Bol. Soc. Paran. Mat.
©SPM – E-ISSN-2175-1188
SPM: www.spm.uem.br/bspm

(3s.) **v. 2025 (43)** : 1–11.
ISSN-0037-8712
doi:10.5269/bspm.75751

MHD Casson flow of a Rotating liquid past a porous medium in the presence of Thermal Radiation and Chemical Reaction

Mohd Khalid*, Gladys Tharapatla, G. Venkata Ramana Reddy , Ali Akgül and W. Sridhar

ABSTRACT: Soret and Dufour effects have a major impact on flows involving temperature and concentration gradients. To give just one example, the Soret effect has been employed in the process of blending gases that have various molecular weights and in the process of discriminating between isotope pairings respectively. In this work, the laminar Casson flow of a fluid rotating across a permeable plate undergoing a chemical reaction is the subject of investigation. The essay emphasizes investigating how radiation, Soret, and Dufour influence the flow of the fluid. Due to the use of similarity variables, the governing equations and the accompanying boundary conditions are reduced to a dimensionless form. Subsequently, the equations are solved by ND with the assistance of the MATHEMATICA program. By using the flow's dimensionless properties, we were able to derive numerical estimates of temperature, concentration, and velocity. The images that were produced because of this process were exhibited. Higher Soret and Dufour parameters, in conjunction with a rise in the radiation factor, led to improved velocity profiles and warm temperature distribution. These are the most important findings that were uncovered as a result of the investigation.

Key Words: Soret and Dufour effect; laminar flow; thermal radiation; porous media.

Contents

1 Introduction 1
2 Mathematical formulation 2
3 Results and Discussion 4
4 Conclusions 8

1. Introduction

Thermal radiation in fluid dynamics is crucial in multiple fields of engineering, including aeronautical, solar power, chemical, environmental, and mechanical. Controlling heat is essential for preserving operational effectiveness and avoiding overheating in electronic equipment, industrial processes, and power plants. Engineers who are knowledgeable about radiative heat transfer may create efficient cooling solutions like heat sinks and radiative shields. Heat and mass transport in a liquid with varying viscosity via a penetrable upright plate subject to a magnetic field was considered through Makinde and Ogulu [1] and their findings indicate that an upsurge in the viscosity will reduce the velocity profiles and greater estimations of radiation factor will increase the temperature distribution. In the presence of a power-law velocity [2,3], MHD flow with heat transfer across a stretched surface was postulated by Anjali Devi and David [4]. Sulochana et al. [5] explored the mass & heat transport behavior of magnetized flow across a vertically rotating cone in a permeable media subject to chemical reaction, Soret effects, and thermal radiation and results showed that varying the porosity parameter improved heat and mass transport. Multiple models have been used in recent research in this field [6,7,8,9,10,12].

Rotating porous media refers to a type of material or medium that has a porous structure and is capable of rotation. When pores are present, fluids or gases may pass through the material, and rotation adds another dynamic component. Rotation and porosity work together to provide a variety of intriguing phenomena and applications in a wide range of industries. A few instances of rotating porous medium are separation and filtering filtration, and separation procedures may be carried out using a rotating porous medium [13]. The medium may successfully separate suspended particles or separate various components

* Corresponding author

Submitted February 16, 2025. Published August 24, 2025
2010 *Mathematics Subject Classification:* 76R10, 76S05, 80A20

of a mixture depending on their density or size by applying centrifugal forces as a result of rotation. This is very helpful for the chemical processing, oil and gas sector, and wastewater treatment. Rotating porous media may improve the processes of heat and mass transmission [14]. Rotating porous media, for instance, may increase the thermal convective coefficient and decrease boundary layer heaviness to enhance the thermal efficiency in heat exchangers. This has uses in cooling devices, HVAC (ventilation, heating, and air conditioning) systems, and electronic device thermal management. Rotating porous media may be used in biomedical applications such as tissue engineering, bio-filtration, and drug delivery systems [15]. The development and survival of cells and tissues may be aided by the controlled rotation of porous scaffolds by improving nutrition and oxygen delivery. Additionally, it may aid in waste elimination and boost the effectiveness of medicine administration. Anika et al. [16] conducted an experiment to examine the effect of Hall current on MHD fluid flow across an endlessly rotating vertical plate with heat transfer. They found that increasing the rotation parameter reduced the velocity profiles. Hayat and Hutter [17] examined the behavior of a second-order incompressible rotating flow past a porous plate and their research reveals that the velocity field exhibits a non-Newtonian influence in both the steady and the unsteady states. The magnetohydrodynamic (MHD) flow of an elastic viscous fluid through a permeable media is affected by Hall and ion slip effects. Krishna and Chamka's [18] computer analysis revealed that both elasticity and the magnetic field impede fluid velocity. Krishna [19] discovered in a different analytical study that raising the importance of the Hall and ion slip parameters increases the fluid's velocity when it passes by a vertical plate that rotates indefinitely in an MHD field. Several recent research projects using various models have been carried out in this field [20,21,22,23,24,25].

Two important transport phenomena that are seen in multi-component systems are the Soret and Dufour effects. They stand for the mass and heat transfer that is out of balance due to temperature gradients and concentration gradients, respectively. The Soret effect is helpful in many areas. The Soret effect can be applied to separation procedures in the field of isotope separation, where different isotopes have different Soret coefficients. Procedures for isotope enrichment such as thermal diffusion columns or thermos gravitational columns may make use of these phenomena [26,27].

