JP Journal of Heat and Mass Transfer
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https://pphmjopenaccess.com
https://doi.org/10.17654/0973576324034
Volume 37, Number 4, 2024, Pages 491-520 **P-ISSN: 0973-5763**

HALL AND HEAT SOURCE EFFECTS OF FLOW STATE ON A VERTICALLY ACCELERATING PLATE IN AN ISOTHERMAL ENVIRONMENT, INCLUDING CHEMICAL REACTIONS, ROTATION, RADIATION, AND THE DUFOUR EFFECT

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Received: May 21, 2024; Revised: June 29, 2024; Accepted: July 15, 2024
Keywords and phrases: Laplace, parabolic flow, rotational flow, hall current, heat source.
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How to cite this article: D. Lakshmikaanth, A. Selvaraj, L. Tamilselvi, S. Dilip Jose and V. Velukumar, Hall and heat source effects of flow state on a vertically accelerating plate in an isothermal environment, including chemical reactions, rotation, radiation, and the Dufour effect, JP Journal of Heat and Mass Transfer 37(4) (2024), 491-520.
https://doi.org/10.17654/0973576324034

Published Online: August 5, 2024

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Abstract

We examine the collective impact of Hall current and radiation-enhanced thermal sources on the laminar flow of a first-order fluid. The fluid under investigation is incompressible, and the analysis pertains to the heat transfer and accumulation dynamics when this fluid flows over a uniformly heated vertical plate, which is in motion at an elevated speed with rotational motion and the inclusion of the Dufour (Df) effect. We applied the Laplace method to derive solutions for the pertinent mathematical expressions. Subsequent to the investigation, measurable data was obtained by analyzing the accelerated flow, taking into account specific parameters such as Prandtl, Schmidt, thermal, and accumulation Grashof values. According to the findings, speed rises with higher values of heat source, Hall current and Grashof parameters, but drops as radiation levels rise. Temperature similarly rises with a higher heat source and drops with increased radiation levels. Furthermore, with a rise in the chemical reaction rate, the concentration drops.

1. Introduction

The assessment of fluid flow is a crucial factor within the domain of heat transfer in reactors. This examination has practical uses across a broad spectrum of systems, encompassing biological systems as well as household and workplace appliances. This analysis is relevant to a wide range of applications, spanning business and industrial operations, food preparation, cooling of electronic equipment, building HVAC systems, food freezing and refrigeration, among many others. In the research presented in reference [1-3] Selvaraj et al., the study examines the Dufour (Df) effect on MHD flow over a vertically oriented plate that undergoes rapidly increasing speed while traversing a permeable substance with fluctuations in both temperature and mass diffusion. In a study conducted by Lakshmikaanth and colleagues [4, 5] explore how the presence of a heat source affects the fluid flow around a vertical plate maintained at a constant temperature subject to parabolic acceleration. Reddy and Rao [6] investigated the impact of radiational effects over free convection mass-transfer. Velu et al. [7-9] discussed about the fluid rotation over vertical plate undergoing acceleration that follows an exponential pattern while encountering fluctuations in temperature and the influence of Hall current. Satya Narayana et al. [10] showed the existence of a chemical process that results in a deceleration of fluid movement. This occurs due to the fact that the consumption of chemical species reduces the concentration field, subsequently diminishing the buoyancy effects resulting from concentration gradients. As a result, the flow field experiences a deceleration. Prasada et al. [11] showed that when the Darcy number increases, there is rise in acceleration of the flow because of the simultaneous increase in medium permeability and a decrease in Darcian impedance. Dursunkaya and Worek [12] conducted a study on transient and steady natural convection from a vertical surface with diffusion-thermo and thermal-diffusion effects. Seddeek [13] investigated the impact of thermal-diffusion (Soret) and diffusion-thermo (Dufour) effects on a continuous laminar boundary layer flow over an accelerating surface featuring a heat source. Abreu et al. [14] conducted study on encompassed forced, natural convection scenarios and also effects of Dufour-Soret. Bég et al. [15] conducted a study focusing on heat and mass transfer behaviors within the context of natural convection flow. This flow encompasses a chemically-reacting Newtonian fluid and occurs along both vertical and inclined plates. Rout and Pattanayak [16] investigated the influence of the introduction of a heat source into the MHD flow in the vicinity of a vertical plate experiencing exponential acceleration. Srihari [17] investigated how a dissipative fluid flowing across a permeable plate impacts Soret-Dufour-radiation on the MHD flow while simultaneously experiencing the occurrence of a chemical process combined with the existence of a heat source. Pandya and colleagues [18, 19] examined the impacts of Soret-Dufour effects, radiation, and chemical reactions on an unsteady MHD flow of an incompressible viscous and electrically conducting fluid (dusty) as it flows past a continuously moving inclined plate. Rajput and colleagues [20-22] examined the behavior of accelerated plates, both vertical and inclined, as well as oscillating plates in the context of MHD flow. Their study encompasses various effects, including Dufour (Df) and Hall effects. Reddy et al. [23] investigated the influence of radiation on the unsteady movement of a thick, non-compressible liquid. This fluid also exhibits consistent mass spreading subject to the influence of a magnetic field and heat generation source. In [24], Anil Kumar et al. focused on investigating the effects of Hall current, radiation, diffusion of Soret and Dufour in the context of an unsteady MHD flow driven by natural convection over an infinitely tall vertical plate that is immobile within a porous medium. Hetnarski [25, 26] offered a methodology for deriving inverse Laplace transform formulas.

