Numerical Case Study of Chemical Reaction Impact on MHD Micropolar Fluid Flow Past over a Vertical Riga Plate

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Abstract: The purpose of this article is to investigate the mass and heat transport phenomena associated with micropolar fluid flow created by a vertically stretched Riga surface. This is constructed using an array of irregular electrodes and permanent magnets that are oriented spanwise. Additionally, we investigate the particles’ micro rotational impacts. Furthermore, the flow behaviour of the modeled problem has been numerically calculated with bvp4c solver and the obtained results are presented graphically. Numerical data are used to illustrate physical parameters such as skin friction, Nusselt, and Sherwood numbers. For precise values of different flow parameters, the characteristics of fluid velocity, angular velocity, temperature, and concentration gradients are investigated graphically. The flowing parallel to the Riga plate in a positive x-path is aided by Lorentz forces introduced into the flowing simulation by the electro-magnetic poles of the Riga plate, which produces a rapidity greater than the inner speed. It is confirmed that the numerical calculations fit well with the results of earlier published investigations. Due to the participation of the Riga plate, the updated Hartmann number has a considerable effect on flow profiles.

Keywords: micropolar fluid; bvp4c; MHD; chemical reaction; Riga plate

1. Introduction

The heat transfers and problem of flow caused by a stretching (shrinking) surface are highly essential and have piqued the attention of many academics owing to their numerous applications in manufacturing and other industries. Some examples of such uses include in artificial fibers, hot rolling, metal spinning, paper manufacture, glass-fiber manufacturing, and drawing of plastic films. Sakladis [1] was the earliest to demonstrate how a boundary-layer moves over a continuously moving hard plate. Later, Gupta and Gupta [2] investigated the solutal and heat transport associated with a similar solution for a boundary-layer stretched by sucking or blowing. The flowing and thermal transmission in an influence of wall mass suction across an exponentially stretched sheet were probed.
by Elbashbeshy [3]. The exponential surface rapidity and solutal transmission of a continually shrinking sheet were probed by Fang [4].

Magnetic fields are important in fluid mechanics owing to their many uses in enhancing the physical thermal assets of a liquid. Astrology and earth sciences both deal with a variety of liquids that are bad conductors of electrical energy. Consequently, an outside mediator is constantly required to improve the heat transport phenomenon due to increased conductance and further thermophysical qualities. The simulation of these liquids might be described using Maxwell’s equation. Transverse magnetic fields are caused by electrical impulse transmission into moving fluids. A transverse magnetic field is a kind of resistive energy that is formed by the relationship between these undercurrents and the magnetic force, which is recognised as the Lorentz force. With the existence of heat-generation (absorption) as well as a chemically reactive species, Chamkha [5] explored the MHD flow of an equally extended vertical permeable surface. Makinde [6] probed thermal and solutal transfer via a moving perpendicular surface with a convection boundary constraint. Sharma and Gupta [7] conducted an analytical examination on magneto boundary-layer streaming and thermal transmission to a penetrable exponential stretched surface in the existence of radiative flux.

Significant challenges in manufacturing and in several science and engineering disciplines must be addressed nowadays due to their substantial applications in daily life, such as managing engine temperature, machinery performance, building, and other scientific purposes. The micropolar liquid type might be used to create simulations of dust or smoke particles in gas or the environment. Nevertheless, many concerns or models contain certain complex nonlinear variables that are difficult to deal with rationally. Considering the rising relevance of materials whose shear behaviours can’t be defined by Newtonian law, a new step in the review of the liquid dynamical model is now underway. Micropolar fluids are liquids that have micro-components that can rotate, which changes the hydrodynamics of the movement. For this instance, it can be very different from what we think of as Newtonian. Eringen came up with the theory of micropolar fluids [8], which discusses a group of fluids that have certain microscopic impacts because of local composition micro-indications of the liquid parts. Subsequently, Hassanien and Gorla [9] inspected the mathematical solution for thermal transportation in a micropolar liquid across an extendable plate. Takhar et al. [10] investigated the mixed convective flowing of a micropolar liquid across a stretched plate. Eldabe et al. [11] analysed MHD micropolar fluid flowing through a stretchable sheet using the Chebyshev finite difference approach. MHD micropolar liquid flowing in a penetrable media with different slippage constraints was investigated by Fatunmbi et al. [12].

