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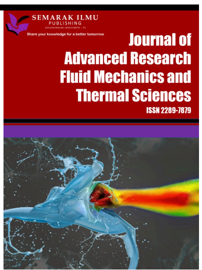

Impact of Hall and Dufour Effects on Magnetohydrodynamic Flow Along a Vertically Accelerated Parabolic Plate with Uniform Temperature and Mass Diffusion Under Rotational Influence

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ABSTRACT

This study presents a numerical investigation into the Hall and Dufour effects on a parabolic accelerated vertical plate under unsteady magnetohydrodynamic (MHD) flow conditions, considering an initial velocity profile, constant temperature, and mass diffusion in a rotating fluid. The study focuses on electrically conducting, incompressible viscous fluids that do not scatter in any medium. It also evaluates heat transfer from the plate and accumulation levels in the surrounding region. The governing equations were solved using the Inverse Laplace Transform method. The analysis explores the influence of two key flow parameters—rotation and diffusion—on accumulation, temperature, and velocity of the vertical plate. Simulations were conducted using MATLAB R2020a. The results indicate that increasing velocity enhances physical dimension metrics such as the Dufour number (Df), Prandtl number (Pr), and Thermal Grashof number (Gr). Conversely, an increase in the Schmidt number (Sc), Mass Grashof number (Gm), and Hall parameter (m) leads to a reduction in velocity.

1. Introduction

Considering the value of heat and mass transmission to everyday existence, numerous scientists have been researching these topics for a very long time. MHD, the generation of electricity, various processes, and geophysical study. In several real-world circumstances, a magnetic field in conductive fluid is particularly significant. In many applications, magnetic fields are unavoidable, and their impacts are critical to comprehending as well as optimizing a range of industrial processes along with natural phenomena, including the production line's use of polymer materials. In an unsteady flow scenario, Kavitha *et al.,* [1] examined the vertically infinite plate's motion and behavior with a parabolic initial velocity profile, accounting for a variety of factors like chemical reaction, rotation, as well as the Dufour effect Aruna *et al.,* [2] examined effects of the Hall effect. The flow's behavior has been examined by them while taking temperature changes, accumulation diffusion, and thermal

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radiation into consideration. For solving the ascendant mathematical statement, Lakshmikaanth *et al.,* [3] utilized inverse Laplace transform method to examine “Hall current, heat source with the radiation, incompressible fluid with heat, chemical reaction of first order viscous fluid flow, along with mass transfer past an accelerated isothermal vertical” plate.

Selvaraj *et al.,* [4] studies indicate that a decline in Sc outcomes in a rise in concentration. As this study considers heat and mass transmission phenomena, the Dufour effect as well as MHD must be considered. Non-dimensional administrative condition is emphasized through the utilization of Laplace transform techniques. Selvaraj and Jothi [5] investigated fluid flow by a porous material past exponentially accelerating vertical plate with exponentially varying temperatures along with mass diffusion with of impact of heat sources on MHD, radiation absorption, their results show that velocity increases when thermal gradient number Gr and the plate's expansion time t increase, but it also increases when the permeable medium's absorptivity increases and the presence of a hypnotic parameter reduces, according to research.

The most recent paper, by Radha *et al.,* [6], examines free convection MHD flow of the viscous, electrically conducted, incompressible, chemically reactive, along with Casson fluid past a parabolically accelerated vertical plate in addition to HMT (heat and mass transfer”) in incidence of the thermal radiation. Inverse Laplace approach has been utilized for solving dimensionless equations. In addition to changing viscosity and nanoparticle aggregation, Rafique *et al.,* [7] studied impact of heat radiation on unsteady bidirectional rotating stagnation point flow of the nanofluid. The imposed hypotheses will guide the modelling of governing equations. A similarity transformation can be utilized to reduce a large collection “of nonlinear partial differential equations to a smaller set of ordinary differential equations. Equations may be resolved more easily because of this simplification. The procedure will then be used to solve simplified sets of the equations numerically. Runge-Kutta (RK-IV) as well as shooting approach has been utilized to obtain numerical outcomes.

An unsteady convection flow of a viscous, incompressible, as well as electrically conducting flow through a vertical plate” influenced by uniform mass diffusion applied transversely was investigated by A. Neel Armstrong *et al.,* [8] to determine the influence of rotation and medium porosity on the HMT. The Laplace-transform application is employed during this research to resolve governing equations. Muthucumaraswamy *et al.,* [9] investigated the mass transfer effects on an accelerated vertical plate immersed in a rotating fluid in the presence of a first-order chemical reaction. Their work provided valuable insights into how rotation and chemical kinetics influence concentration and velocity profiles. The analytical solutions derived therein revealed the significant coupling between Coriolis effects and reactive mass diffusion. They examined how flow behaved while taking thermal radiation, accumulation diffusion, and temperature changes into account. The impact of rotation on the unsteady flow of electrically conducting along with incompressible fluid past a uniformly accelerated infinite isothermal vertical plate with the variable mass diffusion when a magnetic field has been applied transversely was precisely analyzed by Muthucumaraswamy *et al.,* [10] and Muthucumaraswamy *et al.,* [11]. Jha *et al.,* [12] studied how free convection and mass transfer affect the flow of fluid over a vertical plate that is accelerating and has heat sources, and they summarized their results in conclusions.

Basant Kumar and Singh [13] examined the influence of Soret effects on free convection and mass transfer in the Stokes flow problem for an infinite vertical plate, focusing on how temperature gradients affect the flow dynamics and transfer processes. Krishna *et al.,* [14] investigated Soret and Joule effects of the MHD mixed “convective flow of an electrically conducting, compressible fluid through an infinite vertical porous plate while accounting for Hall effects. Krishna and Ali [15] investigated the impact of non-dimensional variables on temperature, velocity, along with concentration. In further research on HMT in a 2-D viscous, electrically conducting fluid oscillating by an infinite vertical permeable moving plate in the saturated porous material subject to a transverse magnetic field, Kumar *et al.,* [16] examined numerical solutions to issues of heat generation as well as chemical reaction. Alam *et al.,* [17] and Alam *et al.,* [18] most likely talked about studies on non-small cell lung cancer" along with exploration of signaling pathways which could be utilized as a target for treatment. Muthucumaraswamy *et al.,* [19] explored the impact of rotation on MHD flow over an accelerated isothermal vertical plate, focusing on the effects of heat and mass diffusion on the flow behavior.