The Soret effect contributes to the movement of fuel and oxidizer species during combustion processes. Optimizing combustion processes, increasing efficiency, and lowering pollutant emissions, are helpful to understand the Soret effect. The Dufour effect, also known as thermal diffusion of heat, is a term used to describe how concentration gradients in a multi-component system induce heat to move. It defines the process where temperature gradients cause the mass to move, causing heat to transfer and chemical species to diffuse at the same time. In biological systems such as blood flow and tissue engineering, the Dufour effect plays a critical role. It affects the flow of heat and metabolites across tissues and plays a role in medical procedures like thermal ablation and drug delivery. Jawad et al. [28] investigate magnetohydrodynamic laminar flow on a vertical permeable surface in the context of Dufour and Soret implications. They find that an increase in the Prandtl number maximizes heat transfer. Mahdy [29] reviewed the heat characteristics of a Casson liquid caused by a stretching cylinder with the Soret and Dufour impacts. The study undertaken by Reddy et al. [30] examined the implications of radiation and Dufour consequences on the laminar motion of a rotating liquid that passes through a vertical plate. There have been recent attempts to inspect this subject [31,32,33,34,35,36,37,38]. Readers interested in solving differential equations using integral transforms can refer to the following sources: [41,41,43,44].

In this work, the effects of Soret, Dufour, and chemical processes are examined in relation to the flow of a fluid through a porous media that is experiencing unstable MHD laminar flow past a vertical plate that is spinning. The ND Solve command in MATHEMATICA was used to solve the dimensionless equations. The influence of several physical factors on temperature, velocity, and concentration profiles was visualized using numerical simulations. Furthermore, a comparison study with extant literature was conducted, which demonstrated a robust association between the present findings and prior research outcomes.

2. Mathematical formulation

Consider a rotating fluid that flows laminarly through a permeable plate in a conducting field of varying temperature and concentration. x-Axis is taken along the plate, which is in the vertical direction, considering the chemical reaction, radiation, and Dufour effects. The y-axis is considered normal to the plate's surface. In a rigid body condition, both the plate and the liquid rotate through an unvarying angular velocity around the y-axis. At $t^*\leq 0$, both the liquid and the plate were at rest, with uniform temperatures and concentrations T_∞ & C_∞. The plate begins moving in the x-direction via uniform velocity. $u_0 a^* t^*$ at time t*>0. The temperature as well as concentration rise to $T_\infty + (T_w^* - T_\infty)\left(\frac{t^*}{t_0}\right)$ and $C_\infty + (C_w^* - C_\infty)\left(\frac{t^*}{t_0}\right)$ respectively. Later T_∞ and C_∞ are kept constant. Fig. 1 describes the physical interpretation of the above hypothesis.

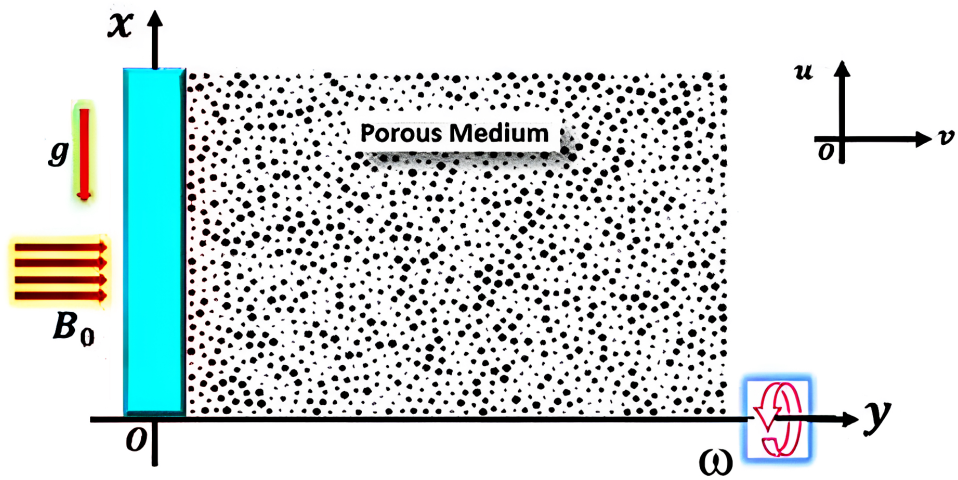

Figure 1: Physical model of the problem

The equations that determine the flow may be written as follows, taking these factors into account [25].

$$\frac{\partial u^*}{\partial t^*} + 2wv^* = v(1+\frac{1}{\beta})\frac{\partial^2 u^*}{\partial {y^*}^2} + g\beta_T\left(T^* - T_\infty\right) + g\beta_c\left(C^* - C_\infty\right) - \frac{\sigma B_0^2 u^*}{\rho} - \frac{v}{k}u^* \tag{2.1}$$

$$\frac{\partial v^*}{\partial t^*} - 2wu^* = v(1+\frac{1}{\beta})\frac{\partial^2 V^*}{\partial {y^*}^2} - \frac{\sigma B_0^2 v^*}{\rho} - \frac{v}{k}v^* \tag{2.2}$$

$$\rho C_p \frac{\partial T^*}{\partial t^*} = k\frac{\partial^2 T^*}{\partial {y^*}^2} + Q^*\left(T^* - T_\infty\right) - \frac{\partial q_r^*}{\partial y^*} + \frac{D_M k_T \rho}{C_s}\frac{\partial^2 C^*}{\partial {y^*}^2} \tag{2.3}$$

$$\frac{\partial C^*}{\partial t^*} = D\frac{\partial^2 C^*}{\partial {y^*}^2} + \frac{D_M k_T}{T_M}\frac{\partial^2 T^*}{\partial {y^*}^2} - Kr^*\left(C^* - C_\infty\right) \tag{2.4}$$

