International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Mathematical Modelling of Engineering Problems
Vol. 11, No. 4, April, 2024, pp. 953-964
Journal homepage: http://iieta.org/journals/mmep

Soret Effect on Magneto Hydrodynamic Free Convective Heat and Mass Transfer Effects Flow over an Inclined Plate Embedded in a Porous Medium

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https://doi.org/10.18280/mmep.110412

Received: 11 October 2023
Revised: 12 January 2024
Accepted: 30 January 2024
Available online: 26 April 2024

Keywords:
heat and mass transfer, magneto hydrodynamic, Soret effect, radiation parameter, inclined porous plate

ABSTRACT

The primary aim of the study is to offer a precise analysis of the impact of the radiation parameter and Soret number on the magneto hydrodynamic (MHD) free convective flow of an incompressible, electrically conducting viscous fluid (IECVF) over an inclined plate immersed in a porous material (IPIPM). The impulsively started plate with changing mass diffusion and temperature is taken into account. Perturbation technique is applied to solve the non-dimensional momentum equation along with the energy diffusion and mass diffusion equations. Equations are found for the fields of velocity (u), temperature (θ) and concentration (φ). Expressions are obtained for skin friction (SF), Nusselt number (Nu) and Sherwood number (Sh). The graphical representations of the outcomes of various parameters on 'u, 'θ', and 'φ' and on SF, Nu and Sh are drawn, to highlight their effects.

1. INTRODUCTION

Researchers working on alternative energy sources, astrophysics, and hypersonic aerodynamics have shown a great deal of interest in investigations of heat transfer and mass transfer using MHD flow over an inclined plate.

The study of movement of electrically conducting fluids is known as Magnetohydrodynamic. Examples of MHD are salt water, liquid metals, electrolytes and plasmas. MHD is basis to many exciting fields of astrophysics and geophysics and has a wide range of applications in engineering, laboratories and society. Magneto fluid mechanics and magneto gas dynamics are other different terms used to denote MHD. Manufacturing process of petroleum industries, cooling of clear reactors, boundary layer control in aerodynamics are some of the important applications of MHD.

In the problem a solid plate submerged within a porous medium is considered. The porous medium encircling the plate has the potential to influence the movement of fluids and the transport of mass. The inclination of the plate influences the movement of the fluid. Some applications of inclined plates immersed in porous media encompass the investigation of flow patterns within soil containing buried obstacles, the refinement of designs aimed at controlling soil erosion, and the examination of fluid interactions within densely packed beds.

Heat Transfer (HT): The process by which thermal energy is transferred from a region of higher temperature to lower temperature region is called as HT. It can be functions of time and geometric coordinates, inside the area of matter. HT occurs through three primary modes: conduction, convection, and radiation. HT foretells the speed at which energy is conveyed over a surface because of difference in temperature at the surface and difference of temperature amidst varied surfaces. The quantity of HT per unit area through unit time is known as the heat flux.

HT theory finds practical applications in various fields. It finds application in computing thermal stresses in jet engine turbine blades, optimizing the layout of combustors in internal combustion engines, directing heat treatment procedures, estimating the power loads required for furnace operation, and evaluating the essential cooling water demands for electrical power plants. Mass Transfer (MT): The concept of transfer of mass from higher concentration part to region of lower concentration is termed as MT. The three modes of MT are 1. Diffusion MT, 2. Convective MT and 3. Phase change MT. Examples of MT are dissolution of salt in gravy and evaporation of naphthalene balls into atmosphere.

The HT task consistently goes with MT procedure in circumstances like evaporation, chemical reaction and condensation. Hence the study of consolidated HT and MT is useful in perception of various technical transmit activities.

The transmit of mass caused by gradient in temperature is called as Soret effect (Sr). The transferral of heat by concentration difference is termed as dufour effect (Df). In hydrology, petrology and geosciences the reaction of Sr and Df play a fundamental role.

The incorporation of Sr in MHD free convective flow over an IPIPM provides further applications and considerations across various engineering fields such as crystal growth, astrophysical fluid dynamics, chemical process industry, electrokinetic devices, geological fluid dynamics and food processing.

The reaction of Df and heat generation on MHD free convection flow of an IECVF above an IPIPM using closed analytical method has been considered by Islam et al. [1]. Taid and Ahmed [2] worked on the outcome of heat source, chemical reaction and Sr on the stable 2D MHD free convective flow across IPIPM, using perturbation method. Here, it was noticed that the velocity, concentration and SF drop off with the rise in Kr, also temperature, Nu and Sh hikes with the boost up in the value of Kr.

The consequence of Sr, hall current and rotation on an unstable MHD free convection heat and MT flow of IECVF past an IPIPM was measured by Sarma and Pandit [3]. In this scenario, the entire system rotates at a constant angular velocity perpendicular to the plate, while a uniform magnetic field is applied in the same perpendicular direction. Falodun et al. [4], worked on the reactions of negative and positive Sr and Df on unsteady mass and HT flow in the existence of viscous dissolution, heat and mass buoyancy. A spectral relaxation method, known for its robustness and accuracy, is utilized to solve unsteady nonlinear PDEs. The outcome of Sr on unstable free convection flow of incompressible viscous fluid past a permeable means with peak porosity bounded by an erect unbounded plate under the effect of heat source, chemical reaction and thermal radiation was addressed by Ibrahim et al. [5]. The study shows that 'u' increases with increment in the values of buoyancy parameters, 'θ' declines with rise in the value of Pr and 'φ' drops off with boost up in the values of Sc and Kr.

Dhanalakshmi et al. [6] studied the results of Sr and Df reaction of Kuvshinshiki fluid on MHD free convection flow through an erect permeable plate in the existence of chemical reaction with heat and MT by applying perturbation technique. Also by using Matlab, the results are obtained both in graphical and numerical ways for different values of flow factors.

Numerical investigations have been conducted on the steady 2D MHD free convective flow, as well as MT, occurring around a semi-infinite erect porous plate within a permeable medium. This study also encompasses the consideration of the Dufour and Soret effects which was done by Alam and Rahman [7]. The momentum, energy, and concentration equations are normalized using similarity transformations. These equations are then numerically solved using the Nachtsheim-Swigert shooting method combined with a sixth-order Runge-Kutta integration scheme.

Reddy et al. [8] had examined the impact of thermodiffusion and chemical influences on HT in MHD mixed convection flow and MT alongside an infinite vertical plate. This investigation takes into account Ohmic heating and viscous dissipation as significant factors in the analysis. The results are obtained by perturbation techniques. The existence of the chemical effect leads to a reduction in 'u' and 'θ' caused by thermal diffusion. The values of 'u' and 'θ' are greater for mercury when compared to electrolytic solution. 'φ' increases with rise in Sr while decreases with increment in chemical effect.

The analytical analysis of the flow of free convection and MT within a vertical channel created by two vertical parallel plates was done by Jha and Ajibade [9]. The values of 'u', 'θ' and 'φ' are obtained by Laplace transform technique. Df is noted for inducing anomalous conditions in 'u' and 'θ' especially for small Pr. The study also disclosed that the equilibrium state of the problem remains unaffected by Df effect.

Postelnicu [10] explored the heat and MT features of natural convection around an upstanding surface embedded in a saturated porous medium and exposed to a magnetic field. This analysis takes into consideration both Df and Sr, aiming to comprehensively understand the complex interactions within this. The governing PDE are converted into a set of coupled DEs and are solved in a numerical way. Finite difference method is used here. There is a rise in the values of Nu and Sh number by an increment in the value of magnetic parameter.

Niche et al. [11] numerically studied the transient double-diffusive natural convection occurring within a square cavity. In this setup, the erect walls of the enclosure are subjected to heating and cooling, resulting in both solutal and thermal gradients. The two flat walls of the enclosure remain impermeable and adiabatic; while the analysis takes into account the Dufour and Soret effects. The governing equations are solved by SIMPLER algorithm and control volume method. The primary objective of this study is to determine the flow regime in situations where thermal and solutal factors dominate.