Hamid *et al.,* [20] utilized Yamada–Ota model to investigate unsteady non-axisymmetric the MHD Homann stagnation point flow of a nanofluid that includes carbon nanotubes over a convective surface with the radiation. Rao *et al.,* [21] conducted the study and the study explored the impact of heat generation along with viscous dissipation on unsteady MHD natural convection heat transfer of an electrically conductive non-Newtonian Casson fluid over a stretching sheet via a vertical porous plate. With help of similarity transformations, controlling partial differential equations are converted into ordinary" differential equations. Adnan and Lioua [22] investigated the thermal behavior of a single-phase nanofluid model using γ-Al_2O_3 nanoparticles under the combined effects of thermal radiation, Hall current, and momentum slip. By applying similarity transformations, the governing equations were simplified and solved numerically. The study showed that radiation and nanoparticle concentration significantly improve heat transfer. Hall current influences the fluid's velocity by inducing a secondary flow, while the momentum slip condition reduces wall shear stress. These findings offer a more realistic model for nanofluid applications in magnetohydrodynamic environments, such as cooling in microelectronic devices and energy systems requiring efficient thermal control. The Runge-Kuttas well as shot methods have been utilized to resolve the altered equations numerically.

Hamid *et al.,* [23] discussed about the Thermal study on single phase nanofluid model using radiative γ Al_2O_3 nanomaterial under Hall current and momentum slip Phenomena. Li *et al.,* [24] studied about the thermal performance of iron oxide and copper in hybrid nanofluid flow of casson material with hall current. Li *et al.,* [25] investigated the Hall effects and viscous dissipation in the peristaltic transport of Jeffrey nanofluid within a wave frame, as published in Colloid and Interface Science Communications. Their study revealed that Hall currents significantly influence the velocity distribution, while viscous dissipation enhances heat transfer within the fluid. The findings contribute to a better understanding of nanofluid behavior in peristaltic motion, with potential applications in biomedical engineering and industrial fluid transport. Sahu and Rudra [26] investigated the dynamic interaction of stratifications in an MHD parabolic flow with periodic temperature variation and variable mass diffusion within a porous medium. Their study revealed that the interplay between thermal and solutal stratifications significantly influences flow stability, heat transfer, and mass transport characteristics.

Das and Rudra [27] studied unsteady MHD parabolic flow past an infinite vertical plate, considering thermal and mass stratification through a porous medium with variable temperature and mass diffusion. Their analytical investigation revealed that thermal and solutal stratification significantly affect velocity, temperature, and concentration profiles. The presence of a magnetic field and porous medium further modifies flow behavior. This research is relevant for engineering and geophysical applications involving heat and mass transfer in stratified environments. In their study of unsteady parabolic flow past an infinite vertical plate in a porous medium, [28] Nath and Rudra concentrated on mass and thermal stratification with variable mass diffusion and exponentially decaying temperature. Their analysis demonstrated that velocity, temperature, and concentration profiles are significantly influenced by both thermal and mass stratification. The thermal boundary layer is diminished by the exponential temperature decay. Heat and mass transfer in porous and stratified environments, such as industrial and geothermal systems, are better understood thanks to this research. The findings highlight the role of periodic temperature variations in modulating velocity profiles and concentration distributions, which has implications for industrial and geophysical fluid dynamics. Prakash *et al.,* [29] investigated the thermal and radiative effects on the unsteady MHD flow of Casson fluid over a rotating porous medium with variable mass diffusion. To further strengthen the discussion on magnetohydrodynamics (MHD), incorporating recent and relevant studies on MHD flow, heat transfer, and mass diffusion would provide deeper insights into the influence of magnetic fields on fluid dynamics in various applications.

This study aims to analyze the influence of Hall and Dufour effects on an electrically conducting, incompressible, and viscous fluid subjected to unsteady magnetohydrodynamic (MHD) flow past a parabolic accelerated vertical plate in a rotating medium. The investigation focuses on understanding heat and mass transfer characteristics, accumulation levels, and velocity variations under different flow conditions. The main objective is to solve the governing equations using the Inverse Laplace Transform method. To examine the impact of key flow parameters, including rotation and diffusion, on velocity, temperature, and accumulation. To evaluate the effect of physical dimension metrics such as the Dufour number (Df), Prandtl number (Pr), Thermal Grashof number (Gr), Schmidt number (Sc), Mass Grashof number (Gm), and Hall parameter (M) on fluid flow behavior. To perform numerical simulations using MATLAB R2020a for validation and visualization of results. Despite extensive research on MHD flow, limited studies have explored the combined effects of Hall and Dufour parameters on a parabolic accelerated vertical plate in a rotating fluid. Previous studies primarily focused on linear acceleration without considering the influence of initial velocity profiles, mass diffusion, and rotational effects in a unified framework. This study bridges the gap by integrating these factors into a comprehensive numerical analysis, providing deeper insights into heat and mass transfer mechanisms in unsteady MHD flows.

2. Mathematical Analysis

Here, we have examined MHD movement of a viscous incompressible fluid that conducts electrical in an infinite vertical plate. In this instance, y'-axis is normal to x-axis, as well as x-axis is oriented upward in plate's motion direction (Figure 1). This flow has been exposed to a uniformly strong transverse magnetic field (B_0). Induced magnetic fields along viscous dissipation are ignored because of their negligible impacts. Primarily, C'_∞ is concentration of fluid, T'_∞ is the temperature. Presumably, it is at rest. When the plate's temperature and concentration rise to C'_w and T'_w, correspondingly, and its velocity is $u = t^2$, plate begins to move exponentially in its plane at the time t > 0. As per Boussinesq's Approximations, ruling equations are as subsequent.