Associated initial & boundary conditions are [25],

$$\begin{cases} u^* = 0, \quad v^* = 0, \quad T^* = T_\infty, \quad C^* = C_\infty \text{For all} \quad t^*, y^* \leq 0 \\ u^* = u_0 a^* t^*,\ v^* = u_0 a^* t^*, \quad T^* = T_\infty + (T_w^* - T_\infty)\left(\frac{t^*}{t_0}\right), \quad C^* = C_\infty + (C_w^* - C_\infty)\left(\frac{t^*}{t_0}\right) at \qquad y^* = 0 \\ u^* = 0, \quad T^* = T_\infty, \quad C^* = C_\infty \text{ As} \qquad y \to \infty \end{cases} \tag{2.5}$$

Rosseland's estimate for radiative heat flux approximation:

$$q_r^* = -\frac{4\sigma^*}{3k^*}\frac{\partial T^{*4}}{\partial y^*} \tag{2.6}$$

Here $\boldsymbol{k}^*$ denotes the mean absorption term and $\boldsymbol{\sigma}^*$ denotes the Stefan-Boltzmann constant. The equation of $\boldsymbol{T}^{*4}$ is a linear function to keep the flow temperature variance as small as possible. As an impact, $\boldsymbol{T}^{*4}$ has been expanded utilizing the Taylor series about $\boldsymbol{T}^*{}_\infty$. By neglecting the higher-power components greater than the first degree, so:

$$T^4 \approx 4T_\infty^{*3} T - 3T_\infty^{*4} \tag{2.7}$$

Using Eqs. (2.6) and (2.7), Eq. (2.3) becomes

$$\rho C_p \frac{\partial T^*}{\partial t^*} = k\frac{\partial^2 T^*}{\partial {y^*}^2} + Q^*\left(T^* - T_\infty\right) + \frac{16T_\infty^{*3}\sigma^*}{3k^*}\frac{\partial^2 T^*}{\partial y^{*2}} + \frac{D_m k_T \rho}{C_w}\frac{\partial^2 C^*}{\partial {y^*}^2} \tag{2.8}$$

The following are the non-dimensional quantities:

$$u = \frac{u^*}{u_0},\quad v = \frac{v^*}{u_0},\ t = \frac{t^* {u_0}^2}{v},\quad y = \frac{y^* u_0}{v},\quad \theta = \frac{T^* - T_\infty}{T_w^* - T_\infty},\ C = \frac{C^* - C_\infty}{C_w^* - T_\infty},\quad a = \frac{a^* v}{{u_0}^2}, {l_1}^2 = \frac{wv}{u^2}$$

$$Gr = \frac{vg\beta_T\left(T_w^* - T_\infty\right)}{{u_0}^3},\ Gm = \frac{vg\beta_c\left(C_w^* - C_\infty\right)}{u^3}, M = \frac{\sigma {B_0}^2 v}{\rho {u_0}^2}, K = \frac{K_1 {U_0}^2}{v^2}, Pr = \frac{\rho v C_p}{k},\ Kr = \frac{Kr^* v}{{u_0}^2},$$

$$Q = \frac{Q^* v}{\rho C_p {u_0}^2}, R = \frac{4\sigma^* T_\infty^{*3}}{3kk^*}, S_c = \frac{v}{D}, D_f = \frac{D_m K_T\left(C_w^* - C_\infty\right)}{vC_s C_p (T_w^* - T_\infty)}, Sr = \frac{D_m k_T}{\nu T_m}\frac{\left(T_w^* - T_\infty\right)}{\left(C_w^* - C_\infty\right)} \tag{2.9}$$

Equations (2.1), (2.2), (2.4), and (2.8) are recast as the following PDE's considering Eq. (2.9).

$$\frac{\partial u}{\partial t} + 2l_1^2 v = (1 + \frac{1}{\beta})\frac{\partial^2 u}{\partial y^2} + Gr\theta + Gm\ C - Mu - \frac{1}{K}u \tag{2.10}$$

$$\frac{\partial v}{\partial t} - 2l_1^2 u = (1 + \frac{1}{\beta})\frac{\partial^2 V}{\partial y^2} - Mv - \frac{1}{K}v \tag{2.11}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{Pr}(1 + \frac{4R}{3})\frac{\partial^2 \theta}{\partial y^2} + Q\theta + Df\frac{\partial^2 C}{\partial y^2} \tag{2.12}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - KrC + Sr\frac{\partial^2 \theta}{\partial y^2} \tag{2.13}$$

The initial boundary conditions (BCs) are:

$$\begin{aligned}
&u = 0, \quad v = 0, \quad \theta = 0, \quad C = 0, \quad \forall y,\ t \le 0 \quad t > 0;\\
&u = e^{at}, \quad v = e^{at}. \quad \theta = t, \quad C = t \quad \text{at} \quad y = 0,\\
&u = 0, \quad v = 0, \quad \theta^* = 0, \quad C = 0, \quad as \quad y \to \infty
\end{aligned} \tag{2.14}$$

3. Results and Discussion

To extract the physical significance of the problem depicted in Figures 2–13, a simulation for transient MHD rotating laminar flow through a vertical plate in a permeable material by Soret, Dufour, and chemical reactions has been constructed using numerous dissimilar non-dimensional flow parameters. Many real-world applications, including geosciences and chemical engineering, include the Soret and Dufour effects. Analysis of the Grid Independence is presented in Table 1, 2 and 3 for different mesh lengths which demonstrates the consistency of the numerical approach. In the progression of this investigation, the following default parameters have been selected:

$$M = 1.0,\ \ Df = 1.0,\ K = 0.5,\ \ Q = 0.5,\ t = 0.2,\ a = 2,\ Sc = 0.22,\ Gr = 5.0,$$

