy–Forchheimer Drag Model, taking into account radiant heat and slip issues. These findings indicate that while an increased solutal Grashof amount improves species concentration and velocity, a higher Weissenberg number discourages skin friction and decreases velocity. The process of heat and volume transfer of a vibrating angled plate in a porous medium that is saturated is investigated by Mopuri *et al*., with a focus on the function of Dufour effects. The work improves predictions of thermal behavior by integrating radiation, heat generation, and mixed convection. Applying the perturbation approach, computations are performed, yielding precise and trustworthy results. Using MATLAB's explicit finite difference method (FDM), Obulesu *et al*., investigated revolving magnetohydrodynamic (MHD) natural convective fluid flow in ramped boundary constraints, considering Dufour, radiation, heat conduction, thermos-diffusion, and Hall effects. The results showed that while stronger magnetic constraints result in higher fluid velocity, increasing ramped parameters improves momentum, heat, and mass transfer. Furthermore, the finite response method (FRM) was presented in order to improve predictive modeling and optimize parameter interactions. Santhi *et al*., investigate the naturally occurring convection MHD flow of a viscous solution over two permeable plates that are parallel while taking into account thermal radiation, an angled magnetic field, and the consequences of mass and heat transfer. The adiabatic condition is met by one plate. Dimensionless variables are used to simplify the issue, and the perturbation technique is used to solve it analytically. Obulesu *et al*., investigate the time-dependent MHD natural convective boundary layer fluid flow of a Jeffery fluid, which is viscoelastic fluid flow through a permeable plate that is inclined vertically while taking thermal radiation, heat absorption, and diffusion into consideration. Using the perturbation technique, the governing equations are numerically solved, yielding insights directly applicable to the agriculture, geology, and glass manufacturing industries. Tanuja *et al*., examine the flow of a nanofluid that is a hybrid via a semi-infinite flat plate in a porous medium while accounting for radiation, magnetic force, diffusion thermo effect, convective heat and volume transfer, and chemical processes. The equations that govern are solved using the perturbation method. The primary findings demonstrate that Casson's nanofluids, which are hybrid, are superior to monofluids in terms of heat transmission. With the help of the Buongiorno model, Sekhar *et al*., investigate the magnetohydrodynamic (MHD) flow of a Casson nanofluid over an inclined stretched surface, taking into account the effects of thermal radiation, heat source/sink, and the coupled influences of the Dufour and Soret numbers. By taking into account Brownian motion and thermophoresis, the study looks at the dynamics of heat and mass transport. The governing non-linear equations are solved numerically using the homotopy analysis method (HAM), which offers a deeper understanding of the complex interactions between thermophysical forces that shape nanofluid behavior.

We tried to examine the impacts of Soret, heat source, and viscosity with the work of other scholars, dissipation, and Hall current as a time-dependent MHD natural fluid movement via convection across an inclined permeable plate when it occurs for velocity, temperature, and concentration. This work is novel since it examines heat sources/sinks, including viscous dissipation towards energy conservation. By adding the aforementioned flow factors, we have expanded on the work of Santhi Kumari *et al*. [24]. This is not just a straightforward continuation of the earlier research. It differs from that in a number of ways, including the addition of the species thermodiffusion equation, the inclusion of radiation absorption and Dufour effects in the energy equation, and the existence of mass convection in the momentum equation. The presence of nonlinearly simultaneous partial differential equations necessitated a change in the technique or resolution in addition to modifying a set of governing equations. The explicit finite difference scheme, which is computationally efficient, was used to obtain the solutions. In order to observe potential changes in the fluid's behavior, a thorough analysis of the resulting changes and behavior of several features, including concentration, flow rate, temperature, and engineering factors, has been conducted.

There are still some gaps even though this study expands on earlier studies and includes novel elements like heat sources in addition to the Dufour and Soret effects. The practical usability of MHD models might be significantly increased by incorporating turbulence effects, doing practical verification, taking variable field effects into consideration, and putting optimization techniques into practice. Future studies in these fields will surely produce more thorough and flexible MHD models that can handle challenging real-world problems

Mathematical formulation of the problem

consider time-dependent magnetohydrodynamics in order to account for stable mass diffusion in the presence having a heat source & energy dissipation associated with viscosity with varying temperatures; a viscous, electrically conducting, incompressible flow interacts with an inclined plate. Perpendicular to the fluid flow applies a constant magnetic field, B, with an intensity of B_0. When its y' is taken above the surface in an upward direction, the y'-axis is perpendicular at y' and orthogonal to the $x'y$-plane. Fig. 1 shows the problem's physical model. The interaction between the fluid and the inclined plate leads to complex boundary layer behaviours, which are crucial for understanding heat transfer and momentum exchange in the system. Additionally, the effects of the magnetic field on the flow dynamics introduce challenges in predicting the overall performance and efficiency of the thermal management process.

The fluid concentration and plate and fluid temperature are initially in that time $t'\leq 0$. The plate then initiates to vibrate within the particular plane on frequency ω' time $t'>0$, raising the plate's temperature along with fluid concentration, respectively. Thus, heat transfer over the x'- direction is thought to be insignificant in comparison to that in the y' direction. With the exception of pressure, all physical parameters are dependent on y' and t'. Ohm's law that accounts for Cowling's Hall current is provided by

$$\vec{J}+\frac{\omega_e\tau_e}{B_0}\left(\vec{J}\times\vec{B}\right)=\sigma\left(\vec{B}+\vec{q}\times\vec{B}\right) \tag{1}$$

Where $\sigma,\ \vec{E},\vec{B},\vec{q},\tau_e,\vec{J}\ and\ \omega_e$. These have been, in turn, the vectors characterizing electric conductivity, electric field, magnetic field, along with the velocity, electron collision time, current density vector and cyclotron frequency.