Ahmed et al. [12] studied the influence of thermal diffusion and radiation on a transient free convective flow of an IECVF through an infinite upstanding porous plate within a rotating system, where the Hall current is considered. Additionally, this investigation accounts for variations in temperature and concentration at the plate, both of which fluctuate periodically with time. Under the assumption of a non-scattered medium and a non-gray nature of the fluid with emitting-absorbing characteristics, the equations are resolved using analytical methods.

Sarma et al. [13] endeavored to explore the Schmidt number (Sr) in MHD free convective flow through a porous medium. The flow is constrained by an infinitely tall erect porous plate with constant heat flux. Furthermore, a uniform magnetic field is applied perpendicular to the plate.

Hasan and Hossain [14] performed numerical studies of MHD mixed convection flow occurring through a permeable, impulsively stretched erect plate. The investigation takes into account of Sr and Df.

Mondal et al. [15] investigated the characteristics of Prandtl fluid when subjected to the effects of MHD heat and MT. The fluid flow occurs along an exponentially inclined vertical plate, and the analysis of the flow model employs boundary layer approximations.

Sheri and Modugula [16] aimed to analyze the combined heat and MT effects within an unsteady MHD flow scenario. The flow occurs over an IPIPM. In this analysis, the presence of Sr and Df as well as chemical reactions are considered.

Studying the influence of chemical reactions, heat sources and sinks, and the Joule effect on HT and MT mixed convection flow along an infinitely tall erect plate in magnetohydrodynamics (MHD) is a major research focus. Additionally, the study includes analyses of viscous dissipation and ohmic heating. This study was done by Ananthi and Sujatha [17].

Chamka [18] investigated the problem of 2D, unsteady, laminar boundary layer flow by examining an IECVF with heat absorption properties. The flow takes place along a semi-infinite vertical permeable moving plate. The study also accounts for the existence of a uniform transverse magnetic field and buoyancy effects due to thermal and concentration gradients. Rama Prasad et al. [19] investigated the effects of an aligned magnetic field and the Kuvshinski fluid model on unsteady MHD free convective flow over a moving inclined plate. The study also takes into account thermal radiation,

radiation absorption with chemical effects, and mass blowing or suction.

In the current work, the emphasis is given to Soret effect. To analyze the impact of Sr and radiation parameter on the MHD free convective flow of an IECVF over a slanting plate immersed in a permeable substance is the prime aim of this paper.

2. MATHEMATICAL FORMULATION

The flow of an incompressible viscous fluid in which velocity varies with respect to time, through a limitless leaning plate with fluctuating heat and MT is considered in the study. In Figure 1, the 'x'-axis is oriented along the plate at an inclination angle α to the vertical, while the 'y'-axis is perpendicular to the plate. The fluid being analyzed is assumed to be electrically conductive and fills the permeable half-space where y > 0. Along the 'y' direction, a strong magnetic field B_0 is applied uniformly, crosswise to the plate. The generated magnetic field caused by movement of fluid is supposed to be modest and ignored because of the powerful enforced magnetic field. For partly ionized fluids and metallic liquids, Cramer and Pai [20] contend that supposition is physically supported by the low magnetic Reynolds number of these fluids. The electric field resulting from polarization is nullified because there is neither an applied voltage nor a polarization voltage imposed on the flow field. In the beginning, the plate and the fluid are idle with steady temperature '$T\infty$' and steady concentration '$C\ \infty$'. The plate is prone to quick jerk at time $t' > 0$ and the movement is induced in opposition to the gravity along the direction of the flow with constant velocity u_0. With respect to time the concentration and temperature of the plate are lifted linearly. It is noted that the viscous dissipation is minimal, and the fluid is a dense gray absorbing-emitting radiation medium rather than a scattering medium. All physical quantities depend on 'y' and 't', as the plate extends infinitely in the (x, z) plane.

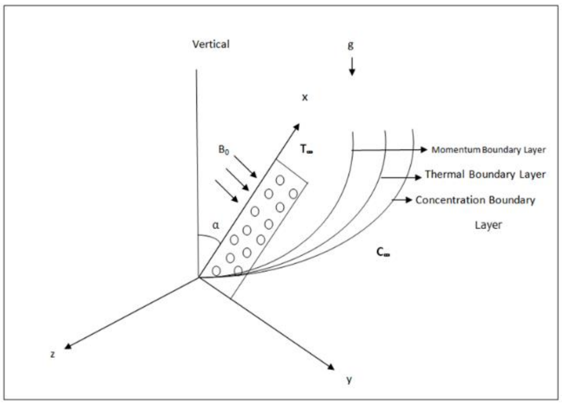

Figure 1. Geometry and co-ordinate system of the problem

3. GEOMETRY OF THE PROBLEM

Boussinesq's approximation is a simplifying assumption utilized in fluid dynamics, specifically in the examination of buoyancy-driven flows. It is typically applied in scenarios where density fluctuations resulting from temperature differences are relatively minor. The buoyancy term emerges from density differences induced by temperature variations, giving rise to the inherent buoyant forces observed in fluids.

By the presumptions mentioned earlier and Boussinesq's approximation, the governing equations are mentioned as follows:

Equation of Conservation of Linear Momentum is represented in Eq. (1).

Equation of Energy is presented in Eq. (2).

Equation of Mass transfer is presented in Eq. (3).

$$\frac{\partial u'}{\partial t'} = v\frac{\partial^2 u'}{\partial y'^2} + g\beta\left(T - T_\infty\right)\cos\alpha + g\beta_c\left(C - C_\infty\right)\cos\alpha - \frac{\sigma B_0^{\ 2}}{\rho}u' - \frac{v}{K^*}u' \tag{1}$$

$$\frac{\partial T}{\partial t'} = \frac{K}{\rho C_p}\frac{\partial^2 T}{\partial y'^2} - \frac{1}{\rho C_p}\frac{\partial q'}{\partial y'} \tag{2}$$

$$\frac{\partial C}{\partial t'} = D_M\frac{\partial^2 C}{\partial y'^2} - K_1\left(C - C_\infty\right) + D_1\frac{\partial^2 T}{\partial y'^2} \tag{3}$$

The conditions for the boundary are:

$$\begin{aligned} & t' \le 0: u' = 0, T = T_\infty, \\ & C = C_\infty \text{ for all } y' > 0; t' > 0: u' = U_0, \\ & T = T_\infty + \left(T_w - T_\infty\right)At', \\ & C = C_\infty + \left(C_w - C_\infty\right)At', \text{ at } y' = 0; u' = 0, \\ & T \to T_\infty, C \to C_\infty \text{ as } y' \to \infty \end{aligned} \tag{4}$$

where, $A = \frac{u_0^{\ 2}}{v}$. The constant At', implies the gradual change in temperature over time. It is influenced by initial temperature difference and the rate of change of temperature. The Rosseland approximation has been accepted for radiative heat flux $q_r{}'$, as follows:

$$q_r' = \frac{-4\sigma^*}{3a}\frac{\partial T^4}{\partial y'} \tag{5}$$

Here'$\sigma *$' is Stefan Boltzmann constant and 'a' is mean absorption coefficient. By Taylor series expansion of T^4about T_∞ and ignoring higher order terms, the following term is obtained:

$$T^4 \approx 4TT_\infty^3 - 3T_\infty^{\ 4} \tag{6}$$

The Eqs. (1)-(3) are normalized by introducing the dimensionless quantities mentioned below:

$$\begin{aligned} & u = \frac{u'}{U_0}, t = \frac{t'U_0^2}{v}, y = \frac{y'U_0}{v}, \theta = \frac{T - T_\infty}{T_w - T_\infty}, \varphi = \frac{C - C_\infty}{C_w - C_\infty}, \\ & Gr = \frac{vg\beta\left(T_w - T_\infty\right)}{U_0^3}, Gm = \frac{vg\beta^*\left(C_w - C_\infty\right)}{U_0^3}, \Pr = \frac{\mu C_p}{K}, \\ & K^* = \frac{a^* U_0^2}{v^2}, Sc = \frac{v}{D_M}, M = \frac{\sigma B_0^{\ 2} v}{\rho U_0^2}, K = \frac{K_1 v}{U_0^{\ 2}}, \\ & N = \frac{16\sigma T_\infty^3}{3Ka^*}, Q = \frac{v^2 Q^1}{KU_0^2}, Sr = \frac{D_1\left(T_w - T_\infty\right)}{v\left(C_w - C_\infty\right)} \end{aligned} \tag{7}$$