2. Numerical Formulation

In this context, we consider a non-conductive vertical plate at $z = 0$, through which a viscous and incompressible fluid, capable of conducting current, is flowing. The x-axis runs vertically along the plate, while the z-axis is oriented perpendicular to the plate, and the velocity is expressed as $u = u_0 t^2$. It should be noted that the pressure remains constant across the entire flow field. The obtained results are based on the fulfillment of the continuity equation, which describes the various components of the velocity vector. Under these conditions, the flow characteristics solely depend on z and t. The following equations govern the transient flow, taking into account these assumptions:

$$\frac{\partial u^*}{\partial t^*} - 2\Omega v^* = \vartheta \frac{\partial^2 u^*}{\partial z^{*2}} + g\beta(T^* - T^*_\infty) + g\beta(C^* - C^*_\infty) - \frac{\sigma B_0^2 \mu^2 (u^* + hv^*)}{\rho(1 + h^2)}, \tag{1}$$

$$\frac{\partial v^*}{\partial t^*} + 2\Omega u^* = \vartheta \frac{\partial^2 v^*}{\partial z^{*2}} + \frac{\sigma B_0^2 \mu^2 (hu^* - v^*)}{\rho(1 + h^2)}, \tag{2}$$

$$\frac{\partial \theta^*}{\partial t^*} = \frac{1}{Pr} \frac{\partial^2 \theta^*}{\partial z^{*2}} - R\theta^* + Q\theta^* + \frac{D_m K_T}{C_s C_p} \frac{\partial^2 C^*}{\partial z^{*2}}, \tag{3}$$

$$\frac{\partial C^*}{\partial t^*} = \frac{1}{Sc} \frac{\partial^2 C^*}{\partial z^{*2}} - kC^*. \tag{4}$$

The conditions are

$$u^* = 0,\ v^* = 0,\ T^* = T^*_\infty,\ C^* = C^*_\infty \text{ at } t^*,\ z^* \le 0,$$

$$u^* = t^{*2},\ T^* = T^*_\infty,\ C^* = C^*_\infty \text{ at } t^* > 0 \text{ for } z^* = 0,$$

$$u^* \to 0,\ T^* \to T^*_\infty,\ C^* \to C^*_\infty \text{ at } z^* \to \infty.$$

The consequent dimensionless aggregates are

$$U = \frac{u^*}{(Vu_0)^{\frac{1}{3}}},\ V = \frac{v^*}{(Vu_0)^{\frac{1}{3}}},\ t = t^*\left(\frac{(u_0^2)}{v}\right)^{\frac{1}{3}},\ Z = z^*\left(\frac{(u_0^2)}{v^2}\right)^{\frac{1}{3}},$$

$$\theta = \frac{T^* - T^*_\infty}{T^*_w - T^*_\infty},\ Gr = \frac{g\beta(T^*_w - T^*_\infty)}{u_0},\ C = \frac{C^* - C^*_\infty}{C^*_w - C^*_\infty},\ Gc = \frac{g\beta(C^* - C^*_\infty)}{C^*_w - C^*_\infty},$$

$$Pr = \frac{\mu C_p}{k},\ k = K_1\left(\frac{v}{u_0^2}\right)^{\frac{1}{3}},\ Sc = \frac{v}{D},\ M^2 = \frac{\sigma B_0^2}{\rho}\left(\frac{v}{u_0^2}\right)^{\frac{1}{3}}.$$