Since there is no gradient of the flow in the y' direction, v^* is zero at all points in the flow according to the continuity equation.

The magnetic field created by fluid motion is disregarded because the Reynolds dimensionless number is so low. In the case in which the magnetic field = (Bx', By', Bz'), By' = constant, let's say $B0$, the solenoid connection. In other words, throughout the flow, = (0, B0, 0). Electric current conservation $\nabla.\vec{J}=0$ results in $j_{y'}$ = constant, where $\vec{J}$ = $(j_{x'}, J_{y''}, J_{z'})$. By the above postulates equation (1) provides

$$J_{x'} - m\,J_{y'} = \sigma\left(E_{x'} - w'B_0\right) \tag{2}$$

$$J_{Z'} - m\,J_{x'} = \sigma\left(E_{Z'} + u'B_0\right) \tag{3}$$

Where $m(=\omega_e\tau_e)$ Denotes Hall current. By dividing when trying to calculate the Hall parameter, the electron-cyclotron frequency is divided across the electron-atom collision frequency. In light of the lack of an "induced magnetic field, the Maxwell equation $\nabla\times\vec{E}=\frac{\partial\vec{H}}{\partial t}$ transformed into $\nabla\times\vec{E}=0$", it provides $\frac{\partial E_{x'}}{\partial y'}=0$ and $\frac{\partial E_{Z'}}{\partial y'}=0$. It suggest that $E_{x'}$ = constant throughout the flow therefore, this constant should be set to zero, i.e. $E_{x'}$ = $E_{Z'}$ =0 when solving for $J_{x'}$ along with $J_{Z'}$ the equations (2) along with (3) utilizing $E_{x'}$ = $E_{Z'}$ =0

$$J_{X'}=\frac{\sigma B_0}{(1+m^2)}(mu^*-w^*) \tag{4}$$

$$J_{Z'}=\frac{\sigma B_0}{(1+m^2)}(mw^*+u^*) \tag{5}$$

Equations (4) and (5) are used to obtain the fundamental Equations governing the fluid motion while taking into account the presumptions above and the approximation from Boussinesq.

Governing equations

This physical problem is described in a manner that substantially resembles that of Santhi Kumari *et al*. Thus, the flow field becomes unstable. In Figure 1, the physical model is shown along with the coordinate system.

Continuity equation

$$\frac{\partial v^*}{\partial y'}=0 \tag{6}$$

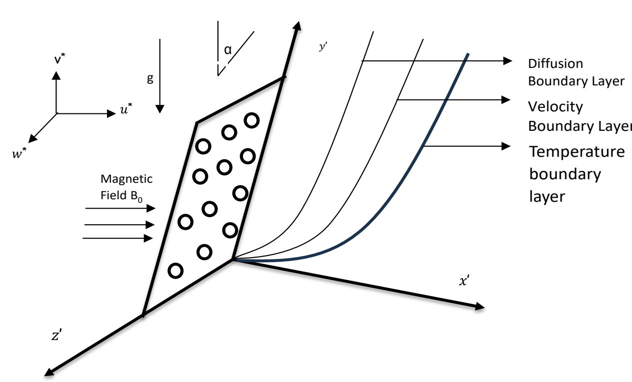

Figure 1: Mathematical model of the problem

Momentum equation

$$\frac{\partial u^*}{\partial t'} = \nu \frac{\partial^2 u^*}{\partial y'^2} + g\beta\,(T' - T'_\infty)\cos\alpha + g\beta'(C' - C'_\infty)\cos\alpha$$
$$-\frac{\sigma B_0^2}{\rho(1+m^2)}(u^* + mw^*) - \frac{\nu}{K_1}u^* \tag{7}$$

$$\frac{\partial w^*}{\partial t'} = \nu \frac{\partial^2 w^*}{\partial y'^2} + \frac{\sigma B_0^2}{\rho(1+m^2)}(mu^* - w^*) - \frac{\nu}{K_1}w^* \tag{8}$$

Energy equation

$$\rho C_P \frac{\partial T'}{\partial t'} = k\frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q'_r}{\partial y'} + \mu\left(\frac{\partial u^*}{\partial y'}\right)^2 - Q_0(T' - T'_\infty)$$
$$+ Q_l(C' - C'_\infty) + \left(\frac{D_m k_T \rho}{C_S}\right)\frac{\partial^2 C'}{\partial y'^2} \tag{9}$$

Concentration equation

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y'^2} - K_c(C' - C'_\infty) + D_1\frac{\partial^2 T'}{\partial y'^2} \tag{10}$$

They specified initial and boundary conditions are

$$\left.\begin{array}{l} t' \le 0;\ u^* = 0,\quad w^* = 0,\quad T' = T'_\infty,\quad C' = C'_\infty \quad for\,all\quad y' \ge 0 \\ t' > 0;\ u^* = u_0\cos\omega' t', w^* = 0 \quad T' = T'_\infty + (T'_w - T'_\infty)\dfrac{tu_0^2}{\nu}, \\ C' = C'_w \ \text{ as } y' = 0 \\ u^* \to 0,\ w^* \to 0,\quad T' \to T'_\infty,\quad C' \to C'_\infty \ \text{ as } y' \to \infty \end{array}\right\} \tag{11}$$