Eqs. (1) to (3) in nondimensional form are as follows:

$$\frac{\partial u}{\partial t}=\frac{\partial^2 u}{\partial y^2}+Gr\theta\cos\alpha+Gm\varphi\cos\alpha -\left[M+\frac{1}{K}\right]u \tag{8}$$

$$\frac{\partial\theta}{\partial t}=\left(\frac{1+N}{\Pr}\right)\frac{\partial^2\theta}{\partial y^2} \tag{9}$$

$$\frac{\partial\varphi}{\partial t}=\frac{1}{Sc}\frac{\partial^2\varphi}{\partial y^2}-K\varphi+Sr\frac{\partial^2\theta}{\partial y^2} \tag{10}$$

The boundary conditions (B.C.) corresponding to above equations are:

$$\begin{aligned}&t\le 0: u=0,\theta=0,\varphi=0 \text{ for all } y>0\\ &t>0: u=1,\theta=t,\varphi=t,\\ &\text{at } y=0 \text{ As } y\to\infty: u\to 0,\theta\to 0,\varphi\to 0\end{aligned} \tag{11}$$

4. SOLUTION OF THE PROBLEM

The field of velocity 'u', distribution of temperature 'θ' and concentration profile 'φ' are considered as:

$$\begin{aligned}u&=u_0e^{\omega t}\\ \theta&=\theta_0e^{\omega t}\\ \varphi&=\varphi_0e^{\omega t}\end{aligned} \tag{12}$$

By substituting Eqs. (7) and (12) in Eqs. (8)-(10), the obtained equations are as follows:

$$u_0''-\left(M+\frac{1}{K}+\omega\right)u_0=-BGre^{m_4y}\cos\alpha -Gm\left(Be^{m_6y}\right)\cos\alpha+B_1Gme^{m_4y}\cos\alpha \tag{13}$$

$$\varphi_0''-Sc(\omega+K)\varphi_0=-B_1e^{m_4y} \tag{14}$$

$$\theta_0''-\left(\frac{\Pr}{1+N}\right)\omega\theta_0=0 \tag{15}$$

The B.C.s in correspondence with above equations are:

$$\begin{aligned}&u_0=e^{-\omega t},\theta_0=te^{-\omega t},\varphi_0=te^{-\omega t}\\ &\text{at } y=0u_0\to 0,\theta_0\to 0,\varphi_0\to 0 \text{ as } y\to\infty\end{aligned} \tag{16}$$

The solutions of the Eqs. (13)-(15) obtained by analytical procedure subject to the B.C. (16) are:

$$\theta_0=B_1e^{m_2y} \tag{17}$$

$$\varphi_0=B_2e^{m_4y}-M_1e^{m_2y} \tag{18}$$

$$u_0=B_3e^{m_6y}-G_1e^{m_2y}-G_2e^{m_4y}+G_3e^{m_2y} \tag{19}$$

In consideration of the overhead results, the velocity 'u', temperature 'θ' and concentration 'φ' in the layer of boundary will be presented as:

$$u=\left(B_3e^{m_6y}-G_1e^{m_2y}-G_2e^{m_4y}+G_3e^{m_2y}\right)e^{\omega t} \tag{20}$$

$$\theta=\left(B_1e^{m_2y}\right)e^{\omega t} \tag{21}$$

$$\varphi=\left(B_2e^{m_4y}-M_1e^{m_2y}\right)e^{\omega t} \tag{22}$$

Skin Friction (SF):

The coefficient of SF on the plate in the non-dimensional form is as follows:

$$\begin{aligned}\tau&=\left(\frac{\partial u}{\partial y}\right)_{y=0}\\ \tau&=\left(\left(B_3m_6\right)-\left(G_1m_2\right)-\left(G_2m_4\right)+\left(G_3m_2\right)\right)e^{\omega t}\end{aligned} \tag{23}$$

Nusselt Number (Nu):

The coefficient of rate of HT - Nusselt number is denoted as:

$$\begin{aligned}Nu&=-\left(\frac{\partial\theta}{\partial y}\right)_{y=0}\\ Nu&=-\left(B_1m_2e^{\omega t}\right)\end{aligned} \tag{24}$$

Sherwood Number (Sh):

The coefficient of rate of MT - Sherwood number is specified as:

$$\begin{aligned}Sh&=-\left(\frac{\partial\varphi}{\partial y}\right)_{y=0}\\ Sh&=-\left(\left(B_2m_4\right)-\left(M_1m_2\right)\right)e^{\omega t}\end{aligned} \tag{25}$$

5. RESULTS AND DISCUSSION

The impact of different parameters like radiation parameter (N), Hartmann number (M), Schmidt number (Sc), thermal Grashof number (Gr), mass Grashof number (Gm), Prandtl number (Pr), permeability parameter (K), Soret number (Sr) on velocity profile (VP), temperature profile (TP), concentration profile (CP), SF, Nu and Sh are studied in this paper by maintaining other parameters as fixed.

Applying magnetic filed in perpendicular manner along the flow of the fluid will lower the velocity, hence VP drops with gain in the value of M, which is implied in Figure 2.

Figure 3 exhibits that velocity is higher for mercury (Pr = 0.025) when compared to electrolytic solution (Pr = 1).

Viscosity of the fluid boosts up if the value of Prandtl number increases. As viscosity rises, the heightened internal friction opposing fluid motion becomes more evident. Elevated viscosity hinders the smooth flow of the fluid. This results in a decrease in velocity. Hence the rise in the value of Pr decreases the VP.