The Hall effect introduces two main factors in the momentum equation. Momentum-Equation:

$$\frac{\partial u}{\partial t'} = v\frac{\partial^2 u}{\partial z^2} + 2\Omega' v - g\beta(T - T_\infty) + g\beta^*(C - C_\infty) - \frac{\sigma\mu^2 {B_0}^2}{\rho(1+m^2)}\,(u + mv) \tag{1}$$

$$\frac{\partial v}{\partial t'} = v\frac{\partial^2 v}{\partial z^2} - 2\Omega' u + \frac{\sigma\mu^2 B^2{}_0}{\rho(1+m^2)}\,(mu - v) \tag{2}$$

$$\rho c_p\frac{\partial T'}{\partial t'} = k\frac{\partial^2 T'}{\partial z^2} + \frac{Dm\,KT}{CsCp}\;\frac{\partial^2 C}{\partial Z^2} \tag{3}$$

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial z^2} \tag{4}$$

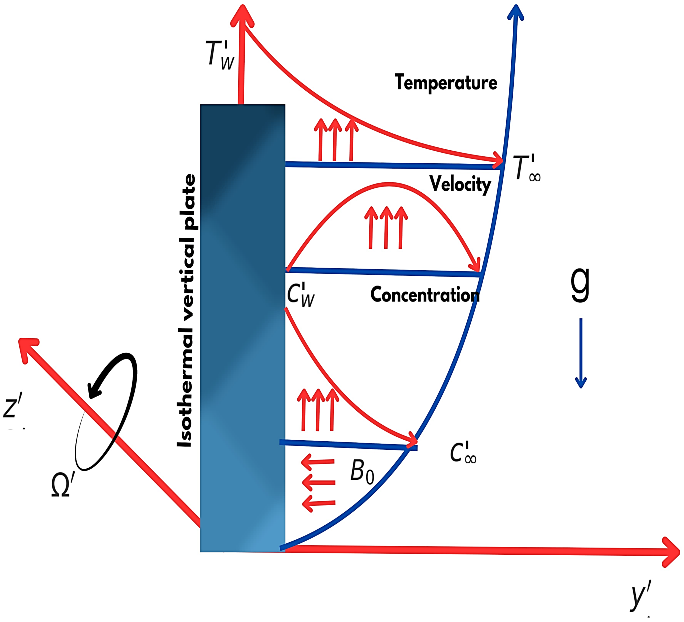

Fig. 1. schematic diagram of the problem

Initially, boundary conditions are:

$$t' \leq 0 : u = 0\,, v = 0\,, T' = T_\infty{}', C' = C_\infty{}' \text{ for all z}$$

$$t' > 0 : u = u_0 t'^2, v = 0\,, T' = T_w{}', C' = C_w{}' \text{ at } z=0$$

$$t' > 0 : u \to 0\,, v \to 0\,, T' \to T_\infty{}', C' \to C_\infty{}' \text{ as } z \to \infty \tag{5}$$

Regional radiant" is expressed in the scenario of a visually slim "gas is stated by:

$$\frac{\partial q_r}{\partial z} = -4a^*\,\sigma(T'^4{}_\infty - T'^4) \tag{6}$$

It is" presumed that heat variations throughout stream are minimal enough to permit the expression of T'^4 as a heat's one-dimensional function. In current scenario, this is carried out through expanding T'^4in a Taylor series with T'_∞as well as neglecting higher-order expressions. "Hence:

$$T'^4 \cong 4T'^3{}_\infty - 3T'^4{}_\infty \tag{7}$$

Through utilizing Eqs. (6) and (7), Eq. (3) reduced for:

$$\rho C_\rho \frac{\partial T'}{\partial t'} = k\frac{\partial^2 T'}{\partial z^2} + 16\,a^*\,\sigma T'^3{}_\infty(T'_\infty - T')$$

Considering the dimensionless values shown below:

$$\bar{Z} = \frac{zu_0}{\vartheta}, \bar{t} = \frac{tu_0{}^2}{\vartheta}, \bar{u} = \frac{u}{u_0}\,, \theta = \frac{T-T_\infty}{T_w-T_\infty}, \bar{C} = \frac{C-C_\infty}{C_w-C_\infty},$$

$$Gm = \frac{g\beta^*\vartheta(C_w-C_\infty)}{u_0{}^3}, Gr = \frac{g\beta\vartheta(T_w-T_\infty)}{u_0{}^3}, M = \frac{\sigma\mu^2 B_0{}^2\vartheta}{\rho u_0{}^2(1+m^2)}$$

$$Pr = \frac{\mu Cp}{k},\ Sc = \frac{\vartheta}{D}\ \mu = \vartheta\rho, \overline{\omega} = \frac{\omega\vartheta}{{u_0}^2},\ Df = \frac{DmK_T(C_w - C_\infty)}{\vartheta CsCp(T_w - T_\infty)}$$

Eq. (1) to (4) are transformed into dimensionless form:

$$\frac{\partial \mathrm{U}}{\partial \mathrm{t}} = \frac{\partial^2 \mathrm{U}}{\partial \mathrm{Z}^2} + 2\Omega\mathrm{V} - \frac{2\mathrm{M}^2}{1+\mathrm{m}^2}\ (\mathrm{U} - \mathrm{mV}) + \mathrm{G_r}\theta + \mathrm{G_m} \tag{8}$$

$$\frac{\partial \mathrm{V}}{\partial \mathrm{t}} = \frac{\partial^2 \mathrm{U}}{\partial \mathrm{Z}^2} - 2\Omega\mathrm{U} + \frac{2\mathrm{M}^2}{1+\mathrm{m}^2}\ (\mathrm{mU} - \mathrm{V}) \tag{9}$$

$$\frac{\partial \theta}{\partial \mathrm{t}} = \frac{1}{\mathrm{Pr}}\frac{\partial^2 \theta}{\partial \mathrm{z}^2} + Df\,\frac{\partial^2 C}{\partial z^2} \tag{10}$$

$$\frac{\partial \mathrm{C}}{\partial \mathrm{t}} = \frac{1}{\mathrm{Sc}}\frac{\partial^2 \mathrm{C}}{\partial \mathrm{z}^2} \tag{11}$$

With accompanying starting as well as limit condition:

$\mathrm{t} \leq 0:\ \mathrm{U} = 0\,, \mathrm{V} = 0\,, \theta = 0\,, \mathrm{C} = 0$ for all z

$\mathrm{t} > 0:\ U = \mathrm{t}^2\,, \mathrm{V} = 0\,, \theta = 1\,, \mathrm{C} = 1$ at $\mathrm{Z} = 0$

$\mathrm{t} > 0: U \rightarrow 0\,, V \rightarrow 0\,, \theta \rightarrow 0\,, C \rightarrow 0\ as\ Z \rightarrow \infty$

Removing the bars from Eqs. (8) to (11) and solving Eqs. (8) and (9) by adding them together, then applying complex velocity q=U+iV, results in combined equations represented as Eq. (12).

$$\frac{\partial \mathrm{q}}{\partial \mathrm{t}} = \frac{\partial^2 \mathrm{q}}{\partial \mathrm{Z}^2} + \mathrm{G_r}\theta + \mathrm{G_m}\mathrm{C} - \mathrm{hq} \tag{12}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial Z^2} + Df\,\frac{\partial^2 C}{\partial Z^2} \tag{13}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial Z^2} \tag{14}$$