Radiation energy flux (q_r) as stated by Roseland approximation

$$q_r = \frac{4\sigma'}{3k'}\frac{\partial T'^4}{\partial y'}. \tag{12}$$

In which k' " Denotes average absorption value is σ' Represents are continuous of Stefan-Boltzmann. While it has been believed that the temperature differential inside its flow is suitably modest, equation (11) may be liberalized through expansion after higher-order terms are ignored T'^4 regarding Taylor series T'_∞ it has been seen below.:

$$T'^4 \cong 4T'^3_\infty T' - 3T'^4_\infty \tag{13}$$

With reference to equation (11) and (12),then Equation (9) goes to

$$\rho C_P \frac{\partial T'}{\partial t'} = k\left(1 + \frac{16\sigma' T'^3_\infty}{3kk'}\right)\frac{\partial^2 T'}{\partial y'^2} + \mu\left(\frac{\partial u'}{\partial y'}\right)^2 - Q_0(T' - T'_\infty)$$
$$+ Q_l(C' - C'_\infty) + \left(\frac{D_m k_T \rho}{C_S}\right)\frac{\partial^2 C'}{\partial y'^2} \tag{14}$$

After Introducing the subsequent dimensionless quantities

$$u = \frac{u^*}{u_0},\ w = \frac{w^*}{u_0}\quad y = \frac{u_0 y'}{\nu},\ t = \frac{t' u_0{}^2}{\nu}, \omega = \frac{\omega'\nu}{u_0^2}\ \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty},$$

$$C = \frac{C' - C'_\infty}{C'_w - C'_\infty},\quad \Pr = \frac{\mu C_p}{k},\ Sc = \frac{\nu}{D},\ M = \frac{\sigma\mu_0^2 H_0^2 \nu}{\rho v_0{}^2},$$

$$Gr = \frac{\nu g\beta\,(T'_w - T'_\infty)}{u_0^3},\quad Gm = \frac{\nu g\beta'(C'_w - C'_\infty)}{u_0^3}$$

$$K = \frac{K_1 u_0^2}{\nu^2},\ Kr = \frac{\nu K_c}{u_0^2}, R = \frac{16\sigma' T_\infty^3}{3k\kappa'},\ Q = \frac{Q_0}{\rho C_P \nu},$$

$$R_a = \frac{Q_l \nu (C'_w - C'_\infty)}{\rho C_P u_0^2 (T'_w - T'_\infty)} \tag{15}$$

$$E_C = \frac{u_0^2}{C_P(T'_w - T'_\infty)} \qquad Df = \frac{D_m k_T (C'_w - C'_\infty)}{\nu C_S C_P (T'_w - T'_\infty)}$$

From above measures (15), equations (7), (8), (14) and (10) reduce in the form

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} - \left(\frac{M}{1+m^2}\right)(u + mw) + Gr\cos\alpha\,\theta + Gm\cos\alpha\,C - \frac{u}{K} \tag{16}$$

$$\frac{\partial w}{\partial t} = \frac{\partial^2 w}{\partial y^2} + \left(\frac{M}{1+m^2}\right)(mu - w) - \frac{w}{K} \tag{17}$$

$$\frac{\partial \theta}{\partial t} = \left(\frac{1+R}{\Pr}\right)\frac{\partial^2 \theta}{\partial y^2} - Q\theta + R_a C + Du\frac{\partial^2 C}{\partial y^2} + E_C\left(\frac{\partial u}{\partial y}\right)^2 \tag{18}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - Kr\,C + S_0\frac{\partial^2 \theta}{\partial y^2} \tag{19}$$

Equation (11) with initial also edge circumstances through non-dimensional have becomes:

$$\begin{array}{l} t \le 0;\quad u = 0, w = 0,\quad \theta = 0 \quad C = 0 \quad for\,all\ \ y \ge 0 \\ t > 0; u = \operatorname{Cos}\omega t,\ w = 0,\quad \theta = t,\quad C = 1 \quad at\ \ y = 0 \\ u \to 0 \quad w \to 0 \quad \theta \to 0 \quad C \to 0 \quad as\ \ y \to \infty \end{array} \tag{20}$$

Solution of the problem

These linear partial derivative comparisons (16) – (19) must be solved utilizing the boundary and beginning conditions (20). The finite-difference approach is what we utilized to solve this set of equations since it is impossible to solve them precisely. The following are similar finite difference methods for equations (16)-(19):

$$\frac{u_{i^*,j^*+1}-u_{i^*,j^*}}{\Delta t}=\frac{u_{i^*-1,j^*}-2u_{i^*,j^*}+u_{i^*+1,j^*}}{(\Delta y)^2}-\left(\frac{M}{1+m^2}\right) \quad (21)$$

$$\left(u_{i^*,j^*}+m\,w_{i^*,j^*}\right)+Gr\cos\alpha\,\theta_{i^*,j^*}+Gm\cos\alpha\,C_{i^*,j^*}-\frac{u_{i^*,j^*}}{K}$$

$$\frac{w_{i^*,j^*+1}-w_{i^*,j^*}}{\Delta t}=\frac{w_{i^*-1,j^*}-2w_{i^*,j^*}+w_{i^*+1,j^*}}{(\Delta y)^2} \quad (22)$$