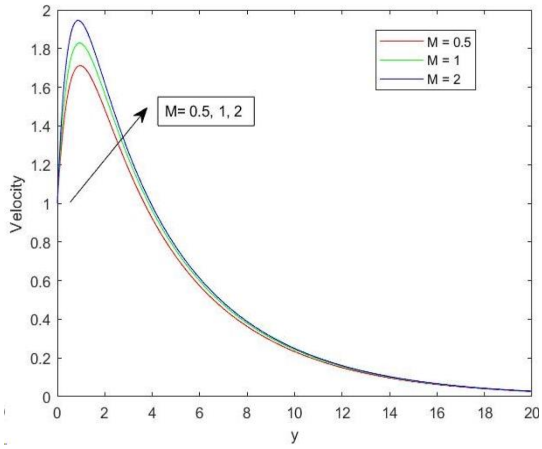

Figure 2. Effect of M on VP

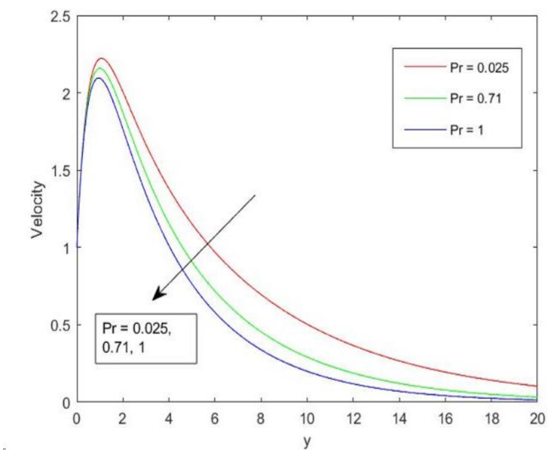

Figure 3. Effect of Pr on VP

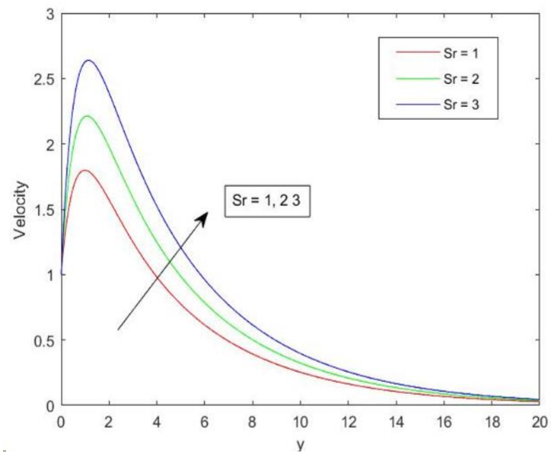

Figure 4. Effect of Soret on VP

The Soret number is a computation of the ratio between thermal diffusion and mass diffusion within a fluid. As Soret effect rises, it signifies an increased impact on thermal gradients and this can lead to enhanced buoyancy-driven flows and convection motions resulting in an increment in velocity. Thus, Figure 4 shows, the increase in Sr value, rises the fluid velocity. As Sc increases, momentum diffusivity improves. Hence from Figure 5 it is noted that, VP rises with hike in the value of Sc. Radiation creates a considerable growth in thermal condition of the temperature of the fluid that leads t more fluid to flow in the boundary layer because of buoyancy effect. Hence velocity in the fluid rises. Thus a surge in N effects to rise in velocity, which is depicted in Figure 6. Figure 7 shows, as time boosts up, the velocity of the flow grows.