To solve equations (1) and (2), use $q = u + iv$, to have

$$\frac{\partial q}{\partial t} = Gr\theta + GcC + \frac{\partial^2 q}{\partial z^2} - mq, \tag{5}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial z^2} - R\theta + Q\theta + \frac{D_m K_T}{C_s C_p}\frac{\partial^2 C}{\partial z^2}, \tag{6}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial z^2} - kC, \tag{7}$$

$$m = \frac{M^2}{(1+ih)} + 2\Omega i$$

with conditions

$$q = 0,\ \theta = 0,\ C = 0 \text{ for all } z,\ t \le 0,$$

$$q = t^2,\ \theta = t,\ C = 1 \text{ for all } z,\ t = 0,$$

$$q \to 0,\ \theta \to 0,\ C \to 0 \text{ as } z \to \infty. \tag{8}$$

3. Solution of the Problem

We solve equation (7):

$$q = \left\{\begin{array}{l} \left[\frac{\eta^2 t}{m} + t^2\right]\frac{1}{2}[e^{-2\eta\sqrt{mt}}\ erfc(\eta - \sqrt{mt}) + e^{2\eta\sqrt{mt}}\ erfc(\eta + \sqrt{mt})] \\ + \left[\frac{1}{4m} - t\right]\frac{\eta\sqrt{t}}{\sqrt{m}}[e^{-2\eta\sqrt{mt}}\ erfc(\eta - \sqrt{mt}) - e^{2\eta\sqrt{mt}}\ erfc(\eta + \sqrt{mt})] \\ - \frac{2}{m}\sqrt{t/\pi}\, e^{(\eta^2 - mt)} \end{array}\right\}$$

$$
+\frac{Gr}{(\Pr-1)}\left[\begin{array}{l}
\dfrac{1}{b^{2}}\left[\begin{array}{l}
\dfrac{e^{bt}}{2}\left[\begin{array}{l} e^{-2\eta\sqrt{t}\sqrt{(b+m)}}\,erfc(\eta-\sqrt{(b+m)t}) \\ +\,e^{2\eta\sqrt{t}\sqrt{(b+m)}}\,erfc(\eta+\sqrt{(b+m)t}) \end{array}\right] \\
-\dfrac{1}{2}\left[e^{-2\eta\sqrt{t}\sqrt{m}}\,erfc(\eta-\sqrt{mt})+e^{2\eta\sqrt{t}\sqrt{m}}\,erfc(\eta+\sqrt{mt})\right] \\
-b\left[\begin{array}{l} t[e^{-2\eta\sqrt{t}\sqrt{m}}\,erfc(\eta-\sqrt{mt})+e^{2\eta\sqrt{t}\sqrt{m}}\,erfc(\eta+\sqrt{mt})] \\ -\dfrac{\eta\sqrt{t}}{2\sqrt{m}}\left(e^{-2\eta\sqrt{t}\sqrt{m}}\,erfc(\eta-\sqrt{mt})-e^{2\eta\sqrt{t}\sqrt{m}}\,erfc(\eta+\sqrt{mt})\right) \end{array}\right]
\end{array}\right] \\
+\dfrac{PrDf\;Sc}{(Sc-Pr)}\left[\begin{array}{l}
\dfrac{k}{ab}\dfrac{1}{2}\left[\begin{array}{l} e^{-\sqrt{m}2\eta\sqrt{t}}\,erfc(\eta-\sqrt{mt}) \\ +\,e^{\sqrt{m}2\eta\sqrt{t}}\,erfc(\eta+\sqrt{mt}) \end{array}\right] \\
+\dfrac{a+k}{a(a-b)}\dfrac{e^{at}}{2}\left[\begin{array}{l} e^{-\sqrt{(m+a)}2\eta\sqrt{t}}\,erfc(\eta-\sqrt{(m+a)t}) \\ +\,e^{\sqrt{(m+a)}2\eta\sqrt{t}}\,erfc(\eta+\sqrt{(m+a)t}) \end{array}\right] \\
-\dfrac{b+k}{b(a-b)}\dfrac{e^{bt}}{2}\left[\begin{array}{l} e^{-\sqrt{(m+b)}2\eta\sqrt{t}}\,erfc(\eta-\sqrt{(m+b)t}) \\ +\,e^{\sqrt{(m+b)}2\eta\sqrt{t}}\,erfc(\eta+\sqrt{(m+b)t}) \end{array}\right]
\end{array}\right]
\end{array}\right]
$$