$$+\left(\frac{M}{1+m^2}\right)\left(mu_{i^*,j^*}-w_{i^*,j^*}\right)-\frac{w_{i^*,j^*}}{K}$$

$$\frac{\theta_{i^*,j^*+1}-\theta_{i^*,j^*}}{\Delta t}=\left(\frac{1+R}{\Pr}\right)\left(\frac{\theta_{i^*-1,j^*}-2\theta_{i^*,j^*}+\theta_{i^*+1,j^*}}{(\Delta y)^2}\right)$$

$$-Q\theta_{i^*,j^*}+R_a C_{i^*,j^*}x\in\mathbb{R}+Du\left(\frac{C_{i^*-1,j^*}-2C_{i^*,j^*}+C_{i^*+1,j^*}}{(\Delta y)^2}\right) \quad (23)$$

$$+E_C\left(\frac{u_{i^*,j^*+1}-u_{i^*,j^*}}{\Delta t}\right)^2$$

$$\frac{C_{i^*,j^*+1}-C_{i^*,j^*}}{\Delta t}=\left(\frac{1}{Sc}\right)\left(\frac{C_{i^*-1,j^*}-2C_{i^*,j^*}+C_{i^*+1,j^*}}{(\Delta y)^2}\right) \quad (24)$$

$$-Kr\,C_{i^*,j^*}+S_0\left(\frac{\theta_{i^*-1,j^*}-2\theta_{i^*,j^*}+\theta_{i^*+1,j^*}}{(\Delta y)^2}\right)$$

Here, the suffixes i^* & j^* stand for time and y, respectively. To split the mesh system,

take Δy = 0.05. The equivalent of the starting condition in (20) is as follows:

$$u(i^*,0)=0\,,\; w(i^*,0)=0, \theta(i^*,0)=0,\; C(i^*,0)=0 \;\; for\, all\, i \quad (25)$$

The following is a finite-difference form of the boundary constraints given (20).

$$u(i^*,0)=\mathrm{Cos}\omega t,\; w(i^*,0)=0, \theta(i^*,0)=t,\; C(i^*,0)=1 \quad at\;\; y=0$$

$$u(i^*_{\max},j^*)=0\,,\; w(i^*_{\max},j^*)=0,\; \theta(i^*_{\max},j^*)=0\,,$$

$$C(i^*_{\max},j^*)=0 \;\; for\, all \;\; j^* \quad (26)$$

(Here $i^*_{\max}$ was taken as 200)

In regards to temperature, concentration, or velocity at sites on the prior time-step, the final velocity for each time step, your (i*, j*+1) (i*=1,200) & w (i*, j*+1) (i*=1,200), are first computed using (21) & (22). Then, using equation (23) and equation (24), we compute

θ (i*, j* +1) along with C (i*, j* +1), respectively. This procedure keeps going until

j* = 5000, or t = 0.5. 0.0001 was chosen as Δt for the calculation.

Results and Discussions

These include the following: Heat source/sink (Q=2), improved (Gm=10), magnetic parameter (M=2), radiation parameter (R=2), oscillation frequency Grashof number (Gr=10), Soret parameter (S0=2), Hall current (m=0.5) (Sc=0.22), Dufour parameter (Du=0.5), (Pr=0.71), and chemical reaction parameter (Kr=0.5).

Figures 2-13 show secondary and primary fluid velocities in heated and cooled plates, and figures 14-18 show the results of various parameters such as» R, Ra, Q, Pr, and Du» on temperature distribution and also observed concentration profiles from figures 19-21 on the effects of parameters of Kr, Sc, and So.

Magnetic parameter's effect on fluid velocity

Figures 2 & 3 illustrate that the primary velocity increases because a magnetic field parameter rises. Field becomes less

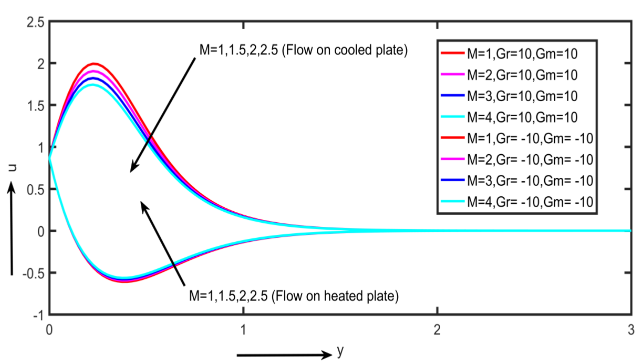

Figure 2: Magnetic field(M) influence on Preliminary Velocity

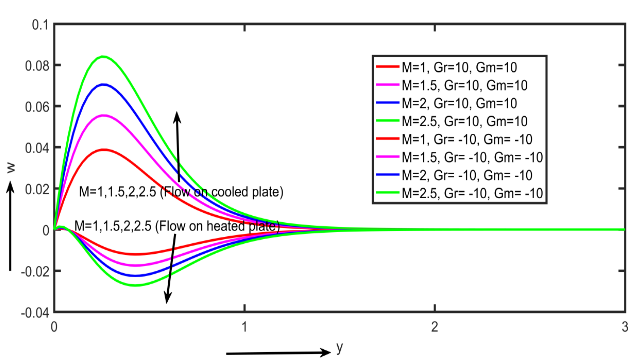

Figure 3: Magnetic field(M) effect on Secondary Velocity

on the cooled plate, but the opposite occurs on the heated plate. The secondary velocity has the reverse tendency, dropping on the heated plate while increasing on the cooled plate. This effect can be described by applying a magnetic field, which induces a Lorentz force. This force acts as a resistive drag, opposing fluid flow and so decreasing primary velocity on the cooled plate while increasing it on the heated one. The secondary velocity is altered in the opposite direction, revealing the complex plate temperatures and the magnetic field's interaction.