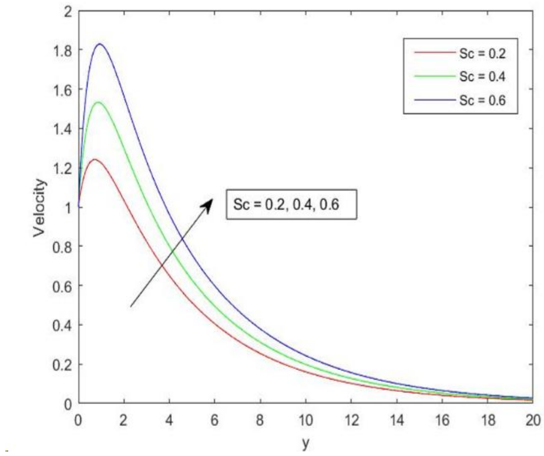

Figure 5. Effect of Sc on VP

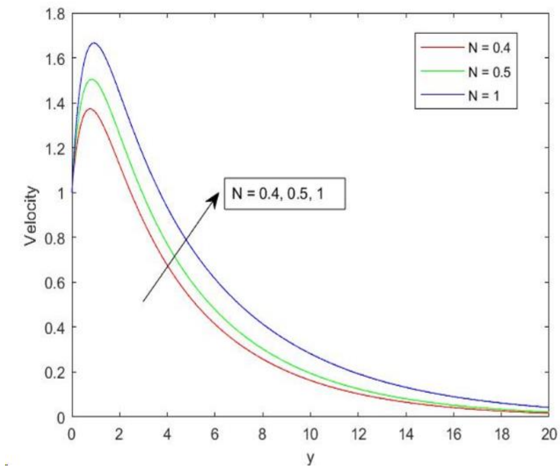

Figure 6. Effect of N on VP

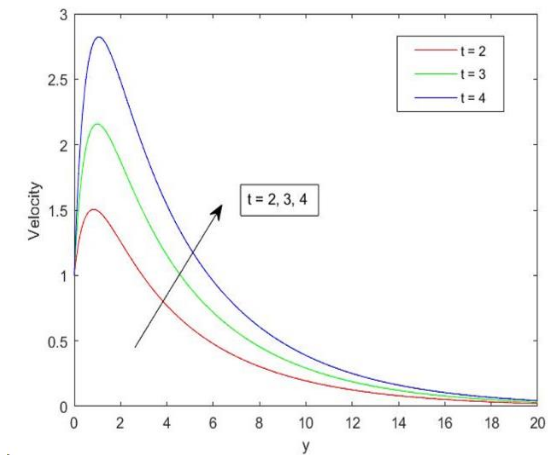

Figure 7. Effect of time on VP

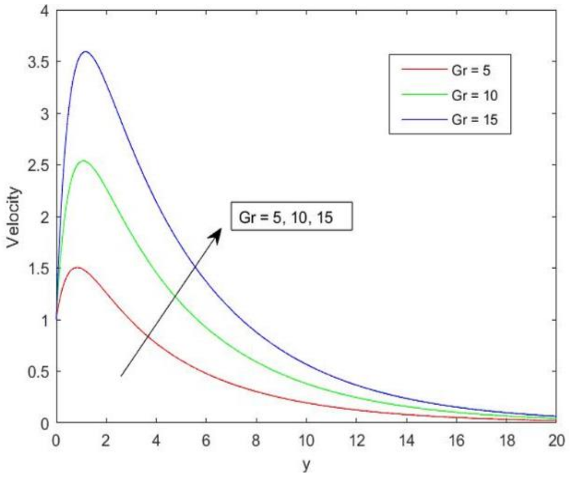

Figure 8. Effect of Gr on VP

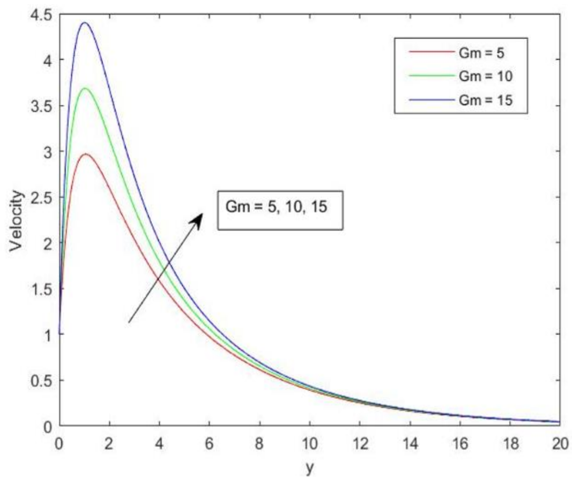

Figure 9. Effect of Gm on VP

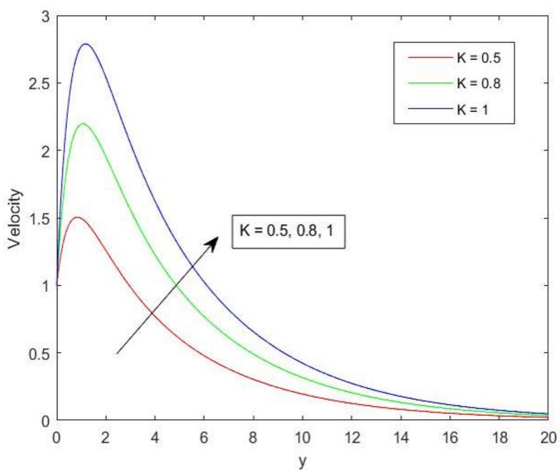

Figure 10. Effect of K on VP

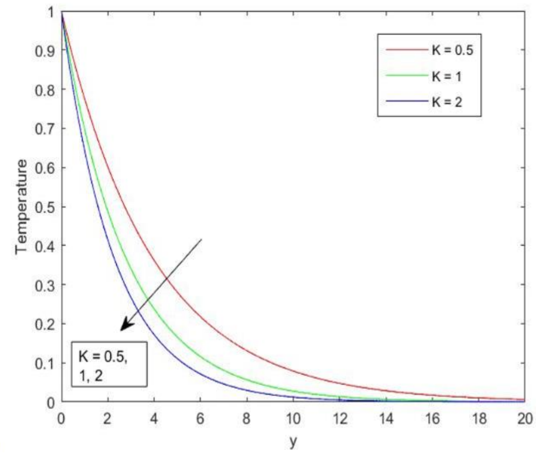

Figure 11. Effect of K on TP

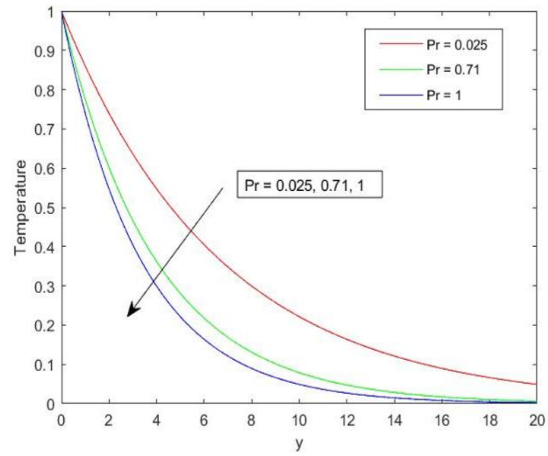

Figure 12. Effect of Pr on TP

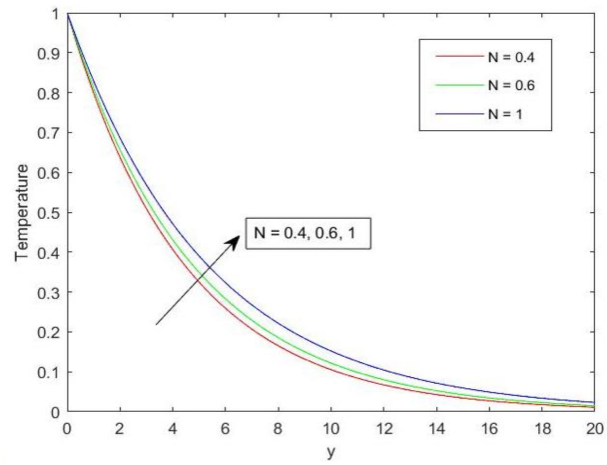

Figure 13. Effect of N on TP

Gr provides insight into the relationship between thermal buoyancy power and the velocity energy due to viscosity in the boundary layer, while Gm explains the ratio of the concentration buoyancy impact to the viscous velocity stamina. Hence VP improves due to the increase of thermal and species buoyancy forces, that is expressed in Figure 8 and Figure 9. Figure 10 implies, when the porosity of the fluid rises, fluid gets further space to flow and hence the velocity rises.

Figure 11 shows, the improvement in the value of K, declines TP, due to distinct interactions between the fluid and the porous medium. Figure 12 depicts that TP diminishes with upsurge of Pr value. The temperature in the boundary layer declines rapidly for greater value of Pr, since the width of the boundary layer diminishes with a rise in Pr value. N defines the specific contribution of heat conduction to thermal radiation transfer. Hence Figure 13 shows the raise in the N value leads to development in TP within the boundary layer. Figure 14 depicts that TP rises with hike in the value of time.

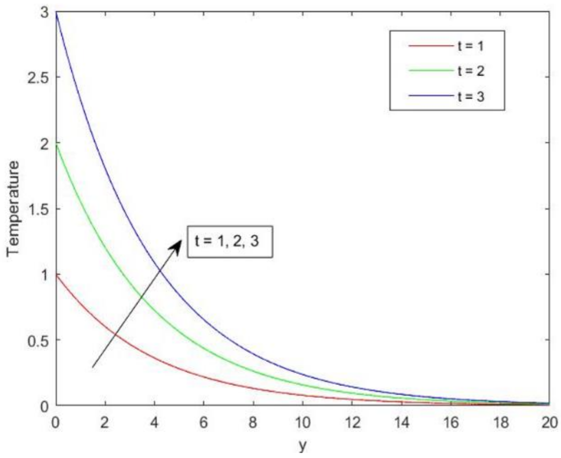

Figure 14. Effect of time on TP

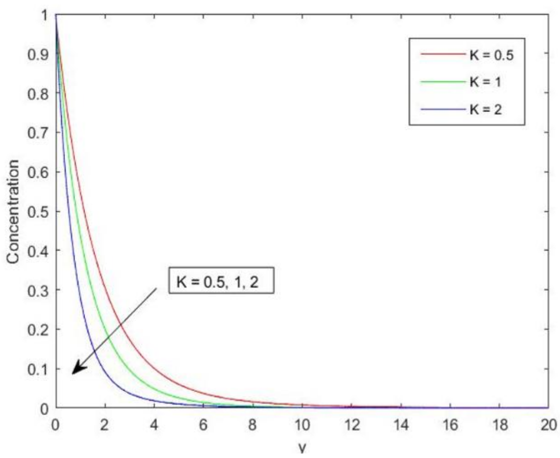

Figure 15. Effect of K on CP

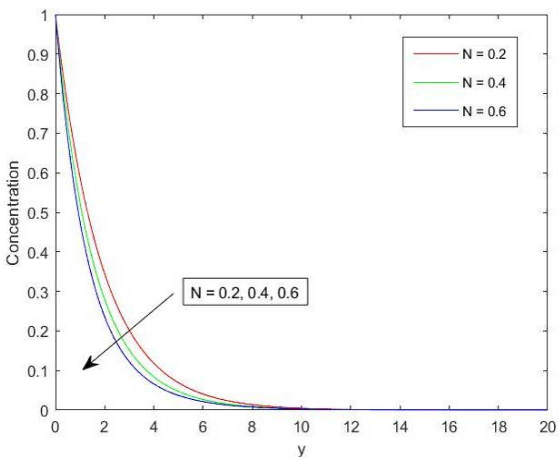

Figure 16. Effect of N on CP

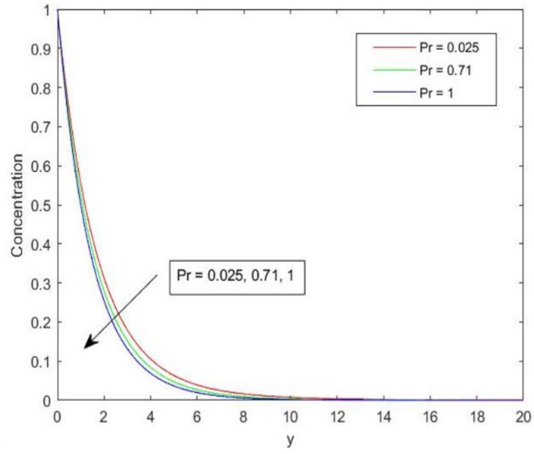

Figure 17. Effect of Pr on CP

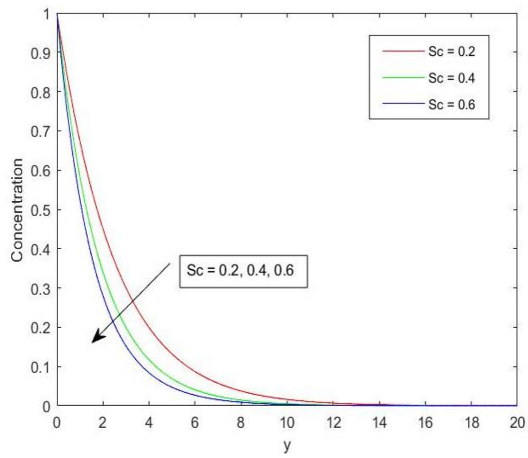

Figure 18. Effect of Sc on CP

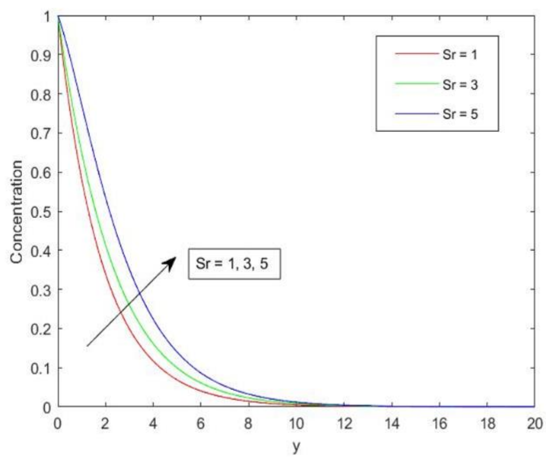

Figure 19. Effect of Sr on CP

Increased permeability enables a greater volume of fluid to pass through the porous medium, leading to a more efficient dispersion of solutes. This enhanced fluid flow facilitates the reduction of solute concentration, resulting in reduction of CP, with increase in K, which is shown in Figure 15. Radiative HT usually results in fluid cooling, consequently impacting the distribution of concentration. The unique interactions between radiation and the fluid induce alterations in temperature gradients, affecting the mass transport of fluid components and leading to a decline in CP and is depicted in Figure 16.