$$Sr = 1.0,\ Gc = 5,\ \ R = 0.5,\ Pr = 0.71\ \&\ Kr = 0.5.$$

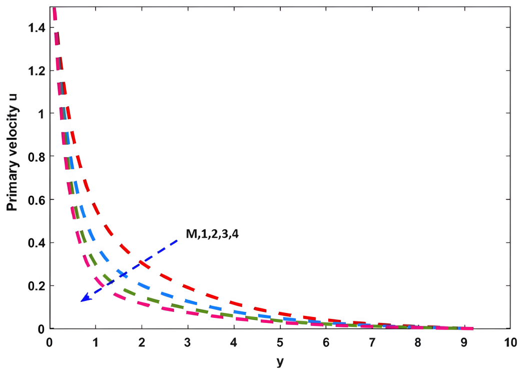

Figure 2: Primary velocity profiles on M

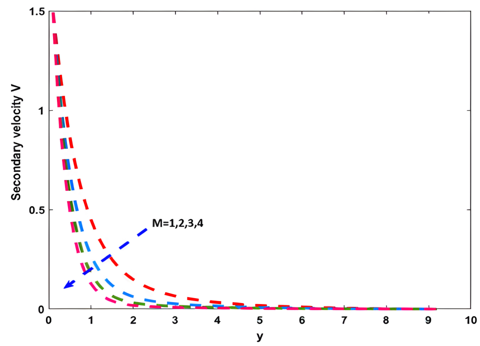

Figure 3: Secondary velocity profiles on M

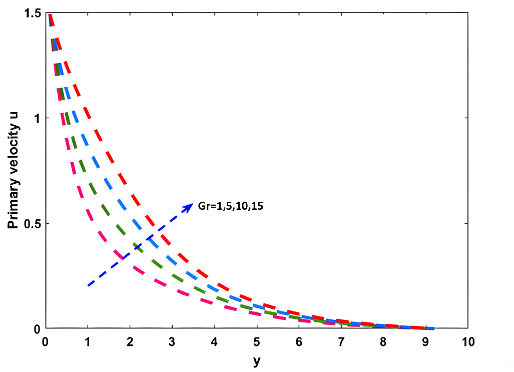

Figure 4: Primary velocity profiles on Gr

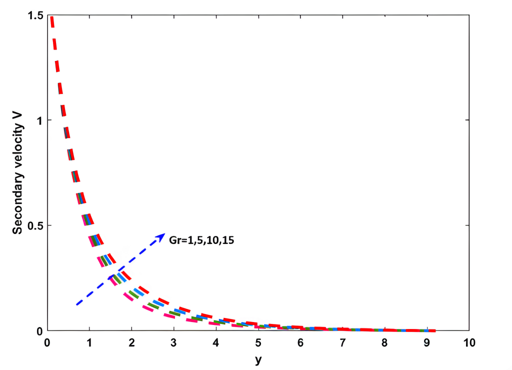

Figure 5: Secondary velocity profiles on Gr.

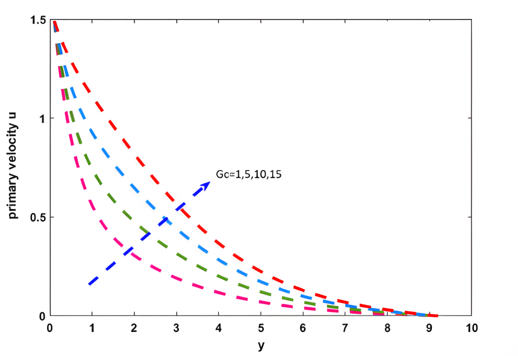

Figure 6: Primary velocity profiles on Gc

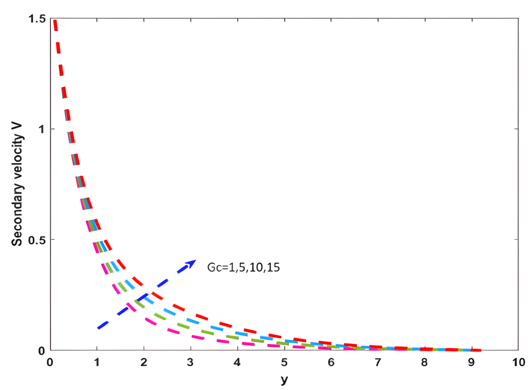

Figure 7: Secondary velocity profiles on Gc.

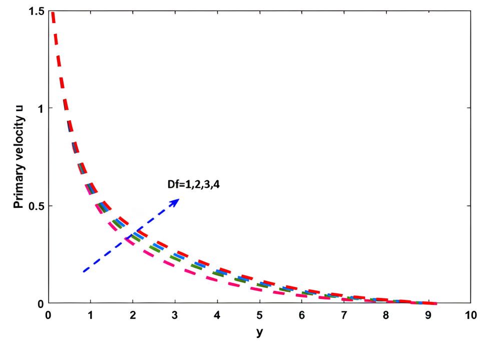

Figure 8: Primary velocity profiles on Df

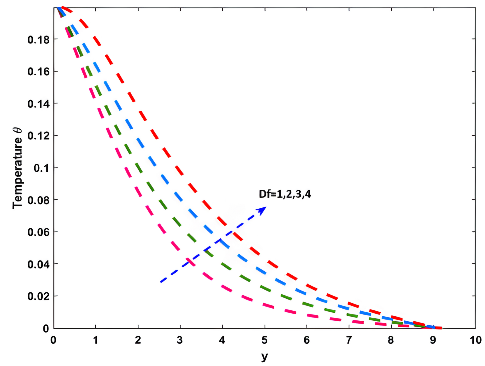

Figure 9: Temperature profiles on Df.