EMHD (electromagnetohydrodynamic) research has had an enormous influence on pioneering dynamical applications, including micro-coolers, submarines, and thermoelectric reactors. This outside factor might be a magneto bar or a matrix of all electromagnets with varying electrodes that is permanently installed. However, because certain liquids have limited electrical conductivity and a little induced current when a magnetic field is applied, EMHD flowing is regulated by utilising the exterior electrical power implications. This formulation was made for the first time in Riga by [13] and was called a Riga platter, a control device that can organise the magnetic and electric fields concurrently. The Riga surface is an electro-magnetic machine that works on a flat surface by combining magnets and anodes. Gailitis and Lielausis pioneered a novel method for creating a Lorentz force in the way of wall direction [13]. Conducting was facilitated by including a Riga platter in the system, which incorporates the Lorentz power, which declines by exponential relation as well as boosting dislocation as of the plate’s side. The Riga platter has been designed in such a way that it was quickly acquired. The term is well known in industrial operations that include fluid flow phenomena. There is a dearth of literature highlighting the flows generated by a Riga platter. Pantokratoras and Magyari [14] demonstrated this phenomenon in EMHD natural-convective boundary-layer flowing. Ahmad et al. [15] numerically inspected the impact of combined convective on the
behaviour of nanoliquids on the Riga plate. Ayub et al. [16] utilised slip dynamics to drive EMHD nanofluid movement over a horizontal Riga plate. The irreversible assessment for Eyring-Powell nanofluid flowing via magneto Riga platter with nonlinear thermal radioactive fluxing was studied by Ephesus et al. [17]. Rasool and Zhang [18] explored the chemically reactive properties and convection boundary constraints in Powell–Eyring nanomaterial flowing with a radioactive Riga platter.

To the best of our knowledge, there are no earlier investigations of the micropolar fluid flow created by extending a Riga plate to examine the impacts of diverse dissipative on the MHD flow accompanied by a chemical reaction. The literature review concluded that there is no research on the topic under consideration. Consequently, the primary objective of this numerical study is to enhance the work presented by Goud [19] over a heated vertical Riga plate with viscous dissipation. A set of nonlinear partial differential equations (PDEs) is used to depict flow mathematically, using conservation principles and boundary layer approximation. The controlling equations are converted into a system of ODEs (ordinary differential equations) with appropriate boundary constraints using similarity transformations, and a MATLAB inbuilt solver bvp4c is used to solve them numerically. Numerous relevant characteristics are explored in detail using graphical representations of velocity, angular velocity, temperature, and concentricity outlines. For various pertinent flow factors, the coefficient of frictional factor as well as the Nusselt and Sherwood quantities are shown in the tabular form. These are some of the unique features of our work, and the research reported on this problem may have applications in metallurgical processes, polymer technology, melting, and the use solidification of the influence of the magnetic field in processing units. In light of current technical advancements, the combination of magnetic and electric fields (EMHD) is particularly successful in regulating the processes involved in melting and solidification. A direct comparison with published findings for specific situations validated the veracity of our current study. The findings of this work will be valuable in chemical and biological purposes such as breast metastatic disease and occupant physiological gradients, as well as other structural materials.

2. Description of Problem

Consider a consistent, 2-D flow behaviour with mass and heat micropolar flowing of a viscous fluid, initiated by a movement plate that is positioned in an incompressible liquid that is electrically conductive. On the continuous extending plate, the $x$–axis runs parallel to it and points in the same way as the motion. This means that the $y$–axis is normal to the $x$–axis, as well as to the orientation in which the continuous stretching plate emerges. Assuming that the magneto force is employed along a path perpendicular to a stretched platter and is an induced magnetic force, the magneto Reynolds numbers are supposed to be very small. Additionally, presume that the entrained electrical field is zero and ignore the Hall current. Consider that the liquids’ properties are isotopous and consistent over their whole length. The flow and Riga plate geometry are shown in Figure 1a,b. The following equations are governed as:
\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}
\]
\[
\frac{\partial u}{\partial x} + \nu \frac{\partial^2 u}{\partial y^2} + \frac{k}{\rho} \frac{\partial N}{\partial y} + \frac{\nu}{8\rho} \mu = 0 \tag{2}
\]
\[
\frac{\partial N}{\partial x} + \nu \frac{\partial^2 N}{\partial y^2} = -k \frac{\partial u}{\partial y} \tag{3}
\]
\[
\frac{\partial T}{\partial x} + \nu \frac{\partial^2 T}{\partial y^2} = \frac{k}{\rho c_p} \frac{\partial u}{\partial y} \tag{4}
\]
\[
\frac{\partial C}{\partial x} + \nu \frac{\partial^2 C}{\partial y^2} = D \frac{\partial^2 C}{\partial y^2} - k_a (C - C_\infty) \tag{5}
\]