$$
-\frac{Gr}{(Sc-1)}\frac{PrDf\,Sc}{(Sc-Pr)}\left(\begin{array}{l}
\dfrac{k}{ac}\dfrac{1}{2}\left[\begin{array}{l} e^{-\sqrt{m}2\eta\sqrt{t}}\,erfc(\eta-\sqrt{mt}) \\ +\,e^{\sqrt{m}2\eta\sqrt{t}}\,erfc(\eta+\sqrt{mt}) \end{array}\right] \\
+\dfrac{a+k}{a(a-c)}\dfrac{e^{at}}{2}\left[\begin{array}{l} e^{-\sqrt{(m+a)}2\eta\sqrt{t}}\,erfc(\eta-\sqrt{(m+a)t}) \\ +\,e^{\sqrt{(m+a)}2\eta\sqrt{t}}\,erfc(\eta+\sqrt{(m+a)t}) \end{array}\right] \\
-\dfrac{c+k}{c(a-c)}\dfrac{e^{ct}}{2}\left[\begin{array}{l} e^{-\sqrt{(m+c)}2\eta\sqrt{t}}\,erfc(\eta-\sqrt{(m+c)t}) \\ +\,e^{\sqrt{(m+c)}2\eta\sqrt{t}}\,erfc(\eta+\sqrt{(m+c)t}) \end{array}\right]
\end{array}\right)
$$

$$
+\frac{Gc}{c(Sc-1)}\left[\begin{array}{l}
\dfrac{e^{ct}}{2}\left[e^{-\sqrt{(m+c)}2\eta\sqrt{t}}\,erfc(\eta-\sqrt{(m+c)t})+e^{\sqrt{(m+c)}2\eta\sqrt{t}}\,erfc(\eta+\sqrt{(m+c)t})\right] \\
-\dfrac{1}{2}\left[e^{-\sqrt{m}2\eta\sqrt{t}}\,erfc(\eta-\sqrt{mt})+e^{\sqrt{m}2\eta\sqrt{t}}\,erfc(\eta+\sqrt{mt})\right]
\end{array}\right]
$$