Inclined angle effect on velocity

Figure 4-5 depicts the influence on the fluid's both primary alongside secondary sources inclined angles velocities. Thermal buoyancy causes primary velocity (tangential to the plate) to increase with increasing angle on a heated plate. A cooled plate has a decrease because buoyancy prevents flow. For heated plates, secondary velocity (perpendicular to the plate) increases as the angle increases. For a cooled plate, it remains smaller and may even contribute to downward movement.

Modified Grashof number influence on velocity

Graphs 6 and 7 show how fluid velocities, both primary along secondary, are affected by modified Gm. Gm is defined as the species' buoyancy force divided by its viscosity force. By increasing Gm, the fluid's primary velocity on the cooled plate also increases. Similarly, secondary velocity increases on the cooled plate. On a heated plate, the primary velocity increases as a modified Grashof number rises (vertical flow), and the secondary velocity (lateral flow) both rise.

Effect of Porosity Parameter on Velocity

Figures 8-9 show that raising K values produces an increase in secondary and primary velocity profiles. In terms of physical properties, increasing K tends to diminish the porous medium's resistance, which increases fluid velocity across the cooled plate and has the opposite impact on the heated plate.

Hall Current Effects on Velocity of Fluid

In fact, Hall current's impact on both secondary and primary velocities dissipated in figures 10-11, shows that both velocities increase as m values increase around the boundary layer field in the cooled plate, and the opposite effect on the heated plate occurs because the presence of Hall currents influences electromagnetic forces, enhancing fluid motion.

Effect of time on velocity

The profile of secondary and primary velocities rises as time «t» increases, as seen in Figures 12 and 13, in the cooled plate,

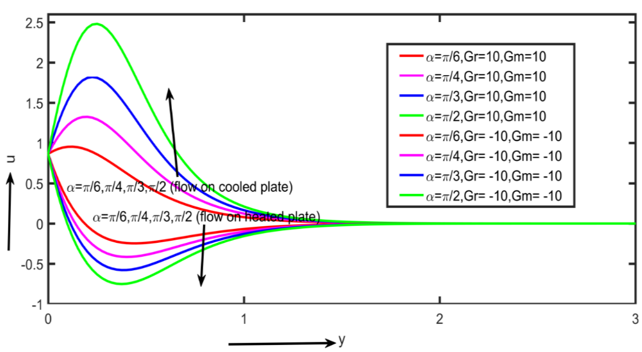

Figure 4: Angle of inclination influence on Primary Velocity

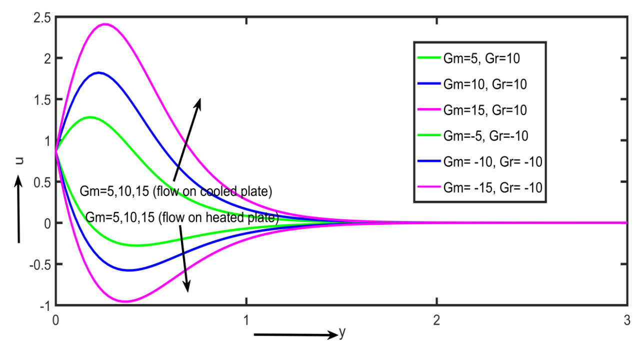

Figure 6: Modified Grashof number reactions on Preliminary Velocity

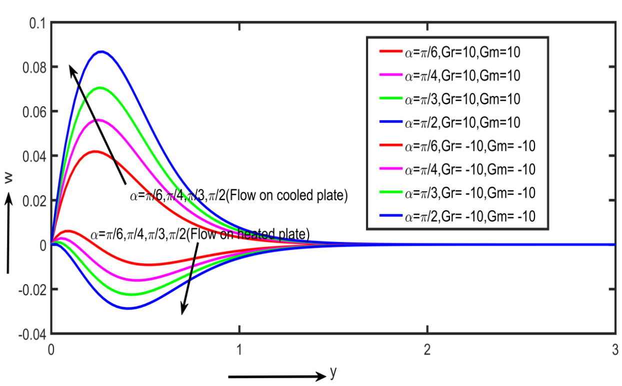

Figure 5: Inclined angle effect on secondary velocity(w)

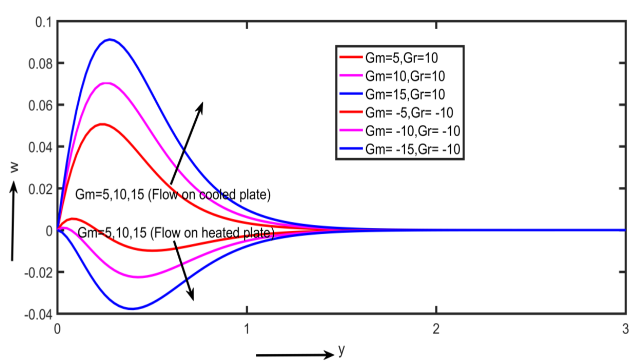

Figure 7: Modified Grashof number consequences on Secondary Velocity

as well as the reverse effect on the heated plate. This study does a comparative analysis with earlier studies that do not account for radiation absorption, Dufour, and Soret impacts to assess the precision and dependability of the generated numerical data. Figures 7 and 8 compare the secondary and primary liquid velocities from the existing study to those from an earlier revision conducted by Santhi Kumar *et al*. This figure shows the good agreement (under certain constraints) between the current work and the earlier in-print work by Santhi Kumari *et al*., on fluid velocity. The velocities on the heated plate decrease with time, while the velocities on the cooled plate increase, as seen in graphs 12 and 13.