Laterally with the boundary conditions:
\[
\begin{align*}
&u = u_w = bx, v = 0, N = 0, T = T_\infty, C = C_\infty, \text{at } y = 0, \\
&u = 0, N = 0, T = T_\infty, C = C_\infty, \text{as } y \to \infty \tag{6}
\end{align*}
\]

In this instance, its miles supposed that \( \gamma \) is given by [4].
\[
\gamma = \left( \mu + \frac{k}{2} \right) j \tag{7}
\]

Here \( j = \frac{v}{b} \) specifying the length of the reference and using (4), Equation (13) expects accurate behaviour when the fine structure influence is not important, and the fine rotation \( N \) is transformed as follows to angular rapidity [3].

By establishing coordinates manipulation and dimensional and physical thermal parameters:
\[
\eta = \sqrt{\frac{b}{v}} y, u = bx f'(\eta), v = -\sqrt{b v} f(\eta), N = \sqrt{\frac{b^3}{v}} x G(\eta),
\]
\[
\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}, K = \frac{k}{\mu}, Pr = \frac{\nu c_p}{k_f}, Ec = \frac{u_w^2}{C_p(T_w - T_\infty)},
\]
\[
Sc = \frac{v}{D}, Kc = \frac{k_c}{b}, M = \frac{\nu}{8 \rho b^2}, \beta = \frac{b}{\rho} \sqrt{v} \tag{8}
\]

Equation (1) automatically fulfilled and by using Equation (8) into Equations (1)–(6) transformed to the subsequent form:
\[(1 + K)f''' + f f'' + K G' - (f')^2 + Me^{-\beta \eta} = 0 \quad (9)\]
\[\left(1 + \frac{K}{2}\right) G'' + f G' - f' G - K(2G + f'') = 0 \quad (10)\]
\[\theta'' + Pr f \theta' + (1 + K) Pr Ec f'' = 0 \quad (11)\]
\[\phi'' + Sc f \phi' - Sc K c \phi = 0 \quad (12)\]

Reduced boundary constraints are:
\[
\begin{align*}
    f' &= 1, \\
    f &= 0, \\
    G &= 0, \quad \text{and} \quad G &= 0, \\
    \theta &= 1, \\
    \phi &= 1 \quad \eta = 0 \\
\end{align*}
\quad (13)
\]

The shear stress is specified by:
\[\tau_w = \left(\mu + k \left(\frac{\partial u}{\partial y}\right) + k N\right)_{y=0} = b x (\mu + k) \sqrt{\frac{b}{\nu}} f''(0) \quad (14)\]

The local skin friction component \(C_f\) described by:
\[C_f = \frac{\tau_w}{\rho U_w^2} = \frac{1 + K}{\sqrt{Re_w}} f''(0) \quad (15)\]

The couple's stress at the side of the platter is stated as:
\[M_w = \gamma \left(\frac{\partial N}{\partial y}\right)_{y=0} = \mu u_w (1 + \frac{K}{2}) g'(0) \quad (16)\]

The Nusselt number, surface heat transition, and neighbourhood mass motion is characterised as:
\[q_w(x) = -k_f \left(\frac{\partial T}{\partial y}\right)_{y=0} = -k_f (T_w - T_\infty) \sqrt{\frac{b}{\nu}} \theta'(0) \quad (17)\]
\[Nu = \frac{x q_w(x)}{k_f} = \frac{x q_w(x)}{k_f} = -\sqrt{\frac{b}{\nu}} \theta'(0) \quad \text{on simplification} \quad \frac{Nu}{\sqrt{Re_w}} = -\theta'(0) \quad (18)\]

The mass flux can be well-demarcated as:
\[j_w = -D \left(\frac{\partial C}{\partial y}\right)_{y=0} \quad \text{therefore the rate of mass transfer can be inscribed as} \]
\[Sh = \frac{j_w x}{D(C_w - C_w)} = -\sqrt{\frac{b}{\nu}} \phi'(0) \quad \text{or} \quad \frac{Sh}{\sqrt{Re_w}} = -\phi'(0) \quad (19)\]

### 3. Numerical Process

One way to solve Equations (9)–(13) is to use the software function bvp4c. This function is utilised to resolve all ODEs in the text. This function is used to solve equations based on different physical parameters (14).