The initial as well as boundary conditions in the non-dimensional quantities are:

$q = 0,\ \theta = 0,\ C = 0$ for all Z, $t \leq 0$

$q = t^2,\ \theta = 1,\ C = 1$ at $Z = 0,\ t > 0$

$q \rightarrow 0,\ \theta \rightarrow 0,\ C \rightarrow 0$ as $Z \rightarrow \infty$ (15)

3. Method of Solution

The Inverse Laplace Transform method was employed to obtain analytical solutions for velocity q equation (16), temperature equation (17), and concentration profiles equation (18). MATLAB R2020a was used to compute and visualize the results for varying parametric values. The boundary conditions considered include: At y = 0, initial velocity profile with constant temperature and mass diffusion. As y→0 velocity, temperature, and concentration approach free-stream conditions. Dimensionless governing Eqs. (12) to (14) represent velocity profiles, temperature as well as concentration for study, had been resolved through utilizing Laplace-transform method.

$$
\begin{aligned}
q = {} & \frac{(\eta^2+ht)t}{2h}\left[e^{2\eta\sqrt{ht}}\operatorname{erfc}\left(\eta+\sqrt{ht}\right)+e^{-2\eta\sqrt{ht}}\operatorname{erfc}\left(\eta-\sqrt{ht}\right)\right]+\frac{\eta\sqrt{t}(1-4ht)}{4h^{\frac{3}{2}}} \\
& \left[e^{-2\eta\sqrt{ht}}\, erfc\left(\eta-\sqrt{ht}\right)-e^{2\eta\sqrt{ht}}\, erfc\left(\eta+\sqrt{ht}\right)\right]-\frac{\eta t}{h\sqrt{\pi}}e^{-(\eta^2+ht)} \\
& +d\left[\begin{matrix}
\left[e^{2\eta\sqrt{ht}}\operatorname{erfc}\left(\eta+\sqrt{ht}\right)+e^{-2\eta\sqrt{ht}}\operatorname{erfc}\left(\eta-\sqrt{ht}\right)\right] \\
-e^{at}\left[e^{2\eta\sqrt{(h+a)t}}\operatorname{erfc}\left(\eta+\sqrt{(h+a)t}\right)+e^{-2\eta\sqrt{(h+a)t}}\operatorname{erfc}\left(\eta-\sqrt{(h+a)t}\right)\right] \\
+e^{at}\left[e^{2\eta\sqrt{a\mathrm{Pr}t}}\operatorname{erfc}\left(\eta\sqrt{Pr}+\sqrt{at}\right)+e^{-2\eta\sqrt{a\mathrm{Pr}t}}\operatorname{erfc}\left(\eta\sqrt{Pr}-\sqrt{at}\right)\right] \\
-2\operatorname{erf}c\left(\eta\sqrt{Pr}\right)
\end{matrix}\right] \\
& +c\left[\begin{matrix}
\left[e^{2\eta\sqrt{ht}}\operatorname{erfc}\left(\eta+\sqrt{ht}\right)+e^{-2\eta\sqrt{ht}}\operatorname{erfc}\left(\eta-\sqrt{ht}\right)\right] \\
-e^{bt}\left[e^{2\eta\sqrt{(h+b)t}}\operatorname{erfc}\left(\eta+\sqrt{(h+b)t}\right)+e^{-2\eta\sqrt{(h+b)t}}\operatorname{erfc}\left(\eta-\sqrt{(h+b)t}\right)\right] \\
+e^{bt}\left[e^{2\eta\sqrt{bSct}}\operatorname{erfc}\left(\eta\sqrt{Sc}+\sqrt{bt}\right)+e^{-2\eta\sqrt{aSct}}\operatorname{erfc}\left(\eta\sqrt{Sc}-\sqrt{bt}\right)\right] \\
-2\operatorname{erf}c\left(\eta\sqrt{Sc}\right)
\end{matrix}\right] \\
& +df\left[\begin{matrix}
e^{at}\left[e^{2\eta\sqrt{(h+a)t}}\operatorname{erfc}\left(\eta+\sqrt{(h+a)t}\right)+e^{-2\eta\sqrt{(h+a)t}}\operatorname{erfc}\left(\eta-\sqrt{(h+a)t}\right)\right] \\
-\left[e^{2\eta\sqrt{ht}}\operatorname{erfc}\left(\eta+\sqrt{ht}\right)+e^{-2\eta\sqrt{ht}}\operatorname{erfc}\left(\eta-\sqrt{ht}\right)\right] \\
-e^{at}\left[e^{2\eta\sqrt{a\mathrm{Pr}t}}\operatorname{erfc}\left(\eta\sqrt{Pr}+\sqrt{at}\right)+e^{-2\eta\sqrt{a\mathrm{Pr}t}}\operatorname{erfc}\left(\eta\sqrt{Pr}-\sqrt{at}\right)\right] \\
+2\operatorname{erf}c\left(\eta\sqrt{Pr}\right)
\end{matrix}\right] \\
& +cf\left[\begin{matrix}
\left[e^{2\eta\sqrt{ht}}\operatorname{erfc}\left(\eta+\sqrt{ht}\right)+e^{-2\eta\sqrt{ht}}\operatorname{erfc}\left(\eta-\sqrt{ht}\right)\right] \\
-e^{bt}\left[e^{2\eta\sqrt{(h+b)t}}\operatorname{erfc}\left(\eta+\sqrt{(h+b)t}\right)+e^{-2\eta\sqrt{(h+b)t}}\operatorname{erfc}\left(\eta-\sqrt{(h+b)t}\right)\right] \\
+e^{bt}\left[e^{2\eta\sqrt{bSct}}\operatorname{erfc}\left(\eta\sqrt{Sc}+\sqrt{bt}\right)+e^{-2\eta\sqrt{aSct}}\operatorname{erfc}\left(\eta\sqrt{Sc}-\sqrt{bt}\right)\right] \\
-2\operatorname{erf}c\left(\eta\sqrt{Sc}\right)
\end{matrix}\right] \qquad (16)
\end{aligned}
$$

where $a=\frac{h}{(Pr-1)}, b=\frac{h}{(Sc-1)}, c=\frac{\mathrm{G}_m}{2b(1-\mathrm{S}_c)}, d=\frac{\mathrm{G_r}}{2a(1-\mathrm{P_r})}, f=\frac{\mathrm{D_f.P_r.Sc}}{(\mathrm{S}_c-\mathrm{P_r})}$, $\mathrm{h}=\frac{2\mathrm{M}^2}{1+\mathrm{mi}}+2\Omega\mathrm{i}$