The increment in the value of Pr signifies a prevalence of thermal diffusivity over momentum diffusivity, affecting temperature gradients and subsequently influencing mass transport, resulting in a reduction in CP, which is shown in Figure 17.

Figure 18 shows that the increment in Sc implies reduction of molecular diffusivity that lead to contraction of concentration boundary layer. Thus CP falls off for boost in Sc value. The rise in Sr intensifies the influence of thermal diffusion on concentration distribution, leading to a rise in the fluid's concentration. Hence as Sr raise, CP boosts up, which is presented in Figure 19.

Figures 20 and 21 convey that SF decreases with gain in N and Sr. The elevation in the value of N facilitates radiative cooling, leading to a decline in the temperature and viscosity of the fluid near the surface. This results in a decrease in SF value, and is depicted in Figure 20.

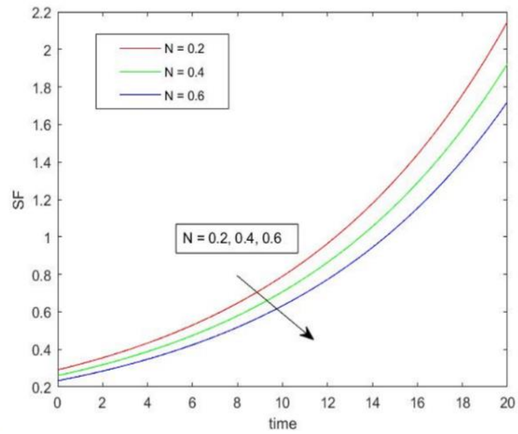

Figure 20. Effect of N on SF

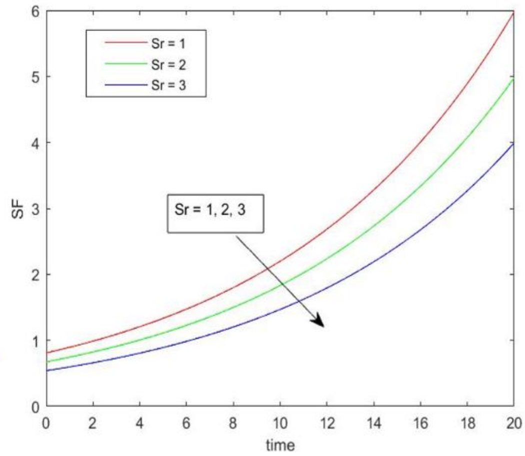

Figure 21. Effect of Sr on SF

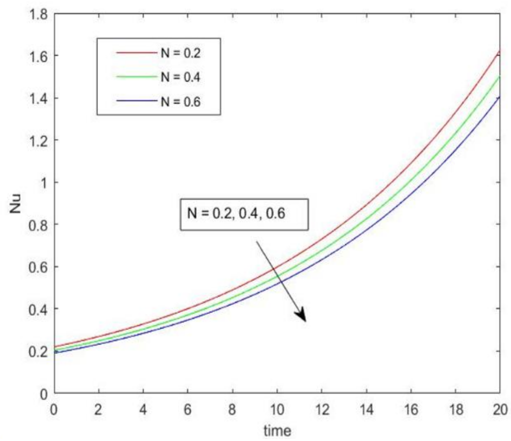

Figure 22. Effect of N on Nu

The hike in the value of Sr modifies concentration distribution due to thermal gradients, resulting in changes in viscosity of the fluid and consequent reduction in SF and is shown in Figure 21.

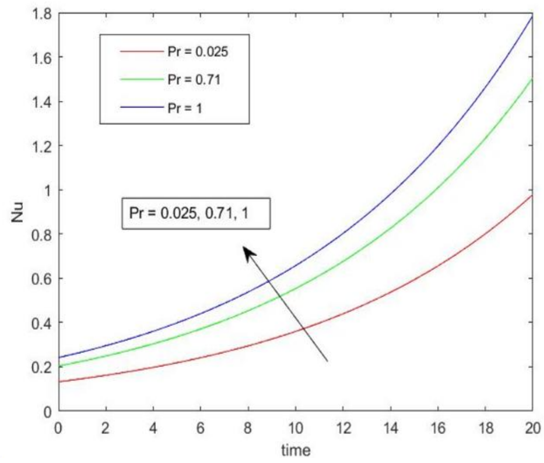

Figure 23. Effect of Pr on Nu

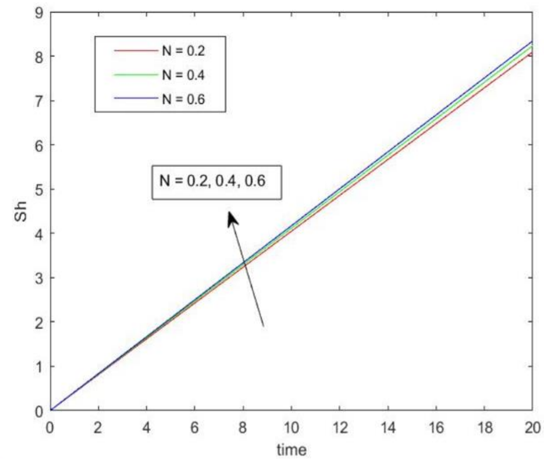

Figure 24. Effect of N on Sh

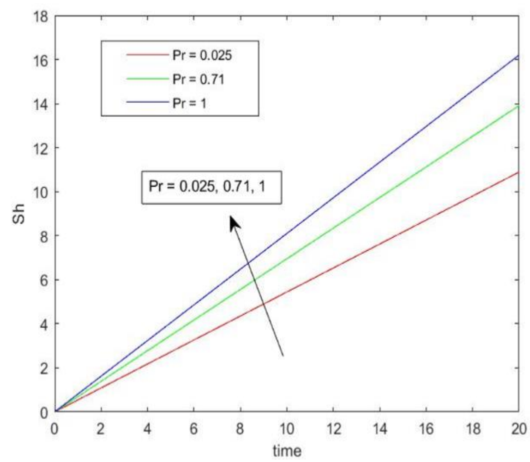

Figure 25. Effect of Pron Sh

Radiation, as a mechanism of heat transfer, may exhibit lower efficiency in enhancing heat transfer compared to convection. At that time as the value of N increases, Nu decreases and is shown in Figure 22.

An increase in Pr indicates that the fluid possesses a lower thermal diffusivity relative to its momentum diffusivity. It results in a thicker thermal boundary layer (BL). This thicker BL facilitates more efficient heat transfer. Hence as Pr rises up, the value of Nu hikes as depicted in Figure 23.

When radiation leads to the augmentation of the convective mass transfer coefficient or induces alterations in the temperature distribution that favour mass transfer, then a rise in N results in increment of Sh value as exposed in Figure 24.

A hike in Pr implies that the fluid exhibits a reduced capability for conducting heat compared to transferring momentum. This contributes to the development of a thicker thermal BL relative to the momentum boundary layer. The increased BL thickness serves to improve mass transfer resulting in an increased Sh. This is exhibited in Figure 25.

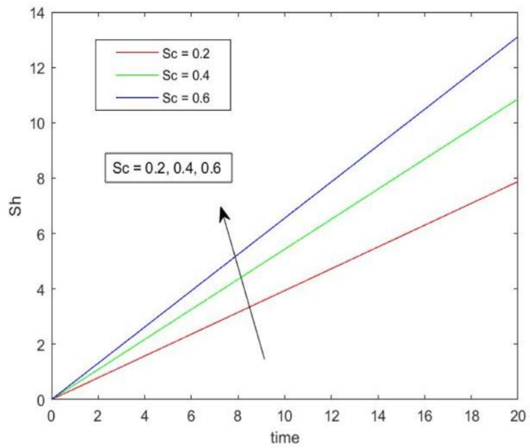

Figure 26. Effect of Scon Sh

An increment in Sc implies that the fluid has reduced efficiency in transporting mass in comparison with momentum. This results in a thinner mass BL relative to the momentum BL. The consequential reduction in mass BL thickness contributes to an improved mass transfer process, leading to a higher Sh, which is shown in Figure 26.