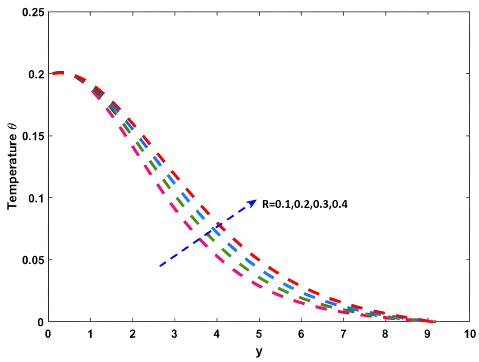

Figure 10: mperature profiles on R.

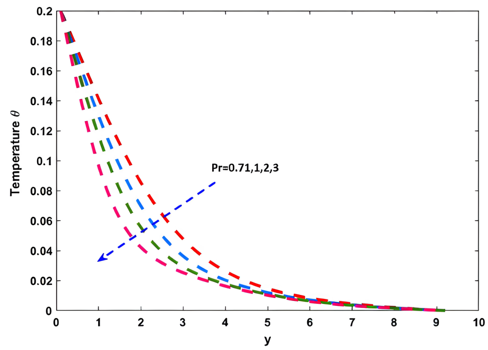

Figure 11: Temperature profiles on Pr.

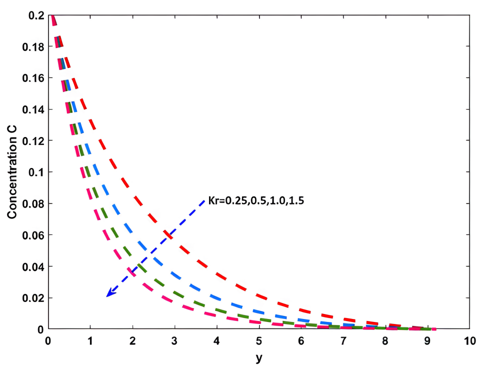

Figure 12: Concentration profiles on Kr.

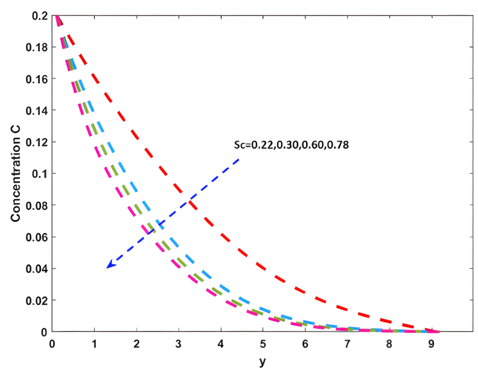

Figure 13: Concentration profiles on Sc.

Figures 2 and 3 illustrate the impact of M on the velocity profile. As the values of M rise, the flow velocity progressively decreases. The Lorentz force, a kind of resistance, was responsible for this phenomenon because it was produced by the induced magnetic field created by the liquid movement. Consequently, both the heaviness of the boundary layer and the motion of the fluid will decrease monotonically. Figs. 4 and 5 portray the impact of Grashof number (Gr) on the velocity profile. Gr is a dimensionless quantity that shows how important buoyancy forces are related to viscous forces in the flow of a stream. It is frequently employed in the study of natural convection, where buoyancy effects resulting from temperature differences drive fluid motion. The Grashof number influences the velocity profile of a fluid enduring natural convection significantly. As the Grashof number goes up, buoyancy forces get stronger, but viscous forces don't, so the velocity curves go up. The behavior of modified Grashof number Gc on the velocity profile is seen in Figs. 6 and 7. The modified Grashof number, a dimensionless quantity, illustrates the relative impact of concentration buoyant forces and viscous forces in stream flow. The buoyant forces get greater while the viscous forces remain constant when the concentration Grashof number Gc rises, increasing the velocity curves.

The effect of the Dufour number (Df) on the primary temperature and velocity is seen in Figures 8 and 9. The Dufour number (Df) is a dimensionless metric that indicates the mass diffusion to heat diffusion ratio in fluid mixtures. In conditions with temperature and concentration gradients, such as chemical reactions and combustion, it is essential for mass and heat transfer mechanisms. By influencing the temperature and concentration distributions within a fluid, the Df indirectly influences the primary velocity. Temperature gradients change when heat diffusion overtakes mass diffusion at increasing Dufour numbers. These fluctuations may result in buoyancy effects that change the density distribution and may have an impact on natural convection flow patterns. The dependency of temperature profiles θ on the radiation parameter R is shown in Figure 10. The radiative heat flux deviation rises with a drop in the mean absorption coefficient, which raises the temperature of the liquid near the surface and increases the rate of radiative heat transfer. As a result, for greater radiation levels, the thermal boundary layer's thickness and temperature profile also rise. The temperature distribution for a range of realistic Prandtl values is displayed in Figure 11. These numbers are notable since oxygen, air, ammonia, and carbon disulfide are all physically identical. The temperature drops as a result of the thermal boundary layer expanding and thermal conductivity decreasing as the Prandtl number Pr rises.

The consequence of chemical reaction parameters on concentration profiles in a chemical reaction system can be quite significant. Fig. 12 illustrates how Kr modifies the molecular concentration profiles. It demonstrates how the concentration of diffusing species quickly falls as Kr increases. The concentration of the diffusing species falls during the fast reaction, as seen above. Concentration distributions for plausible approximations of the Schmidt number are depicted in Fig. 13. The physical similarity between hydrogen, ammonia, oxygen, and water makes these values noteworthy. The Schmidt number denoted as Sc, is a measure of momentum diffusivity to mass diffusivity. Larger values of Sc are associated with lower molecular diffusivity and slower species diffusion in a fluid. These outcomes in a dramatic reduction in the heaviness of the concentration boundary layer as Sc rises.