$$\theta=\operatorname{erf}c\left(\eta\sqrt{Pr}\right)-\frac{\mathrm{D_f.P_r.Sc}}{(\mathrm{S}_c-\mathrm{P_r})}\operatorname{erf}c\left(\eta\sqrt{Pr}\right)+\frac{\mathrm{D_f.P_r.Sc}}{(\mathrm{S}_c-\mathrm{P_r})}\operatorname{erf}c\left(\eta\sqrt{Sc}\right) \qquad (17)$$

$$C=\operatorname{erf}c\left(\eta\sqrt{Sc}\right) \qquad (18)$$

The numerical” values of q have been calculated to have an issue of physical understanding. Evaluation of this expression showed that the error function's argument was complex; as a result, we used the following formula to divide it into real as well as imaginary “parts:

$$
\begin{aligned}
& erf(a+ib)=erf(a)+\frac{exp(-a^2)}{2a\pi}[1-cos(2ab)+i\,sin(2ab)]+ \\
& \frac{2\,exp(-a^2)}{\pi}\sum_{n=1}^{\infty}\frac{exp(-n^2/4)}{n^2+4a^2}[f_n(a,b)+ig_n(a,b)]+\in(a,b) \qquad (19)
\end{aligned}
$$

Here, $f_n = 2a - 2a\,cosh(nb)\,cos(2ab) + n\,sinh(nb)\,sin(2ab)$

4. Results and Discussion

Using” numerical simulations, one can gain an improved comprehension of the issue by adjusting physical parameters (for example, Du, Pr, Sc, Gr, and Gc) in accordance with the characteristics of the flow and transport processes. 0.71 is chosen because it is comparable to the air's Prandtl number. The concentration, temperature, and velocity numerical values for the previously listed components are then combined together. Concentration graph, which displays consistency among the different Schmidt (Sc) values, is shown in Figure 2. As wall concentration rises, it is clear that the expected Schmidt values decrease. Dufour's mixed impact on temperature affects the temperature of fluid fluxes in both air and water, with the air flow having a higher temperature than the water flow. Figure 3 illustrates how the temperature rise in Prandtl (Pr) is correlated with a decline in warmth.

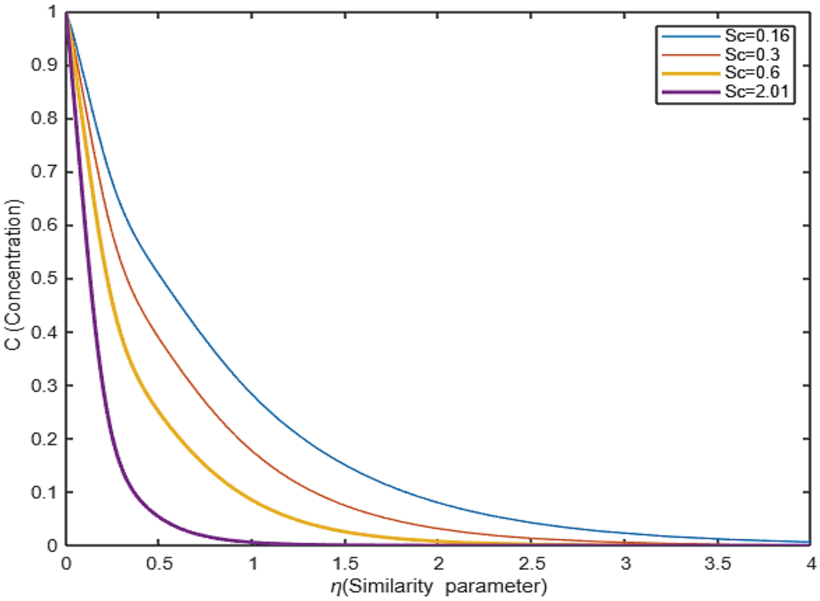

Fig. 2. Concentration graph for various Schmidt number (Sc) values

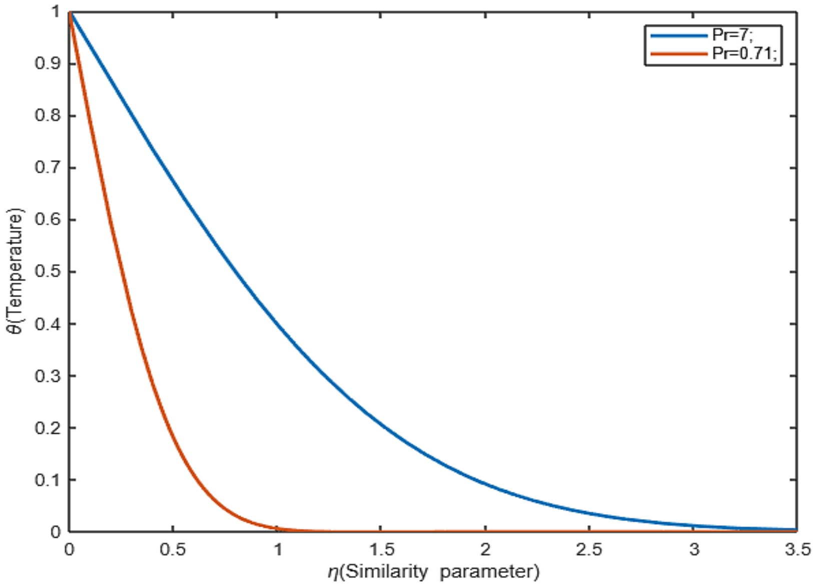

Fig. 3. Temperature tendency for distinct Prandtl number (Pr)

Temperature changes for t = 0.1, 0.2, and 0.3 is depicted in Figure 4. The Dufour, Prandtl, and Sc, along with heat-related features, can be used to interpret the data. The fluid's sensitivity to temperature increases became evident over time. The temperature rises with the increased time estimate. The Sc rises in Figure 5, suggesting an early propensity for temperature to expand. But after that, temperature varies, showing a shift in trend and a drop in warmth at this point. The temperature trajectory for Dufour (Df) values can be examined in Figure 6. Overall, a higher temperature is indicated by the Dufour (Df) value. Figure 7 demonstrates progression of temperature for Dufour (Df) values. Dufour (Df) value generally indicates a greater temperature.