Improved permeability in porous media facilitates increased fluid flow and elevated interaction between the fluid and the medium. This interaction contributes to higher mass transfer rates, resulting in a hike in Sh value and is depicted in Figure 27.

To quantify the impacts of different parameters, the numerical calculations of SF, Nu and Sh at the boundary surface are worked out and expressed in Table 1 and Table 2.

The mentioned parameter values are considered for calculations unless specified otherwise in the table: Gr = 5, Gm = 3, Sc = 0.60, Sr = 1, N = 0.5, α = 60, ω = 0.1, K = 0.5, Pr = 0.71, M = 3, t = 5.

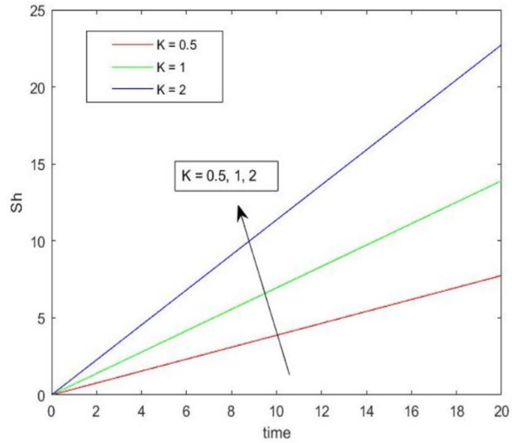

Figure 27. Effect of Kon Sh

Table 1. Numerical results of SF, Nu and Sh for distinct values of parameters

	Gr		**Gm**			**Sc**	
		5	**10**	**15**	**0.20**	**0.40**	**0.60**
SF	5	0.5395	-0.7836	-2.1067	0.9977	1.0396	1.0688
Nu	5	0.3246	0.3246	0.3246	0.3246	0.3246	0.3246
Sh	5	2.8263	2.8263	2.8263	1.6481	2.3157	2.8263
	Sr		**N**			**α**	
		0.4	**0.5**	**1**	**20**	**30**	**40**
SF	1	1.0728	1.0688	1.0532	1.4917	2.6594	6.4372
Nu	1	0.3360	0.3246	0.2811	0.3246	0.3246	0.3246
Sh	1	2.8156	2.8263	2.8649	2.8263	2.8263	2.8263
	ω		**Pr**			**M**	
		1	**2**	**3**	**0**	**0.5**	**1**
SF	0.1	1.0896	1.1398	1.1745	-1.1906	-0.6631	-0.2232
Nu	0.1	0.3852	0.5447	0.6672	0.3246	0.3246	0.3246
Sh	0.1	2.7670	2.5856	2.4271	2.8263	2.8263	2.8263

Table 2. SF, Nu and Sh results for various values of parameters

	Gm		**Gr**			**Sr**	
		5	**10**	**15**	**1**	**2**	**3**
SF	3	1.0688	-0.4376	-1.9439	1.0688	1.0578	1.0468
Nu	3	0.3246	0.3246	0.3246	0.3246	0.3246	0.3246
Sh	3	2.8263	2.8263	2.8263	2.8263	2.6526	2.4789
	Pr		**ω**			**t**	
		0.1	**0.2**	**0.3**	**1**	**2**	**3**
SF	0.71	1.0688	1.7590	2.8329	0.7164	0.7918	0.8750
Nu	0.71	0.3246	0.6848	1.2511	0.2176	0.2404	0.2657
Sh	0.71	2.8263	2.9432	3.0658	0.5653	1.1305	1.6958
	t		**K**			**Sr**	
		0.5	**1**	**1.5**	**1**	**2**	**3**
SF	5	1.0688	0.5591	0.3927	1.0688	1.0578	1.0468
Nu	5	0.3246	0.3246	0.3246	0.3246	0.3246	0.3246
Sh	5	2.8263	3.9242	4.7804	2.8263	2.6526	2.4789

6. CONCLUSION

This study analyzes the MHD mixed convective flow of fluid along a continuously moving boundless inclined permeable plate under the impact of crosswise applied magnetic field. The investigation considers the presence of Schmidt number, radiation parameter, thermal Grashof number, Soret number, mass Grashof number, and Prandtl number. The governing equations in dimensionless form are solved using the perturbation technique, and the findings are presented in the form of graphs and tables. The results can be condensed as follows:

a) VP declines with M and Pr. It is because of the transverse application of M and hike in viscosity of the fluid.
b) Hike in Sr results in increased buoyancy driven flows and convection motion leading to increased VP.
c) Momentum diffusivity increases as Sc hikes up resulting in an improved VP.
d) Increased radiation creates high fluid flow due to buoyancy effect in the BL, resulting in hike of VP.
e) As time increases, VP boosts up.
f) Hike in Gr and Gm leads to increment in the thermal and species buoyancy forces resulting in hike in VP.
g) Higher permeability increases fluid flow leading to increment of VP.
h) With the hike in K, TP drops off.
i) The hike in Pr value leads to fall of temperature in the BL resulting in the declination of TP.
j) TP increases with a rise in the values of N and time.
k) An increment in the value of K results in hike in fluid flow resulting in reduction in concentration. Hence CP drops off with the boost in K.
l) An upsurge in the value of N and Pr affects the mass transport of fluid components resulting CP to fall off.
m) A boost up in the value of Sc results in contraction of concentration BL leading to decline in the value of CP.
n) A rise in fluid concentration occurs with an increment in Sr, resulting in the development of CP.
o) An elevation in the value of N and Sr leads to decline in viscosity of the fluid resulting in reduction of SF.
p) Shootup in the value of N lead to lesser efficiency in amplifying HT causing Nu to decline.
q) An increment in Pr results in the formation of thickened thermal BL and as a result Nu boosts up.
r) A hike in the value of N favours mass transfer resulting Sh to raise up.
s) An increment in Pr and Sc paves way to thicker thermal BL leading to increased mass transfer. As a result, Sh rises up.
t) Increased mass transfer rate occurs due to rise in permeability value leading to a hike in Sh.

7. APPLICATION

Soret effect has many applications in practical life. Various particles move in different speed by the strength of temperature gradient. Hence different types of particles are detached from one another if they are blended together by applying Soret force. In the creation of optical fibre through vacuum coating processes, Soret effect is used. In the realm of optical fiber manufacturing, the Soret effect finds valuable application in precisely controlling the deposition and alignment of materials along the inner surface of a hollow preform. This preform serves as the precursor to the optical fiber. The Soret effect induces the movement of particles or molecules of the cladding material, (made of glass or dielectric materials) causing them to migrate from regions of higher temperature to lower temperature within the preform. This migration aids in the deposition and alignment of the cladding material along the preform' s inner surface. As a result, this technique plays a pivotal role in ensuring that the core and cladding layers attain the exact dimensions and optical properties necessary for efficient signal transmission.

By tracking down aptamer binding, Soret effect aids in drug discovery process. The Soret effect, also referred to as thermophoresis, holds significant potential in assisting drug discovery processes, particularly in the realm of aptamer binding studies. Aptamers, which are short, single-stranded DNA or RNA molecules, possess the remarkable ability to specifically bind to target molecules, encompassing a wide range of biomolecules and potential drug candidates. In the pursuit of drug discovery, aptamers serve as invaluable tools for targeting specific molecules of interest, such as proteins, nucleic acids, or small molecules. A fundamental aspect of this endeavor involves a deep understanding of the binding affinity and kinetics governing these interactions. In this context, the Soret effect emerges as a valuable tool for probing these binding interactions. By leveraging the Soret effect as a means to investigate thermophoretic motion, researchers can gain crucial insights into the binding interactions between aptamers and their target molecules. This approach contributes significantly to the development of novel therapeutic agents.
The consideration of the Sr effect in MHD flows over an IPIPM expands the scope of application, especially in processes where both thermal and mass transport is pivotal.