Skin friction, Nusselt number, and Sherwood number:

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

Table 1: Numerical outcomes of the skin friction ($\boldsymbol{\tau}$)

K	Gm	M	Df	Kr	Gr	Sc	Sr	τ
0.5	5	0.5	1.0	0.5	1	0.22	1	0.018631
1.0								0.014160
1.5								0.012502
2.0								0.011651
	5							0.016919
	10							0.015209
	15							0.013501
		1						0.018632
		1.5						0.020562
		2						0.022339

Nusselt Number: $\boldsymbol{Nu} = \left(\frac{\boldsymbol{\partial\theta}}{\boldsymbol{\partial y}}\right)_{\boldsymbol{y=0}}$

Table 2: Numerical outcomes of Nusselt number $\boldsymbol{Nu}$

Pr	R	Q	Gr	Df	M	Kr	K	Nu
0.71	0.5	0.5	5.0	1.0	1.0	0.5	0.5	0.000101
1.00								0.000120
5.00								0.000241
	1.0							0.000069
	1.5							0.000048
	2.0							0.000019
		1.0						0.000846
		1.5						0.001958
		2.0						0.003688

Sherwood number values: $\boldsymbol{Sh}=\left(\frac{\partial C}{\partial y}\right)_{y=0}$

Table 3: Numerical outcomes of Sherwood number values $\boldsymbol{Sh}$

Sc	Kr	Gm	Df	M	Sr	K	Sh
0.22	0.5	0.5	1.0	1.0	1.0	0.5	-0.000762
0.30							-0.001721
0.60							-0.002581
0.78							-0.003522

4. Conclusions

In a transient magnetohydrodynamic (MHD) laminar flow, this study investigated the effects of Soret, Dufour, and chemical processes on the fluid dynamics within a porous media revolving around a vertical plate. The governing equations were numerically solved using the ND Solve technique. After that, numerical simulations were employed to show how different physical factors affected the profiles of temperature, velocity, and concentration.

1. As the magnitude of the magnetic parameter M expands, the velocity profiles exhibit a decreasing trend.

2. Enhancing the values of the radiation factor causes an upsurge in the temperature.

3. The concentration profiles with respect to higher Sr values are improved.

4. Enhancing the values of permeability causes a reduction in skin friction.

5. Improving the estimations of the heat absorption factor causes again in the Nusselt number values.

Funding: No funding Agency.
Conflict of Interest: There is no conflict of interest.
Availability of Data and Materials: Not required.

References

1. Makinde, O.D. and Ogulu, A., *The effect of thermal radiation on the heat and mass transfer flow of a variable viscosity fluid past a vertical porous plate permeated by a transverse magnetic field*, Chem. Eng. Commun., **195**(12) (2008), 1575–1584. https://doi.org/10.1080/00986440802115549

2. Oke, A.S., *Heat and mass transfer in 3D MHD flow of EG-based ternary hybrid nanofluid over a rotating surface*, Arab. J. Sci. Eng., **47**(12) (2022), 16015–16031. https://doi.org/10.1007/s13369-022-06838-x

3. Oke, A.S., *Theoretical analysis of modified Eyring-Powell fluid flow*, J. Taiwan Inst. Chem. Eng., **132** (2022), 104152. https://doi.org/10.1016/j.jtice.2021.11.019

4. Devi, S.A. and Gururaj, A.D.M., *Effects of variable viscosity and nonlinear radiation on MHD flow with heat transfer over a surface with a power-law velocity*, Adv. Appl. Sci. Res., **3**(1) (2012), 319–334.

5. Sulochana, C., Samrat, S.P. and Sandeep, N., *Numerical investigation of magnetohydrodynamic (MHD) radiative flow over a rotating cone in the presence of Soret and chemical reaction*, Propuls. Power Res., **7**(1) (2018), 91–101. https://doi.org/10.1016/j.jppr.2018.01.001

6. Krishna, Y.H., Reddy, G., Ramana, V. and Praveen, J.P., *Balancing chemical equations by using matrix algebra*, World J. Pharm. Pharm. Sci., **6**(2) (2017), 994–999.

7. Reddy, G.V.R. and Krishna, Y.H., *Soret and Dufour effects on MHD micropolar fluid flow over a linearly stretching sheet, through a non-Darcy porous medium*, Int. J. Appl. Mech. Eng., **23**(2) (2018), 485–502. https://doi.org/10.2478/ijame-2018-0028

8. Padmaja, V., Harikrishna, Y. and Ramana Reddy, G.V., *An innovative approach of matrix algebra to balancing chemical-reaction equations*, World J. Pharm. Pharm. Sci., **6**(3) (2017), 260–266.

9. Krishna, Y.H., Murthy, M.R. and Reddy, G.R., *Radiation and chemical reaction effects on unsteady MHD free convective periodic heat transport modeling in a saturated porous medium for a rotating system*, Int. J. Recent Innov. Trends Comput. Commun., **5**(6) (2017), 994–1001.

10. Hari Krishna, Y., Ramana Murthy, M.V., Bhikshu, N.L. and Venkata Ramana, G., *Effects of radiation and chemical reaction on MHD flow past an oscillating inclined porous plate with variable temperature and mass diffusion*, Int. J. Chem. Sci., **15**(3) (2017), 1–12.

11. Sreedevi, G., Rao, D.R.V., Makinde, O.D. and Reddy, G., *Soret and Dufour effects on MHD flow with heat and mass transfer past a permeable stretching sheet in presence of thermal radiation*, 2017.

12. Nagasantoshi, P., Ramana Reddy, G.V., Gnaneswara Reddy, M. and Padma, P., *Influence of non-uniform heat source on Casson and Carreau fluid flows over a stretching sheet with slip and convective conditions*, Int. J. Pure Appl. Math., **117**(13) (2017), 363–371.