$$
-\frac{Gr}{(Pr-1)}\left\{
\begin{array}{l}
\dfrac{1}{b^2}\left[
\begin{array}{l}
\dfrac{e^{bt}}{2}\left[\begin{array}{l} e^{-2\eta\sqrt{t}\sqrt{Pr}\sqrt{(b+R-Q)}}\ erfc(\eta\sqrt{Pr}-\sqrt{(b+R-Q)t}\,) \\ +\ \ e^{2\eta\sqrt{t}\sqrt{Pr}\sqrt{(b+R-Q)}}\ erfc(\eta\sqrt{Pr}+\sqrt{(b+R-Q)t}\,) \end{array}\right] \\
-\dfrac{1}{2}\left[\begin{array}{l} e^{-2\eta\sqrt{t}\sqrt{Pr}\sqrt{(R-Q)}} erfc(\eta\sqrt{Pr}-\sqrt{(R-Q)t}\,) \\ +\,e^{2\eta\sqrt{t}\sqrt{Pr}\sqrt{(R-Q)}} erfc(\eta\sqrt{Pr}+\sqrt{(R-Q)t}\,) \end{array}\right] \\
-b\left[\begin{array}{l}
t\left[\begin{array}{l} e^{-2\eta\sqrt{t}\sqrt{Pr}\sqrt{R-Q}}\ erfc(\eta\sqrt{Pr}-\sqrt{(R-Q)t}\,) \\ +\,e^{2\eta\sqrt{t}\sqrt{Pr}\sqrt{R-Q}}\ erfc(\eta\sqrt{Pr}+\sqrt{(R-Q)t}\,) \end{array}\right] \\
-\dfrac{\eta\sqrt{t}\sqrt{Pr}}{2\sqrt{R-Q}}\left(\begin{array}{l} e^{-2\eta\sqrt{t}\sqrt{Pr}\sqrt{R-Q}}\ erfc(\eta\sqrt{Pr}-\sqrt{(R-Q)t}\,) \\ -\,e^{2\eta\sqrt{t}\sqrt{Pr}\sqrt{R-Q}}\ erfc(\eta\sqrt{Pr}+\sqrt{(R-Q)t}\,) \end{array}\right)
\end{array}\right]
\end{array}\right] \\
+\dfrac{PrDfSc}{(Sc-Pr)}\left[
\begin{array}{l}
\dfrac{k}{ab}\dfrac{1}{2}\left[\begin{array}{l} e^{-\sqrt{Pr}\sqrt{(R-Q)}2\eta\sqrt{t}} erfc(\eta\sqrt{Pr}-\sqrt{(R-Q)t}\,) \\ +\,e^{\sqrt{Pr}\sqrt{(R-Q)}2\eta\sqrt{t}} erfc(\eta\sqrt{Pr}+\sqrt{(R-Q)t}\,) \end{array}\right] \\
+\dfrac{a+k}{a(a-b)}\dfrac{e^{at}}{2}\left[\begin{array}{l} e^{-\sqrt{Pr}\sqrt{(a+R-Q)}2\eta\sqrt{t}} erfc(\eta\sqrt{Pr}-\sqrt{(a+R-Q)t}\,) \\ +\,e^{\sqrt{Pr}\sqrt{(a+R-Q)}2\eta\sqrt{t}} erfc(\eta\sqrt{Pr}+\sqrt{(a+R-Q)t}\,) \end{array}\right] \\
-\dfrac{b+k}{b(a-b)}\dfrac{e^{bt}}{2}\left[\begin{array}{l} e^{-\sqrt{Pr}\sqrt{(b+R-Q)}2\eta\sqrt{t}} erfc(\eta\sqrt{Pr}-\sqrt{(b+R-Q)t}\,) \\ +\,e^{\sqrt{Pr}\sqrt{(b+R-Q)}2\eta\sqrt{t}} erfc(\eta\sqrt{Pr}+\sqrt{(b+R-Q)t}\,) \end{array}\right]
\end{array}\right]
\end{array}\right\}
$$

$$
+\frac{Gr}{(Sc-1)}\frac{PrDfSc}{(Sc-Pr)}\left(
\begin{array}{l}
\dfrac{k}{ac}\dfrac{1}{2}\left[\begin{array}{l} e^{-\sqrt{Sc}\sqrt{k}\,2\eta\sqrt{t}} erfc(\eta\sqrt{Sc}-\sqrt{kt}\,) \\ +\,e^{\sqrt{Sc}\sqrt{k}\,2\eta\sqrt{t}} erfc(\eta\sqrt{Sc}+\sqrt{kt}\,) \end{array}\right] \\
+\dfrac{a+k}{a(a-c)}\dfrac{e^{at}}{2}\left[\begin{array}{l} e^{-\sqrt{Sc}\sqrt{(a+k)}2\eta\sqrt{t}} erfc(\eta\sqrt{Sc}-\sqrt{(a+k)t}\,) \\ +\,e^{\sqrt{Sc}\sqrt{(a+k)}2\eta\sqrt{t}} erfc(\eta\sqrt{Sc}+\sqrt{(a+k)t}\,) \end{array}\right] \\
-\dfrac{c+k}{c(a-c)}\dfrac{e^{ct}}{2}\left[\begin{array}{l} e^{-\sqrt{Sc}\sqrt{(c+k)}2\eta\sqrt{t}} erfc(\eta\sqrt{Sc}-\sqrt{(c+k)t}\,) \\ +\,e^{\sqrt{Sc}\sqrt{(c+k)}2\eta\sqrt{t}} erfc(\eta\sqrt{Sc}+\sqrt{(c+k)t}\,) \end{array}\right]
\end{array}\right)
$$