(i) Biomedical Engineering: The mentioned study has potential applications in drug delivery systems, where heat transfer and controlled fluid flow are essential. The Sr effect can influence the concentration distribution of drug particles within the fluid.
(ii) Heat Exchangers: The considered concept becomes crucial in applications demanding precise temperature and concentration control, as in chemical processing industries.
(iii) Environmental Engineering: For simulating contaminant transport in porous media, the prescribed concept of the paper is applied. Grasping the impact of temperature gradients on concentration gradients is essential for accurate modelling and effective management of ground water contamination.

REFERENCES

[1] Islam, S.H., Begum, P., Sarma, D. (2021). Dufour effect on MHD free convection heat and mass transfer effects flow over an inclined plate embedded in a porous medium. Journal of Scientific Research, 13(1): 111-123. http://doi.org/10.3329/jsr.v13i1.48174

[2] Taid, B.K., Ahmed, N. (2022). MHD free convection flow across an inclined porous plate in the presence of heat source, Soret effect, and chemical reaction affected by viscous dissipation Ohmic heating. Biointerface Research in Applied Chemistry, 12(5): 6280-6296. https://doi.org/10.33263/BRIAC125.62806296

[3] Sarma, D., Pandit, K.K. (2018). Effects of hall current,

rotation and Soret effects on MHD free convection heat and mass transfer flow past an accelerated vertical plate through a porous medium. Ain Shams Engineering Journal, 9(4): 631-646. https://doi.org/10.1016/j.asej.2016.03.005
[4] Falodun, B.O., Ayoade, A.A., Odetunde, O. (2023). Positive and negative Soret and dufour mechanism on unsteady heat and mass transfer flow in the presence of viscous dissipation, thermal and mass buoyancy. Australian Journal of Mechanical Engineering, 21(3): 965-978. https://doi.org/10.1080/14484846.2021.1938950
[5] Ibrahim, S.M., Suneetha, K., Reddy, G.V. (2019). A study on free convective heat and mass transfer flow through a highly porous medium with radiation, chemical reaction and Soret effects. Journal of Computational & Applied Research in Mechanical Engineering (JCARME), 8(2): 121-132. https://doi.org/10.22061/jcarme.2017.2018.1175
[6] Dhanalakshmi, M., Jyothi, V., Jayarami Reddy, K. (2019). Soret and Dufour effects on MHD convective flow past a vertical plate through porous medium. Journal of Physics: Conference Series, 1344(1): 012008. https://doi.org/10.1088/1742-6596/1344/1/012008
[7] Alam, M.S., Rahman, M.M. (2005). Dufour and Soret effects on MHD free convective heat and mass transfer flow past a vertical porous flat plate embedded in a porous medium. Journal of Naval Architecture and Marine Engineering, 2(1): 55-65. https://doi.org/10.3329/jname.v2i1.2030
[8] Reddy, N.A., Varma, S.V.K., Raju, M.C., Reddy, N.A. (2009). Thermo diffusion and chemical effects with simultaneous thermal and mass diffusion in MHD mixed convection flow with ohmic heating. Journal of Naval Architecture and Marine Engineering, 6(2): 84-93. https://doi.org/10.3329/jname.v6i.3761
[9] Jha, B.K., Ajibade, A.O. (2010). Free convection heat and mass transfer flow in a vertical channel with the Dufour effect. In Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 224(2): 91-101. https://doi.org/10.1243/09544089JPME318
[10] Postelnicu, A. (2004). Influence of a magnetic field on heat and mass transfer by natural convection from vertical surfaces in porous media considering Soret and Dufour effects. International Journal of Heat and Mass Transfer, 47(6-7): 1467-1472.https://doi.org/10.1016/j.ijheatmasstransfer.2003.09.017
[11] Niche, H.B., Bouabdallah, S., Ghernaout, B., Teggar, M. (2016). Unsteady double diffusive natural convection with Dufour and Soret effects. International Journal of Heat and Technology, 34(1): 39-46.https://doi.org/10.18280/ijht.340106
[12] Ahmed, N., Sarma, K., Deka, H. (2013). Soret and radiation effects on a transient mhd mass transfer flow past an infinite vertical porous plate in a rotating system with hall current. International Journal of Heat and Technology, 31(1): 109-116.https://doi.org/10.18280/ijht.310114
[13] Sarma, D., Pandit, K.K., Ahmed, N. (2014). Soret effects in a mhd free convective flow through a porous medium bounded by an infinite vertical porous plate with constant heat flux. International Journal of Heat and Technology, 32(1-2): 65-70. https://doi.org/10.18280/ijht.320110
[14] Hasan, M.M., Hossain, M.T. (2019). Soret and Dufour effects on the boundary layer magneto-fluid flow past an infinite vertical porous plate. Modelling, Measurement and Control B, 88(2-4): 125-133. https://doi.org/10.18280/mmc_b.882-411
[15] Mondal, M., Biswas, R., Hasan, M., Bulbul MdF, A.S. (2019). Soret effect on MHD unsteady heat and mass transfer of Prandtl fluid flow past an exponentially vertical plate. Model Meas Control B, 88(2-4): 57-63. https://doi.org/10.18280/mmc_b.882-408
[16] Sheri, S.R., Modugula, P. (2017). Heat and mass transfer effects on unsteady MHD flow over an IPIPM with Soret-dufour and chemical reaction. International Journal of Applied and Computational Mathematics, 3: 1289-1306. https://doi.org/10.1007/s40819-016-0177-4
[17] Ananthi, L., Sujatha, E., (2023). MHD heat and mass transfer steady flow of a convective fluid through a porous plate in the presence of multiple parameters along with dufour effect. International Journal of Heat and Technology, 41(1): 208-212. https://doi.org/10.18280/ijht.410122
[18] Chamka, A.J. (2004). Unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption. International Journal of Engineering Science, 42: 217-230. https://doi.org/10.1016/S0020-7225(03)00285-4
[19] Rama Prasad, J.L., Balamurugan, K.S., Varma, S.V.K., (2020). Aligned magnetic field effect on unsteady MHD double diffusive free convection flow of Kuvshinkski fluid past an inclined moving porous plate. Advances in Fluid Dynamics: Selected Proceedings of ICAFD 2018, Springer Singapore, pp. 255-262. https://doi.org/10.1007/978-981-15-4308-1_20
[20] Cramer, K.R., Pai, S.I. (1973). Magnetofluid Dynamics for Engineers and Applied Physicists. McGraw-Hill, New York.

NOMENCLATURE

u'	Component of velocity along the 'x – axis'
t'	time
t	Dimensionless time
B_0	Magnetic field strength
C_p	Specific heat at constant pressure
D_M	Chemical molecular diffusivity
N	Radiation parameter
Gm	Mass Grashof number
Gr	Thermal Grashof number
K	Permeability parameter
$K*$	Permeability of the porous medium
K_1	Chemical reaction parameter
D_1	Coefficient of thermal diffusion
M	Hartmann Number
Nu	Local Nusselt number along the heat source
Pr	Prandtl number
Sc	Schmidt number
Sr	Soret number
g	Acceleration due to gravity
ν	Kinematic viscosity
T	Fluid temperature
C	Fluid concentration

Greek symbols

β	Thermal expansion coefficient
β_c	Solute expansion coefficient
θ	Dimensionless fluid temperature
ϕ	Dimensionless species concentration of the fluid.
ρ	Fluid density
σ	Electrical conductivity
μ	Dynamic viscosity

Subscripts

T_w	Temperature of the stationary plate
T_∞	Temperature of the free flowing fluid
C_w	Concentration of the stationary plate
C_∞	Concentration of the free flowing fluid