Physically, fluid velocity increases in both directions as buoyant force rises over time.

Impact of Radiative Flux on Temperature Profiles

It is evident from graph 14 that a rise in radiation R causes the temperature to drop. As radiation increases, the system loses thermal energy more quickly, lowering the total temperature. Furthermore, heat absorption, chemical reactions, and other thermodynamic factors, such as the Dufour and Soret phenomena, may all contribute to this tendency.

Influence of Absorbed Radiative Heat on Temperature Variation

Temperature distribution is impacted by radiation absorption. Temperature rises with a lower absorbing parameter (Ra), indicating that more energy is retained in the system when heat is not efficiently absorbed. Graph 15 shows how radiation absorption affects temperature and heat transfer. The graph clearly shows that when radiation decreases, temperature increases the exposure absorption parameter (Ra).

Heat Source/Sink Effects on Temperature Profiles

When thermal energy is supplied by a heat source, the fluid's temperature rises; when energy is removed by a heat sink, the temperature falls. Figure 16 demonstrates the impact of

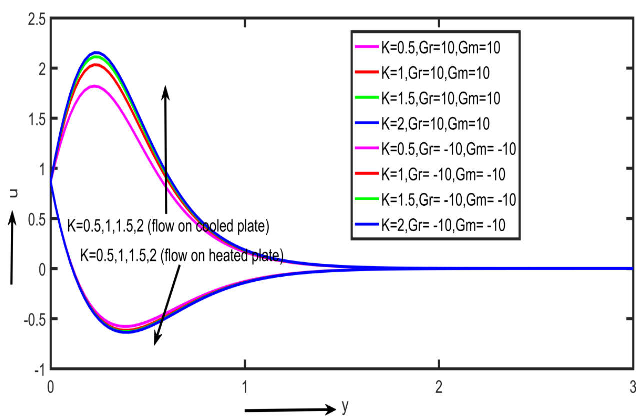

Figure 8: Impact of Porosity on initial Velocity

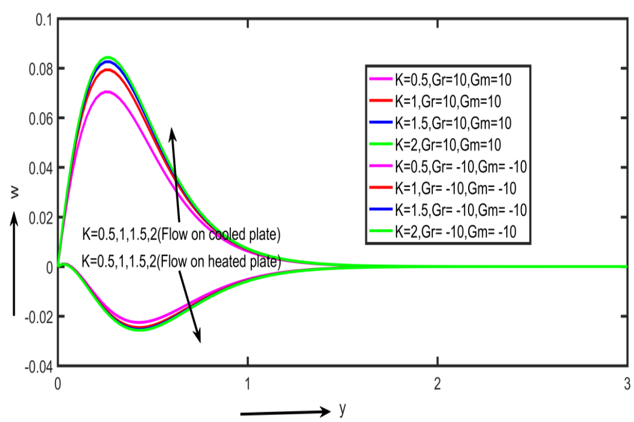

Figure 9: Impact of Porosity on Secondary source Velocity

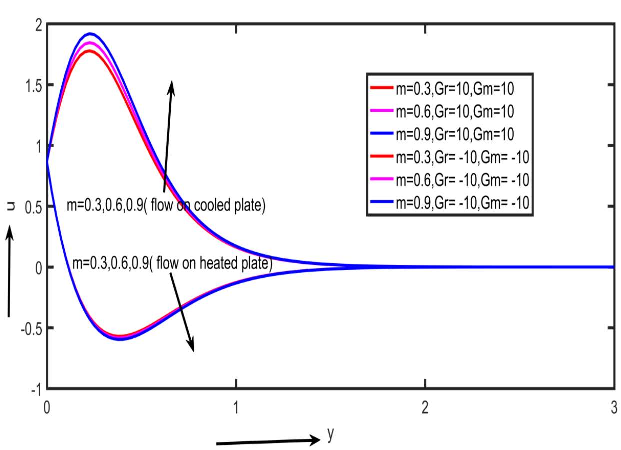

Figure 10: Hall current effect on Original Velocity

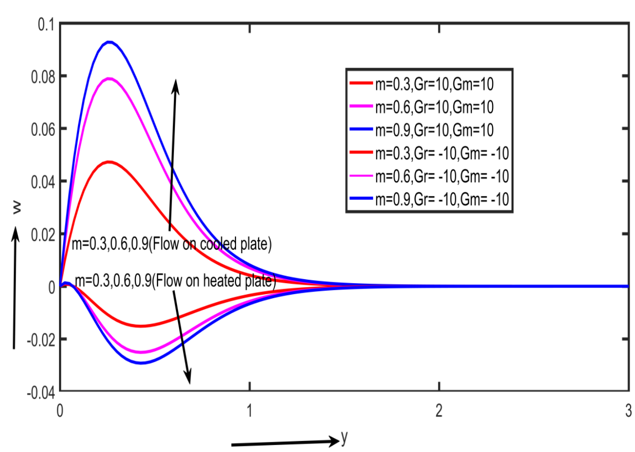

Figure 11: Hall current action over Secondary Velocity

the heat source or sink upon the temperature profile. The fluid's temperature is raised by the heat source or lowered by the heat sink.