The three-stage Lobatto IIIa recipe might be tackled mathematically utilising the MATLAB solver bvp4c (R2014a, The MathWorks, Inc., Galway, Ireland), a limited contrast calculation. MATLAB’s bvp4c must be utilised if the conditions (9)–(13) are changed into an arrangement of first-request conditions;

If \( \xi \equiv [f f' f''' G' \theta \phi \phi']^T \) it gives:

Step 1. We now have a scheme of equations of the first order:
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Step 2. For the numerical solution, the MATLAB inbuilt bvp4c solver is used using the boundary condition listed above and a proper finite value for the distant field boundary condition. This is treated as a boundary value problem (BVP). i.e., \( \eta \to \infty \) say \( \eta \to 10 \).

Initial criteria that apply are as follows:

\[
\frac{d}{d\eta} \begin{pmatrix} \xi(1) \\ \xi(2) \\ \xi(3) \\ \xi(4) \\ \xi(5) \\ \xi(6) \\ \xi(7) \\ \xi(8) \\ \xi(9) \end{pmatrix} = \begin{pmatrix} \xi(2) \\ \xi(3) \\ -(f'G - f''G - K(2G + f''))/\left(1 + \frac{K}{2}\right) \\ \frac{\xi(5)}{f'} \\ \xi(7) \\ -(Pr \theta' + (1 + K)PrEcf'') \\ \xi(9) \\ -(Scf \phi' - ScKc\phi) \end{pmatrix}
\]

(20)

The scaling factor is marked by \( \eta = 0.01 \) and the convergence conditions are specified as accuracy to the fifth decimal place.

When used in association with MATLAB, bvp4c needs just three components to solve the BVP:

- Odes function for evaluating ODEs;
- Function bcs (boundary conditions) for calculating the residual of the boundary condition;
- Solinit structure that includes both a mesh estimate and the mesh solution. ODEs are processed similarly to IVP solvers in MATLAB.

4. Results and Discussion

The MATLAB application bvp4c technique was used to solve the nonlinear differential Equations (9)–(12) through boundary conditions (13). Here, the relevance of physical qualities connected with temperature, velocity, angular velocity, and concentration has been highlighted magnificently using graphs that show the behaviour of the physicochemical properties, and numerical solutions were calculated according to the problem's constraints, and the numerical consequences were charted and exposed graphically.

The non-dimensional velocity \( (f') \), temperature \( (\theta) \), concentricity \( (\phi) \), and angular speed \( (G) \) arcs for various Hartmann number \( (M) \) standards are shown in Figure 2a–d. In Figure 2a,b, the variation in the modified Hartman parameter and the corresponding contours for velocity and angular profiles for a variety of other parameters are shown. Due to the greater impact of stimulated Lorentz force in the non-negative \( x \)–orientation, increased values of the modified Hartman number indicate a rising trend. As the speed difference increases, the thickness of the corresponding boundary-layer decreases. This overextension in a velocity distribution shows that the fluid's velocity around the Riga plate exceeds its velocity in the free stream. A rise in the modified magnetic amount correlates to an increase in the outside electrical profile and, therefore, a rise in the velocity.
field. In addition, the amplitude of the wall velocity gradient grew as the boundary layer thickened. As found in Figure 2c,d, the temperature ($\theta$) and concentration ($\phi$) diminish as $M$ upsurges.

![Graphs](image1.png)