13. Oke, A.S., *Coriolis effects on MHD flow of MEP fluid over a non-uniform surface in the presence of thermal radiation*, Int. Commun. Heat Mass Transf., **129** (2021), 105695. https://doi.org/10.1016/j.icheatmasstransfer.2021.105695

14. Oke, A.S., Animasaun, I.L., Mutuku, W.N., Kimathi, M., Shah, N.A. and Saleem, S., *Significance of Coriolis force, volume fraction, and heat source/sink on the dynamics of water conveying 47 nm alumina nanoparticles over a uniform surface*, Chin. J. Phys., **71** (2021), 716–727. https://doi.org/10.1016/j.cjph.2021.02.005

15. Oke, A.S., *Combined effects of Coriolis force and nanoparticle properties on the dynamics of gold-water nanofluid across nonuniform surface*, ZAMM–J. Appl. Math. Mech., **102**(9) (2022), e202100113. https://doi.org/10.1002/zamm.202100113

16. Anika, N.N., Hoque, M.M. and Islam, N., *Hall current effects on magnetohydrodynamics fluid over an infinite rotating vertical porous plate embedded in unsteady laminar flow*, Ann. Pure Appl. Math., **3**(2) (2013), 189–200.

17. Hayat, T. and Hutter, K., *Rotating flow of a second-order fluid on a porous plate*, Int. J. Non-Linear Mech., **39**(5) (2004), 767–777. https://doi.org/10.1016/S0020-7462(03)00040-4

18. Krishna, M.V. and Chamkha, A.J., *Hall and ion slip effects on MHD rotating flow of elastico-viscous fluid through porous medium*, Int. Commun. Heat Mass Transf., **113** (2020), 104494. https://doi.org/10.1016/j.icheatmasstransfer.2020.104494

19. Krishna, M.V., *Analytical study of chemical reaction, Soret, Hall and ion slip effects on MHD flow past an infinite rotating vertical porous plate*, Waves Random Complex Media (2022), 1–27. https://doi.org/10.1080/17455030.2022.2044094

20. Reddy, B.M., Kesavaiah, D.C. and Reddy, G.R., *Radiation and diffusion thermo effects of visco-elastic fluid past a porous surface in the presence of magnetic field and chemical reaction with heat source*, Asian J. Appl. Sci., **7**(5) (2019). https://doi.org/10.24203/ajas.v7i5.5919

21. Sandhya, A., Reddy, G., and Deekshitulu, G. V. S. R., *Radiation and chemical reaction effects on MHD Casson fluid flow past a semi-infinite vertical moving porous plate*, Indian Journal of Pure & Applied Physics (IJPAP), **58**(7) (2020), 548-557.

22. Venkateswarlu, M., Ramana Reddy, G. V., and Lakshmi, D. V., *Thermal diffusion and radiation effects on unsteady MHD free convection heat and mass transfer flow past a linearly accelerated vertical porous plate with variable temperature and mass diffusion*, Journal of the Korean Society for Industrial and Applied Mathematics, **18**(3) (2014), 257-268. https://doi.org/10.12941/jksiam.2014.18.257

23. Oke, A. S., Prasannakumara, B. C., Mutuku, W. N., Gowda, R. P., Juma, B. A., Kumar, R. N., and Bada, O. I., *Exploration of the effects of Coriolis force and thermal radiation on water-based hybrid nanofluid flow over an exponentially stretching plate*, Scientific Reports, **12**(1) (2022), 21733. https://doi.org/10.1038/s41598-022-21799-9

24. Oke, A. S., and Mutuku, W. N., *Significance of Coriolis force on Eyring-Powell flow over a rotating non-uniform surface*, Applications and Applied Mathematics: An International Journal (AAM), **16**(1) (2021), 36.

25. Nagasantoshi, P., Reddy, G. V., Reddy, M. G., and Padma, P., *Heat and mass transfer of Non-Newtonian Nanofluid flow over a stretching sheet with non-uniform heat source and Variable viscosity*, Journal of Nanofluids, **7**(5) (2018), 821-832. https://doi.org/10.1166/jon.2018.1517

26. Oyem, A. O., Mutuku, W. N., and Oke, A. S., *Variability effects on magnetohydrodynamic for Blasius and Sakiadis flows in the presence of Dufour and Soret about a flat plate*, Engineering Reports, **2**(10) (2020), e12249. https://doi.org/10.1002/eng2.12249

27. Vyakaranam, S., Leelavathi, R., Rao, T. S., Gurrampati, V. R. R., and Samuel, O. A., *Soret-Dufour Mechanisms on Unsteady Boundary Layer Flow of Tangent Hyperbolic and Walters-B Nanoliquid*, Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, **108**(1) (2023), 13-27. https://doi.org/10.37934/arfmts.108.1.1327

28. Jawad, M., Saeed, A., Kumam, P., Shah, Z., and Khan, A., *Case Studies in Thermal Engineering*, **23** (2021), 100792. https://doi.org/10.1016/j.csite.2020.100792

29. Mahdy, A., *Journal of Engineering Physics and Thermophysics*, **88** (2015), 928. https://doi.org/10.1007/s10891-015-1267-6

30. Nagapavani, M., Reddy, G. V. R., Fateh M. Ameen, H., and Singh, H., *Finite element analysis for sand and paraffin wax nanoparticles in propylene glycol-water mixture-based hybrid nanofluid flow over a swirling cylinder with Arrhenius kinetics*, Numerical Heat Transfer, Part A: Applications, (2023), 1-19. https://doi.org/10.1080/10407782.2023.2219834

31. Gladys, T. and Reddy, G. R., *Contributions of Variable Viscosity and Thermal Conductivity on the Dynamics of Non-Newtonian Nanofluids Flow Past an Accelerating Vertical Plate*, Partial Differential Equations in Applied Mathematics, **5** (2022), 100264. https://doi.org/10.1016/j.padiff.2022.100264