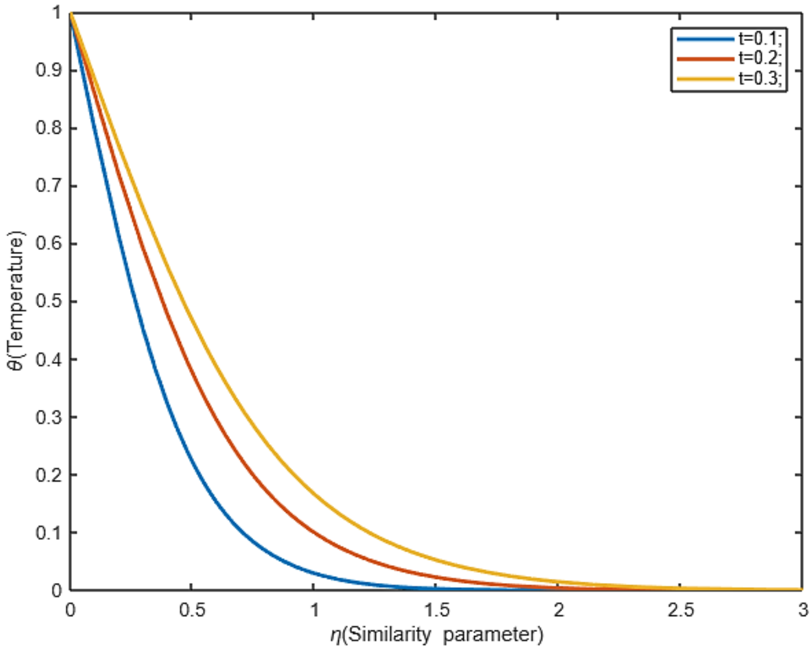

Fig. 4. Temperature graph for distinct t values

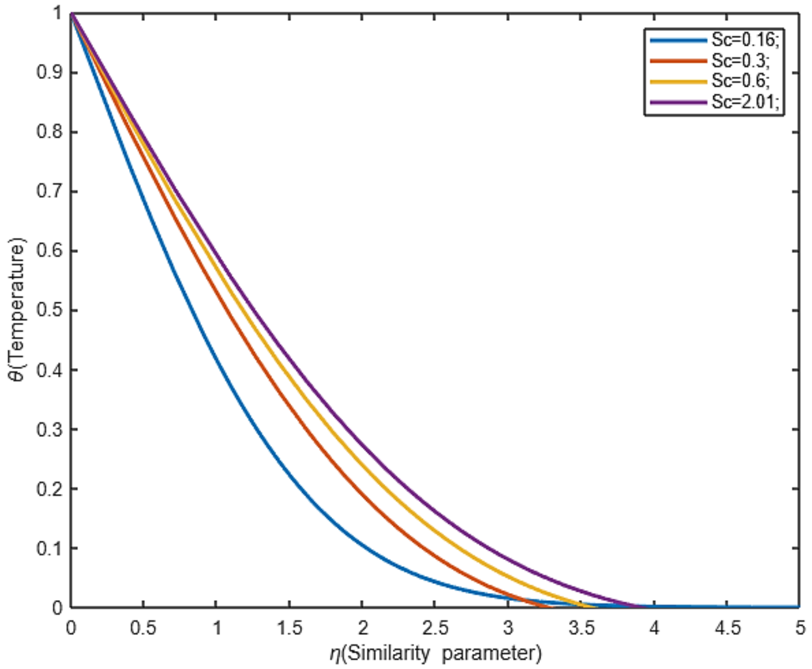

Fig. 5. Temperature graph for distinct Sc values

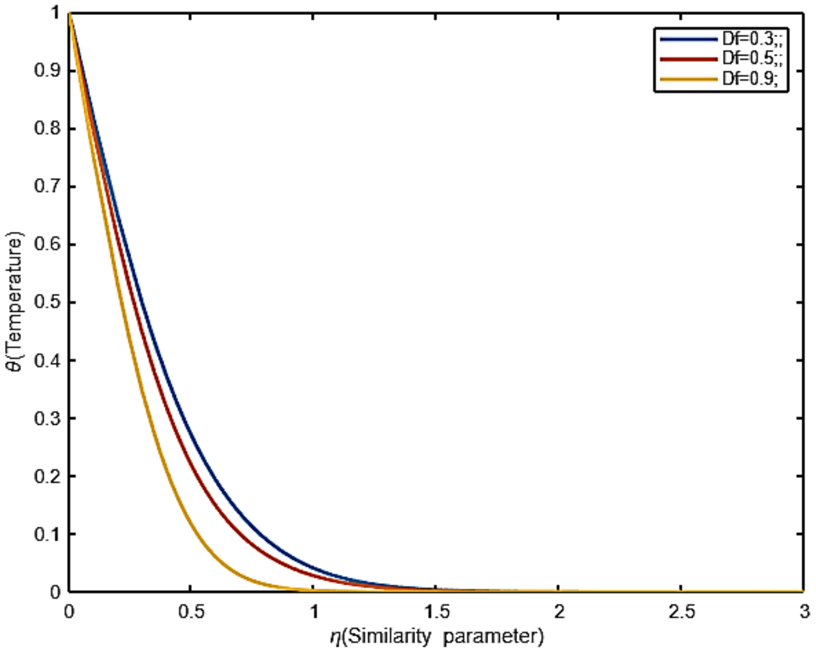

Fig. 6. Temperature for Df values (Pr=0.71)

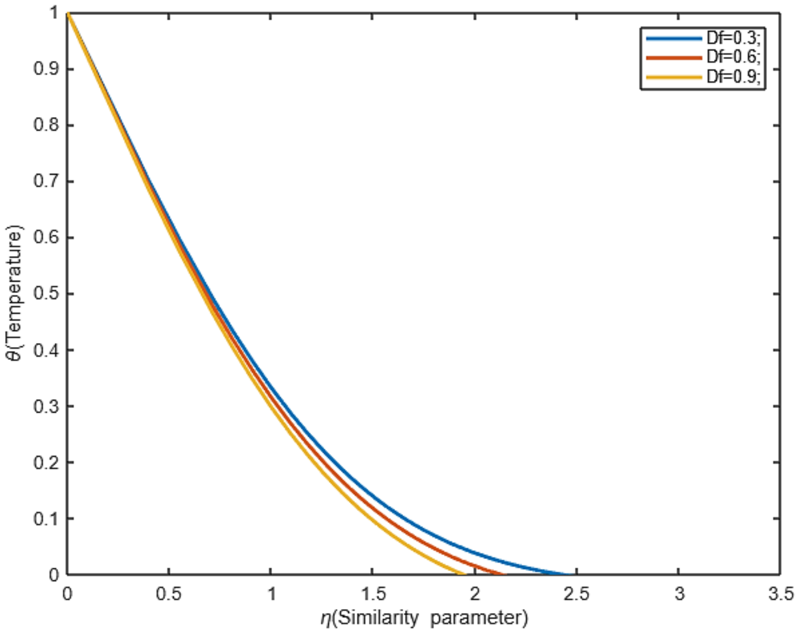

Fig. 7. Temperature for Df values (Pr =7)