$$-\frac{Gc}{c(Sc-1)}\left[\begin{array}{l}\frac{e^{ct}}{2}\left[\begin{array}{l}e^{-\sqrt{Sc}\sqrt{(c+k)}2\eta\sqrt{t}}erfc(\eta\sqrt{Sc}-\sqrt{(c+k)t})\\+e^{\sqrt{Sc}\sqrt{(c+k)}2\eta\sqrt{t}}erfc(\eta\sqrt{Sc}+\sqrt{(c+k)t})\end{array}\right]\\-\frac{1}{2}\left[\begin{array}{l}e^{-\sqrt{Sc}\sqrt{k}2\eta\sqrt{t}}erfc(\eta\sqrt{Sc}-\sqrt{kt})\\+e^{\sqrt{Sc}\sqrt{k}2\eta\sqrt{t}}erfc(\eta\sqrt{Sc}+\sqrt{kt})\end{array}\right]\end{array}\right], \tag{9}$$

$$\theta = t\left[\begin{array}{l}e^{-2\eta\sqrt{Pr}\sqrt{(R-Q)t}}erfc(\eta\sqrt{Pr}-\sqrt{(R-Q)t})\\+e^{2\eta\sqrt{Pr}\sqrt{(R-Q)t}}erfc(\eta\sqrt{Pr}+\sqrt{(R-Q)t})\end{array}\right]$$

$$-\frac{\eta\sqrt{Prt}}{2\sqrt{R-Q}}\left[\begin{array}{l}e^{-2\eta\sqrt{Pr}\sqrt{(R-Q)t}}erfc(\eta\sqrt{Pr}-\sqrt{(R-Q)t})\\+e^{2\eta\sqrt{Pr}\sqrt{(R-Q)t}}erfc(\eta\sqrt{Pr}+\sqrt{(R-Q)t})\end{array}\right]$$

$$+\frac{PrDf\,Sc}{(Sc-Pr)}\left[\begin{array}{l}\frac{a+k}{a}\frac{e^{at}}{2}\left[\begin{array}{l}e^{-2\eta\sqrt{Pr}\sqrt{(a+R-Q)t}}\ erfc(\eta\sqrt{Pr}-\sqrt{(a+R-Q)t})\\+e^{2\eta\sqrt{Pr}\sqrt{(a+R-Q)t}}\ erfc(\eta\sqrt{Pr}+\sqrt{(a+R-Q)t})\end{array}\right]\\-\frac{k}{a}\frac{1}{2}\left[\begin{array}{l}e^{-2\eta\sqrt{Pr}\sqrt{(R-Q)t}}erfc(\eta\sqrt{Pr}-\sqrt{(R-Q)t})\\+e^{2\eta\sqrt{Pr}\sqrt{(R-Q)t}}\ erfc(\eta\sqrt{Pr}+\sqrt{(R-Q)t})\end{array}\right]\end{array}\right]$$

$$-\frac{PrDf\,Sc}{(Sc-Pr)}\left[\begin{array}{l}\frac{a+k}{a}\frac{e^{at}}{2}\left[\begin{array}{l}e^{-2\eta\sqrt{Sc}\sqrt{(a+k)t}}\ erfc(\eta\sqrt{Sc}-\sqrt{(a+k)t})\\+e^{2\eta\sqrt{Sc}\sqrt{(a+k)t}}\ erfc(\eta\sqrt{Sc}+\sqrt{(a+k)t})\end{array}\right]\\-\frac{k}{a}\frac{1}{2}\left[\begin{array}{l}e^{-2\eta\sqrt{Sc}\sqrt{kt}}\ erfc(\eta\sqrt{Sc}-\sqrt{kt})\\+e^{2\eta\sqrt{Sc}\sqrt{kt}}\ erfc(\eta\sqrt{Sc}+\sqrt{kt})\end{array}\right]\end{array}\right], \tag{10}$$

$$C=\frac{1}{2}[e^{-2\eta\sqrt{Sckt}}erfc(\eta\sqrt{Sc}-\sqrt{kt})+e^{2\eta\sqrt{Sckt}}erfc(\eta\sqrt{Sc}+\sqrt{kt})], \tag{11}$$

where

$$\eta=\frac{z}{2\sqrt{t}},\quad a=\frac{\Pr(R-Q)-kSc}{Sc-\Pr},\quad b=\frac{m-\Pr(R-Q)}{\Pr-1}$$

and $C=\frac{m-kSc}{Sc-1}$.