Prandtl Number Influence on Temperature

The ratio that exists of momentum dispersion to thermal dispersion is determined by the Prandtl number (Pr). Figure 17 shows how the Prandtl number (Pr) affects fluid temperature (θ). Heat diffusivity decreases and momentum diffusivity increases when the Prandtl number rises value. This suggests that the flow's temperature decreases as the Prandtl number rises.

Dufour Parameter Influence on Temperature Profile

The Dufour effect depicts the flow of energy resulting from changes in concentration. As the Dufour number increases, Figure 18 illustrates that the fluid becomes hotter. It occurs because energy flux is produced, raising the temperature.

Effect of Chemical Reactions (K) on Species Concentration

By consuming or producing reactants, chemical reactions (K) affect the concentration of species. Graph 19 depicts how chemical reactions affect the concentration profile. The figure plainly demonstrates which concentration dispersion decreases with increasing chemical reaction strength.

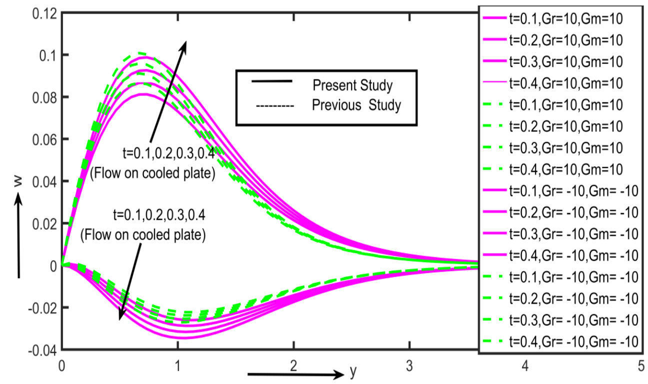

Figure 13: Secondary source velocity response over time

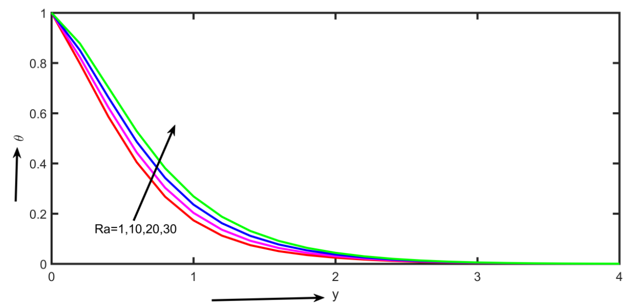

Figure 15: Radiation absorption consequence upon Temperature

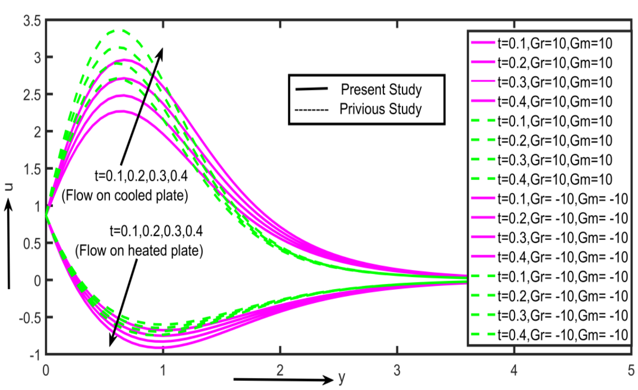

Figure 12: preliminary velocity variation with time

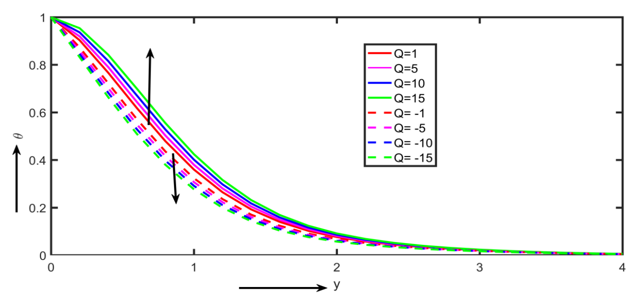

Figure 16: Heat source and sink influence profile

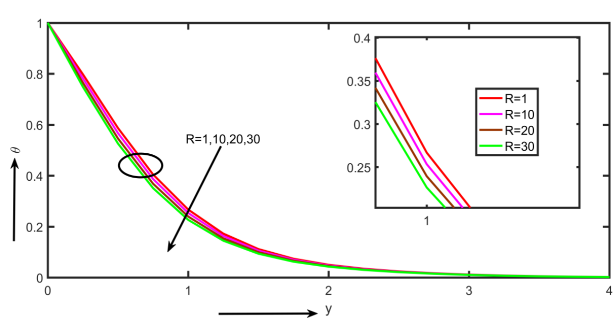

Figure 14: Influence of Radiative flux on Temperature

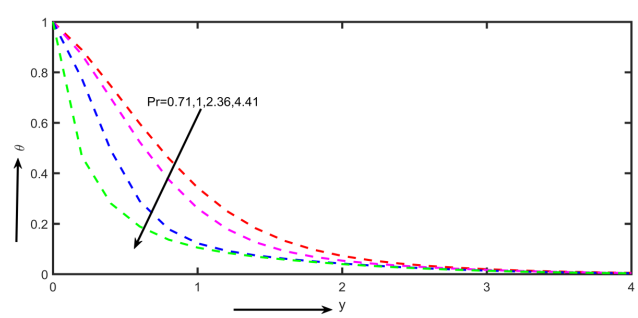

Figure 17: Prandtl Number Influence on Temperature

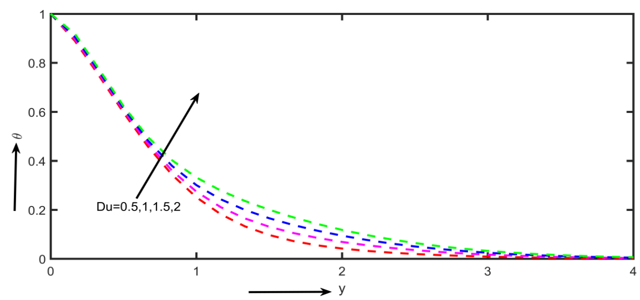

Figure 18: Dufour number reaction upon Temperature

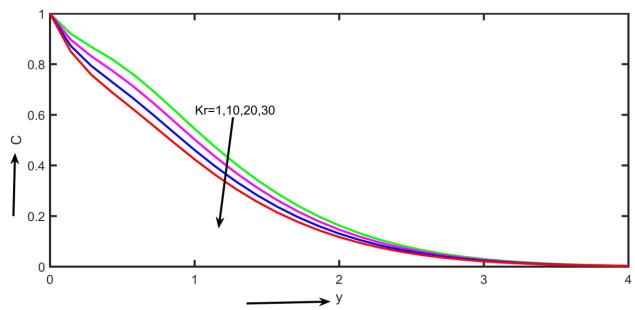

Figure 19: Influence of chemical reaction of the Species Concentration

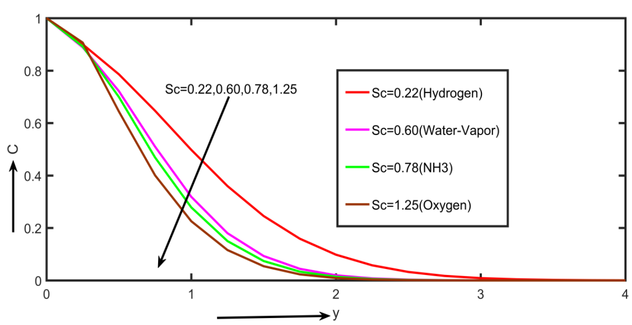

Figure 20: Schmidt Number affect over Species Concentration

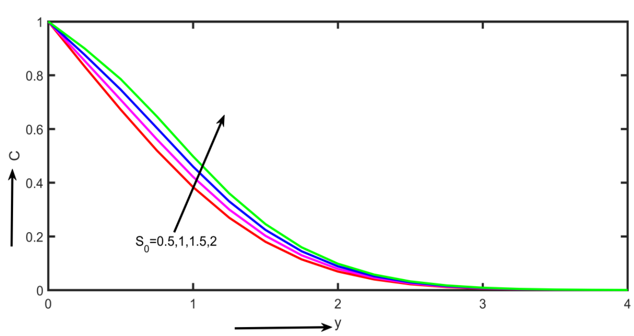

Figure 21: enact of Soret parameter on Concentration

Schmidt Number (Sc) Influence on Concentration Profile