**Figure 2.** (a) Rapidity, (b) Angular quickness, (c) Temperature, and (d) Concentricity vs. $M$.

Figure 3a–d outline the substance factor ($K$) on the speed, angular speed, temperature, and concentration distributions. It can be shown that $f'$ and $g$ grow with an increase in the quantity of $K$, whereas opposite phenomena are observed for $\theta$ and $\phi$. Normally, when the fluid consistency diminishes, the added substance’s angular velocity enhances. The temperature outlines are displayed in Figure 4 for diverse amounts of the Prandtl quantity ($Pr$). It is found that expanding the values of $Pr$ (beginning with water $Pr = 6.2$) diminishes the temperature outline. The behaviour of the Prandtl number is determined by the interaction between the velocity diffusion process and the thermal boundary surface. Due to the dominance of the viscous diffusion over the thermal diffusion, the Prandtl number rises. Therefore, the existence of the Prandtl number ($Pr$) causes a reduction in the thermal boundary layer thickness distribution. In continuum mechanics, the Eckert number ($Ec$) is dimensionless. It characterises heat transfer dissipation by expressing the link between a flow’s kinetic energy and the boundary layer enthalpy differential. The Eckert number quantifies the flow’s kinetic energy concerning the enthalpy.
differential across the thermal boundary layer. It is used to characterise heat dissipation in high-speed flows with strong viscousness dissipative flowing. Figure 5 depicts the behaviour of the Eckert quantity ($Ec$) on the energy outlines. $Ec$ in the flow field increases the energy, resulting in a higher fluid temperature in the fluid area owing to dissipation caused by viscosity and elastic deformation. The quantity of mechanical energy was converted to thermal energy as a result of internal friction heating between molecules of the fluid, and this thermal energy is stored in the fluid. Consequently, a rise in the Eckert number induces an increase in the thermal energy of the flow and raises the temperature of the fluid across the thermal boundary layer. Schmidt quantity’s behaviour on concentration curves is seen in Figure 6. When $Sc$ ($H_2 = 0.22, H_2O = 0.6, CO_2 = 0.94$) is raised, concentrations decline. Schmidt number $Sc$ represents the relationship between momentum and mass diffusivity. It measures the relative effectiveness of momentum and mass transfer through diffusion in the hydrodynamic (velocity) and concentration (species) boundary layer. Larger values of the Schmidt number diminish the fluid’s mass diffusivity, causing the concentration profiles to fall. The concentration profile is affected by the various values of the chemical reaction parameter ($Kc$), as shown in Figure 7. The emergence of the reactive species indicates that the solute profiles have undergone a damaging chemical reaction. From the mathematical statement of the governing equation of the solute profile, the behaviour of the destructive reaction resulting from the positive values examined in the current situation may be described. It is evident that the concentration profile decreases as $Kc$ increases. This is because chemical reactions in this system consume the chemical, resulting in a reduction in the concentration profile. The most significant consequence of the first-order chemical reaction is its propensity to reduce the overshoot in the concentration profiles of the boundary layer. Figure 8 illuminates the relationship between a width variable ($\beta$) and velocity. Increased values of $\beta$ cause an increase in fluid viscosity, which decreases the flow velocity in the positive x-direction owing to the exponential function that decreases as $\beta$ values increase.
Figure 3. (a) Rapidity, (b) Angular rapidity, (c) Temperature, and (d) Concentricity vs. $K$.

Figure 4. Temperature vs. $Pr$.

Figure 5. Temperature vs. $Ec$. 
Figure 6. Concentration vs. Sc.

Figure 7. Concentration vs. Kc.

Figure 8. Velocity vs. $\beta$.

Accordingly, Table 1 has been produced to compare the current problem’s numerical results with previously published literature [19–22] in the limiting case. Comparing the new findings to the previously published ones reveals full agreement, as shown in this table.
Table 1. Comparison results for $-\theta'(0)$ with $K = 0$, $Ec = 0.0$, $M = 0.0$.

| $Pr$ | Ref. [19] | Ref. [20] | Ref. [21] | Ref. [22] | Present Study |
|------|-----------|-----------|-----------|-----------|---------------|
| 0.7  | -         | 0.4539    | -         | 0.4539    | 0.45445       |
| 2    | 0.91142   | 0.9113    | -         | 0.9113    | 0.91135       |
| 3    | 1.1597    | -         | 1.16522   | -         | 1.16525       |
| 7    | 1.89046   | 1.8954    | 1.8954    | 1.8954    | 1.89541       |

Table 2 shows the variation in $-f''(0), g'(0), -\theta'(0)$, and $-\phi'(0)$ owing to $M$, $K$, and $\beta$ impact. It is revealed that raising the value of $M$ causes a drop in the values of $-f''(0)$ and $g'(0)$, but the opposite is seen for $-\theta'(0)$ and $-\phi'(0)$. Furthermore, when $K$ and $\beta$ values grow, $g'(0), -\theta'(0)$, and $-\phi'(0)$ increase while $-f''(0)$ declines. Table 3 shows the $-\theta'(0)$ with different $Pr$ and $Ec$ values. When seen in the table, $-\theta'(0)$ rises as $Pr$ and $Ec$ increase. The impact of $-\phi'(0)$ on different $Sc$ and $Kc$ values is seen in Table 4. It has been observed that raising $Sc$ and $Kc$ causes an increase in $-\phi'(0)$.