Fluid velocity is affected by Thermal Grashof number (Gr), that is "ratio of buoyancy to the viscous force acting on a fluid," as illustrated in Figure 8. Raising Gr causes the velocity to reach its maximum value. It is possible that the buoyancy effect was the primary cause of the rise. In general, velocity tends to increase as Thermal Grashof number (Gr) increases. Velocity contours of plate have been displayed in the Figure 9 for different Gm = 2, 4, and 6. The Gm values rise as the velocity increases. Velocity of plate is displayed in Figure 10 for varying numbers of observations (M = 0.2, 0.5, 0.9), and it decreases as M increases. Figure 11 displays velocity contours of plate for different values of m=12, 8, 4. The m values rise with increasing velocity. The plate's velocity contours at different Schmidt values are shown in Figure 12. Sc = 0.5, 0.6, and 0.7. As speed increases, the plate’s Schmidt number decreases.

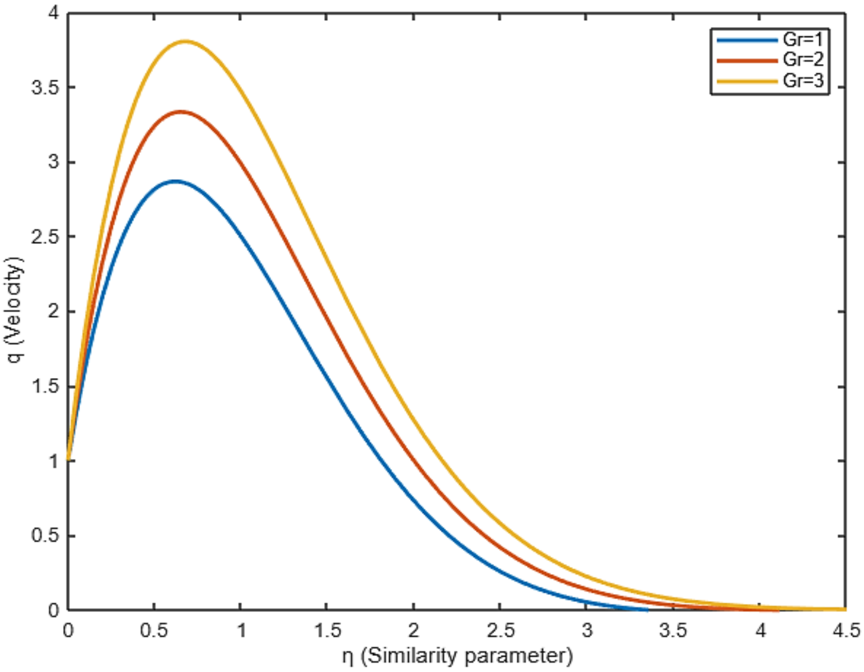

Fig. 8. Velocity trend for Gr

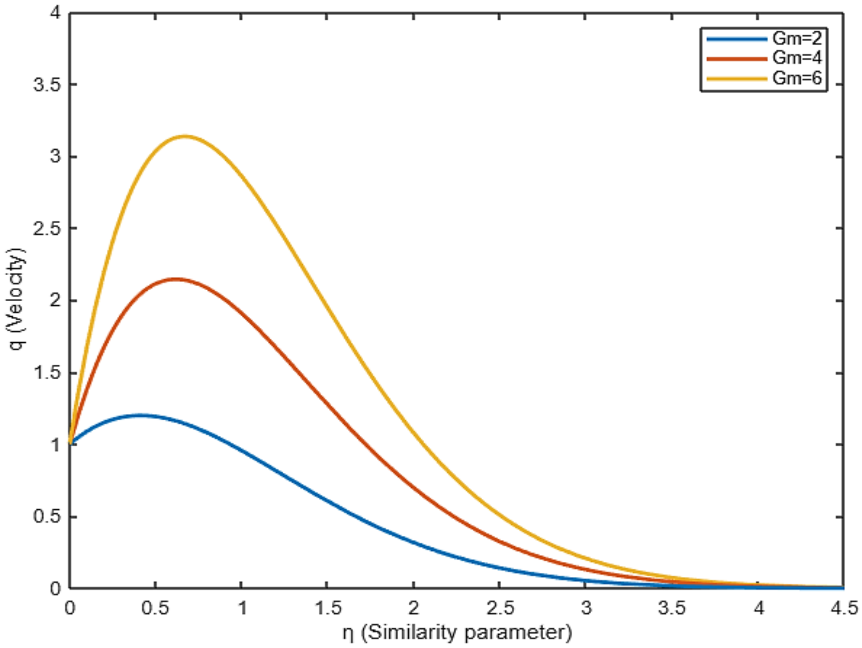

Fig. 9. Velocity trend for Gm

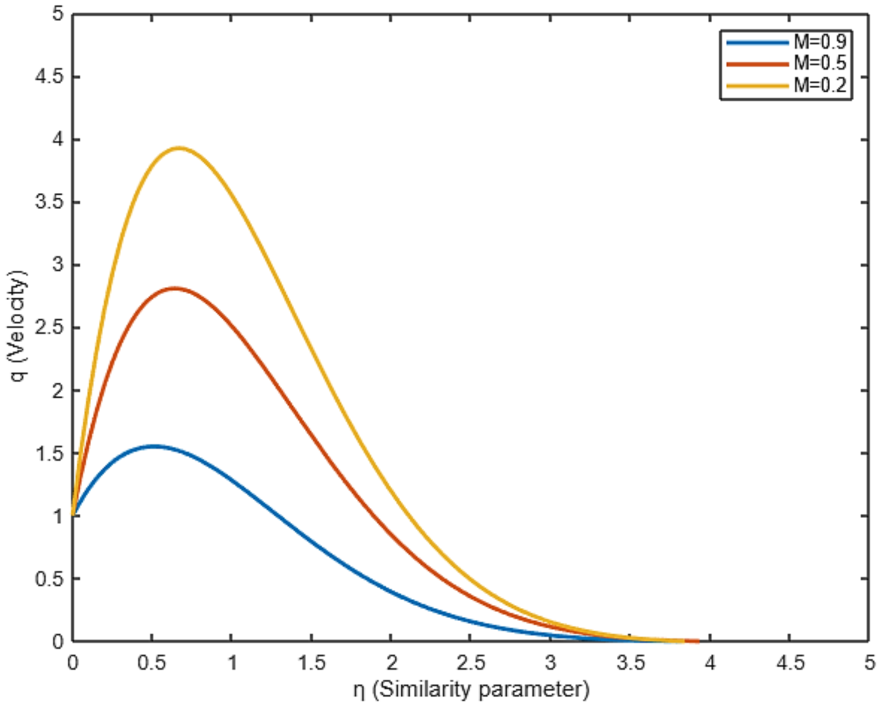

Fig. 10. Velocity trend for M (MHD)