The ratio of diffusivity of matter over momentum diffusion, or kinematic viscosity, is represented by the dimensionless Schmidt number (Sc). Graph 20 illustrates how Sc affects concentration. The Sc is chosen to be 1.25, 0.78, 0.60, and 0.22, representing NH_3, oxygen, water vapor, and hydrogen, respectively. As Schmidt's number grows, concentration drops because a rise in Sc causes the viscous force to increase, which causes a decrease in concentration.

Effect of Soret number on concentration

Temperature gradient-induced mass transport is described by the Soret effect (thermophoresis).

Graph 21 depicts the impact of the Soret parameter on species concentration. If the Soret number rises, concentration has been observed to rise as well.

Conclusions

This work investigates the unsteady natural convection MHD flow of an incompressible wth viscous fluid beyond inclined plate immersed within a permeable media, accounting for thermal radiation, heat absorption, Hall current, chemical processes, and mass diffusion. To study heat and species diffusion interactions, this model incorporates Soret and Dufour effects.

- An improvement in magnetic field (M) reduces primary(verticle) field velocity on the cooled plate. On the heated plate, the main velocity increases during the time secondary flow velocity drops.
- Increasing the modified Grass of number (Gm), Hall current, Porosity parameter(K) and Angle of Inclination causes the primary(main) velocity of heated plates to increase, On the cooled plates, the primary velocity decreases.
- The secondary velocity on heated plates rises as the modified Grass of number (Gm), angle of inclination, Hall current (m), and porosity parameter (K) increases. Downwards moment on the cooled plate.
- As time passes, the cooled plate's main and secondary velocities increase. while they decrease on the heated plate.
- The temperature of the flow grows when the absorbing radiation parameter (Ra) also Dufour number increases.
- Heat sorce raises the fluid temperature and Heat sink reduces temperature of the flow.
- The solution's temperature drops as the Prandtl number (Pr) rises.
- Reduced concentration is the outcome of increasing Sc and Chemical change parameter(K).
- The higher Soret number, the higher the species concentration.

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