Table 2. Numerous standards of $-f''(0)$, $G'(0)$, $-\theta'(0)$ and $-\phi'(0)$ for altered standards of $M$, $K$, and $\beta$ at $Pr = 6.2$, $Sc = 0.22$, $Ec = 0.02$, and $Kc = 0.1$.

| $M$ | $K$ | $\beta$ | $-f''(0)$ | $G'(0)$ | $-\theta'(0)$ | $-\phi'(0)$ |
|-----|-----|---------|-----------|---------|--------------|-------------|
| 0   | 0.2 | 1       | 0.90975   | 0.095   | 1.86537      | 0.26522     |
| 0.5 |     |         | 0.699167  | 0.084668| 1.900295     | 0.280001    |
| 1   |     |         | 0.496288  | 0.07574 | 1.930793     | 0.292783    |
|     | 0   |         | 0.950328  | 0       | 1.845710     | 0.262482    |
|     | 0.5 |         | 0.769444  | 0.171601| 1.906578     | 0.275290    |
| 2   | 0.2 | 0.2     | 0.815108  | 0.083641| 1.883016     | 0.285358    |
| 0.4 |     |         | 0.837795  | 0.088279| 1.878961     | 0.276605    |
| 0.6 |     |         | 0.851606  | 0.090705| 1.876191     | 0.272101    |

Table 3. Calculations of $-\theta'(0)$ for diverse $Ec$ and $Pr$ quantities with $M = 0.1$, $Sc = 0.22$, $K = 0.2$, $Kc = 0.1$, and $\beta = 1$.

| $Pr$ | $Ec$ | $-\theta'(0)$ |
|------|------|--------------|
| 0.71 | 0.02 | 0.496574     |
| 1    |      | 0.625629     |
| 3    |      | 1.235704     |
| 6.2  | 0.04 | 1.872921     |
|      | 0.06 | 2.020310     |

Table 4. Calculations of $-\phi'(0)$ for diverse $Sc$ and $Kc$ quantities with $Pr = 6.2$, $M = 0.1$, $K = 0.2$, $Ec = 0.02$, and $\beta = 1$.

| $Sc$ | $Kc$ | $-\phi'(0)$ |
|------|------|-------------|
| 0.22 | 0.1  | 0.268390    |
| 0.6  |      | 0.502325    |
| 0.96 |      | 0.672557    |
| 0.22 | 0.3  | 0.346935    |
| 0.22 | 0.5  | 0.409794    |

5. Conclusions

Fluid flow containing micro-rotational particles was quantitatively analysed for the impacts of viscous dissipation. This study takes into account the Riga plate’s elongation.
In order to normalise the flow of weakly conducting fluid, the Riga plate may be used to generate an electromagnetic field. The bvp4c approach is used by the MATLAB software to assume a suitable thickness for the boundary layer. The following are some of the most essential aspects of this study:

- With an increase in $M$, velocity and angular velocity enhance. Additionally, Nusselt number and Sherwood number enhance while temperature and concentration drop.
- When the modified Hartman number is increased, the inner velocity exceeds the free stream velocity.
- With a rise in substantial parameter, rapidity, coupling stress, Sherwood, Nusselt quantities, enhances and energy, concentricity, and shearing stress decrease.
- Temperature decreases and $-\theta'(0)$ increases as $Pr$ values grow.
- The result of increasing $Sc$ and $Kc$ is a drop in concentration and a rise in $-\phi'(0)$.

In the future, the bvp4c strategy might be used for a variety of physical and technological difficulties.

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**Nomenclature**

- $k$: Vortex viscosity
- $\gamma$: Viscosity of spin gradient
- $k_f$: Thermal conductivity
- $u_w$: Surface velocity
- $C_w$: Species concentration at the surface
- $Sc$: Schmidt number
- $j$: Microinertia per unit mass
- $v$: Kinematic viscosity
- $M$: Hartmann number
- $\rho$: Free stream density
- $T$: Temperature
- $\beta$: Dimensionless parameter
- $C_p$: Specific heat constant pressure
- $D$: Mass diffusivity
- $K$: Material parameter
- $T_{w}$: Wall temperature
- $C_{\infty}$: Fluid concentration outlying the surface
- $Ec$: Eckert number
- $T_{\infty}$: Ambient temperature
- $\mu$: Dynamic viscosity
- $Pr$: Prandtl number
- $b$: Constant
- $C$: Concentricity
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