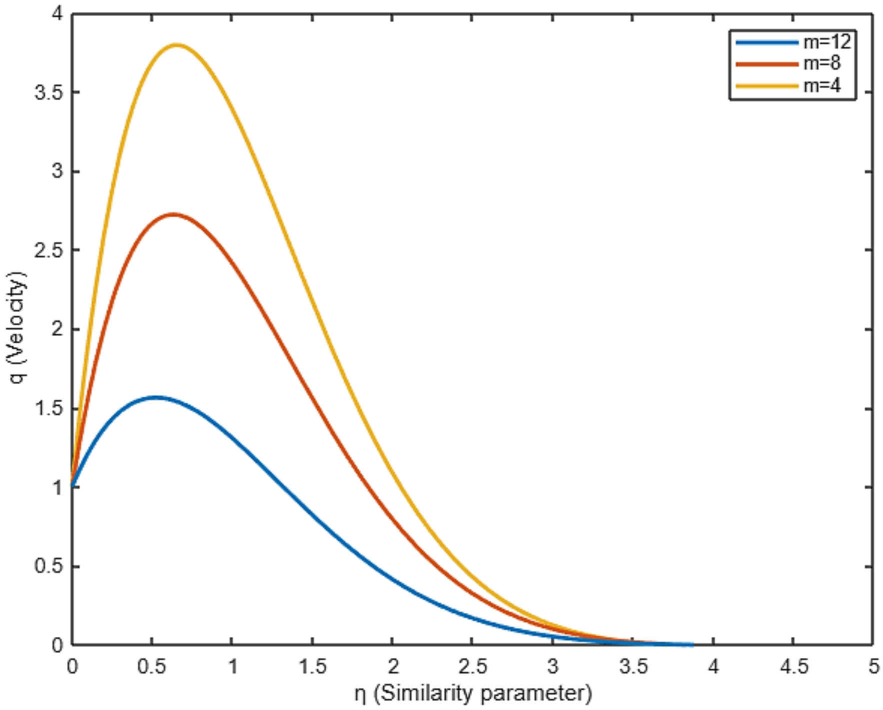

Fig. 11. Velocity trend for m (Hall parameter)

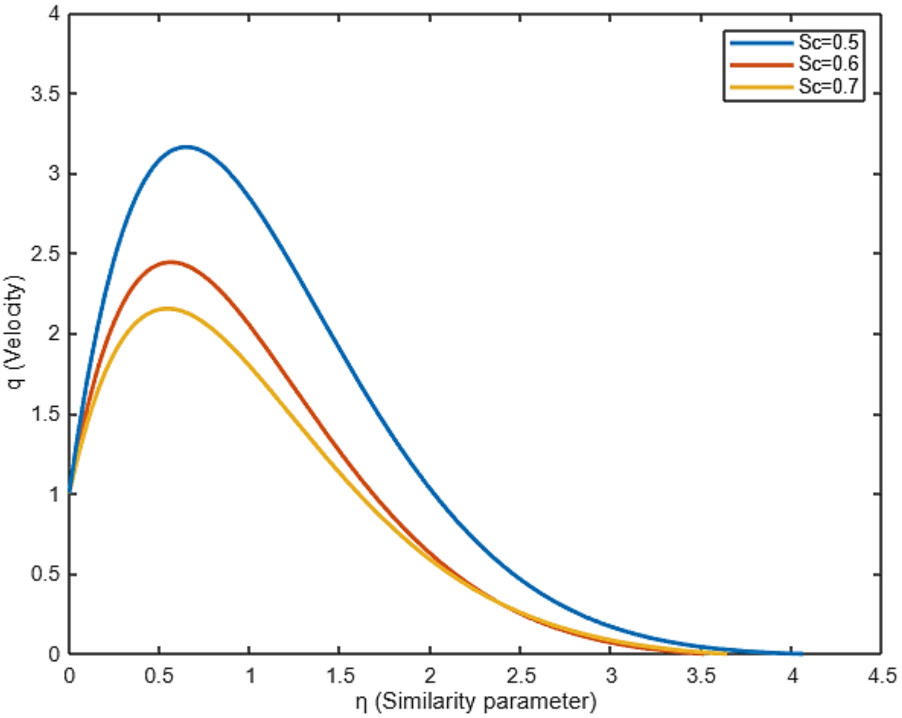

Fig. 12. Velocity for distinct Sc

5. Conclusions

This research provides a comprehensive analysis of Hall and Dufour effects on unsteady MHD flow over a parabolic accelerated vertical plate in a rotating fluid. The governing boundary layer equations have been non-dimensionless and solved using the Laplace method. The results illustrate the flow characteristics for the velocity, temperature and concentration, it is found that as follows:

i. Velocity Distribution: An increase in the Dufour number, Prandtl number, and thermal Grashof number enhances the velocity of the fluid. Conversely, higher values of the Schmidt number, mass Grashof number, and Hall parameter result in a reduction in velocity due to enhanced resistive forces and magnetic field interactions.
ii. Temperature Profile: The temperature rises with an increase in the Dufour number, indicating the influence of thermodiffusion. Additionally, an increase in Prandtl number results in a decrease in temperature due to enhanced thermal conductivity.
iii. Concentration Effects: The concentration field is significantly affected by the Schmidt number and chemical reaction parameter, with higher values leading to a rapid decline in species concentration due to increased mass diffusion resistance.

6. Future Work

The results have practical implications in industrial applications where fluid control under electromagnetic fields is essential. Future research may extend this analysis to include nonlinear effects and three-dimensional flow condition. Investigating these variations may reveal how the Hall and Dufour effects interact differently under diverse configurations, offering a more comprehensive understanding of the role of rotation in magnetohydrodynamic (MHD) flows

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