32. Reddy, K. V., Ramana Reddy, G. V., Sandhya, A. and Krishna, Y. H., *Numerical Solution of MHD, Soret, Dufour, and Thermal Radiation Contributions on Unsteady Free Convection Motion of Casson Liquid Past a Semi-Infinite Vertical Porous Plate*, Heat Transfer, **51**(3) (2022), 2837–2858. https://doi.org/10.1002/htj.22452

33. Veera Reddy, K., Venkata Ramana Reddy, G. and Chamkha, A. J., *Effects of Viscous Dissipation and Thermal Radiation on an Electrically Conducting Casson-Carreau Nanofluids Flow with Cattaneo-Christov Heat Flux Model*, Journal of Nanofluids, **11**(2) (2022), 214–226. https://doi.org/10.1166/jon.2022.1836

34. Reddy, G. V. R., Sekhar, K. C. and Falodun, B. O., *Multiple Slip Effects on Unsteady MHD Casson Nanofluid Flow Over a Porous Stretching Sheet*, Journal of Applied Nonlinear Dynamics, **11**(03) (2022), 651–666. https://doi.org/10.5890/JAND.2022.09.009

35. Al-Zubaidi, A., Sajja, V. S., Gadamsetty, R., Reddy, G. R., Babu, M. J. and Animasaun, I. L., *Dynamics over an Inclined Surface When Entropy Generation, Ohmic Heating, and Lorentz Force are Significant: Comparative Analysis Between Water-Copper Nanofluid and Water-Copper-Iron (II, III) Oxide Hybrid Nanofluid*, Waves in Random and Complex Media, (2022), 1–23. https://doi.org/10.1080/17455030.2022.2089368

36. Vyakaranam, S. and Reddy, G. V. R., *MHD Casson Nano Fluid Over a Nonlinear Penetrable Elongated Sheet with Thermal Radiation and Chemical Reaction*, (2022). https://doi.org/10.22541/au.164865097.76629964/v1

37. Gurrampati, V. R. R. and Vijaya, K., *The Buongiorno Model with Brownian and Thermophoretic Diffusion for MHD Casson Nanofluid Over an Inclined Porous Surface*, Journal of Naval Architecture and Marine Engineering, **19**(1) (2022), 31–45. https://doi.org/10.3329/jname.v19i1.50863

38. Ali, A., Mebarek-Oudina, F., Barman, A., Das, S. and Ismail, A. I., *Title Not Provided*, Journal of Thermal Analysis and Calorimetry, **1** (2023).

39. Bouselsal, M., Mebarek-Oudina, F., Biswas, N. and Ismail, A. A. I., *Title Not Provided*, Micromachines, **14**(5) (2023), 1072. https://doi.org/10.3390/mi14051072

40. Oke, A. S., *Convergence of Differential Transform Method for Ordinary Differential Equations*, Journal of Advances in Mathematics and Computer Science, **24**(6) (2017), 1–17. https://doi.org/10.9734/JAMCS/2017/36489

41. Khalid, M., Mallah, I.A., Alha, S. and Akgul, A., *Exploring the Elzaki Transform: Unveiling Solutions to Reaction-Diffusion Equations with Generalized Composite Fractional Derivatives*, Contemp. Math., (2024), 1426–1438. https://doi.org/10.37256/cm.5220244621

42. Khalid, M. and Akgül, A., *Fractional Frontier: Navigating Cauchy-type equations with formable and Fourier transformations*, Contemp. Math., (2024), 2693–2708. https://doi.org/10.37256/cm.5320244620

43. Khalid, M., Mallah, I.A., Akgül, A., Alha, S. and Sakar, N., *Applications of generalized formable transform with Ψ–Hilfer–Prabhakar derivatives*, Comput. Appl. Math., **43**(7) (2024), 410. https://doi.org/10.1007/s40314-024-02930-0

44. Khalid, M., Alha, S., and Akgül, A., *Hybrid Fractional Operators: A New Approach with Proportional Derivatives*, J. Environ. Account. Manag., **13**(3) (2025), 281–288. https://doi.org/10.5890/JEAM.2025.09.004

Mohd Khalid,

Department of Mathematics,

Lords Institute of Engineering and Technology, Hyderabad, India.

Department of Mathematics,

Maulana Azad National Urdu University,

Hyderabad, India.

E-mail address: khalid.jmi47@gmail.com

and

Gladys Tharapatla,
H&S Department, Methodist College of Engineering and Technology,
Abids, Hyderabad,
India.
E-mail address: gladysharshitha@gmail.com

and

G.Venkata Ramana Reddy,
Department of Mathematics, Koneru Lakshmaiah Education Foundation,
Vaddeswaram, Guntur-522302
India.
E-mail address: gvrr1976@kluniversity.in

and

Ali Akgül,
Department of Electronics and Communication Engineering,
Saveetha School of Engineering, SIMATS, Chennai, Tamilnadu, India.
Department of Mathematics,
Siirt University, Art and Science Faculty, 56100 Siirt, Turkey.
Department of Computer Engineering,
Biruni University, 34010 Topkapı, Istanbul, Turkey.
Department of Mathematics,
Near East University, Mathematics Research Center,
Near East Boulevard, PC: 99138, Nicosia /Mersin 10, Turkey.
Applied Science Research Center,
Applied Science Private University, Amman, 11937, Jordan
E-mail address: aliakgul00727@gmail.com

and

W.Sridhar,
Department of Mathematics, Koneru Lakshmaiah Education Foundation,
Vaddeswaram, Guntur-522302
India.
E-mail address: sridharwuriti@kluniversity.in