4. Results and Discussion

The results for various values of *k*, *Sc*, *Pr*, *Gr*, *Gc*, *Df*, *h*, *R* and *Q*.

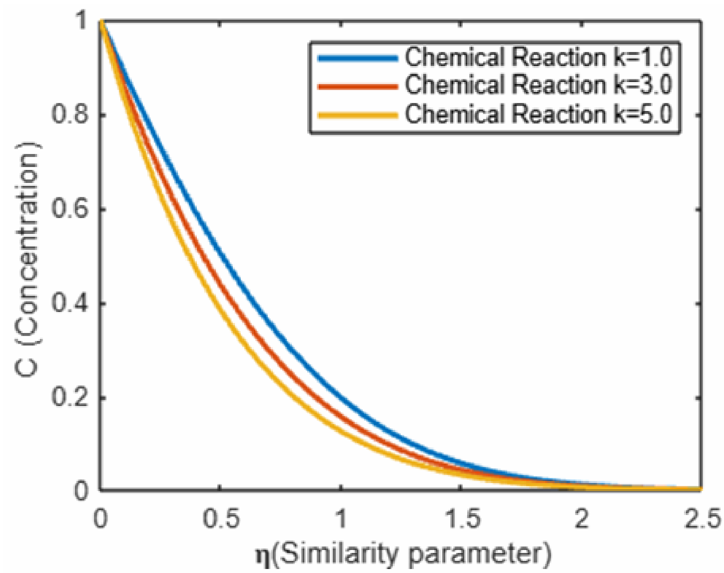

Figure 1. The chemical reaction rate is usually described by a rate equation, which links the changes in the concentrations of reactants and products to their initial concentrations. The specific form of this rate equation is dependent on the reaction mechanism and is determined through experimental techniques. In some situations, a rise in the reaction constant, denoted as '*k*', corresponds to a higher reaction rate. This results in a more rapid consumption of reactants and consequently leads drops in their concentrations as time progresses.

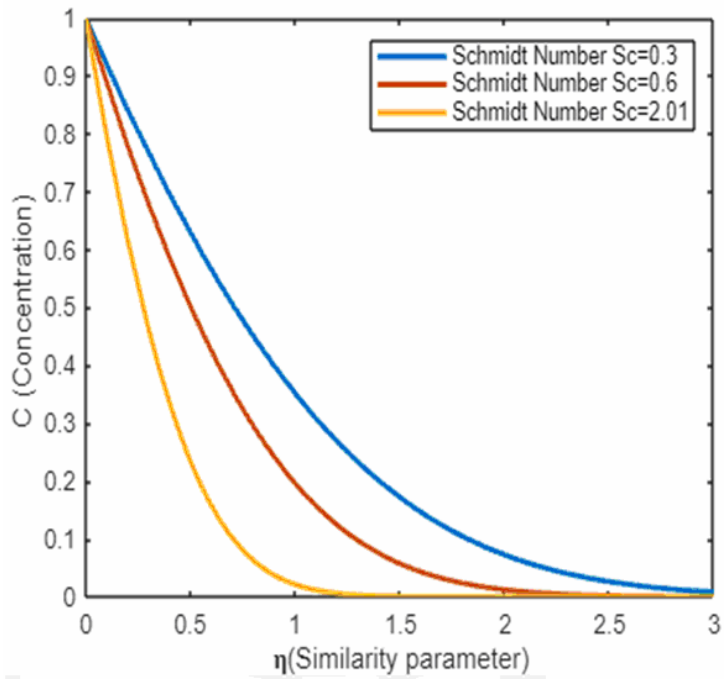

Figure 2. In different circumstances, rising the Schmidt numbers signifies that the diffusivity of a particular species is relatively lower in comparison to the transfer of momentum. This implies that the fluid is more efficient at carrying momentum compared to the specific species in question, like the solute concentration in a liquid. As a result, in such cases, the fluid tends to disperse more easily than the species it is transporting, releads in a decrease in concentration levels.

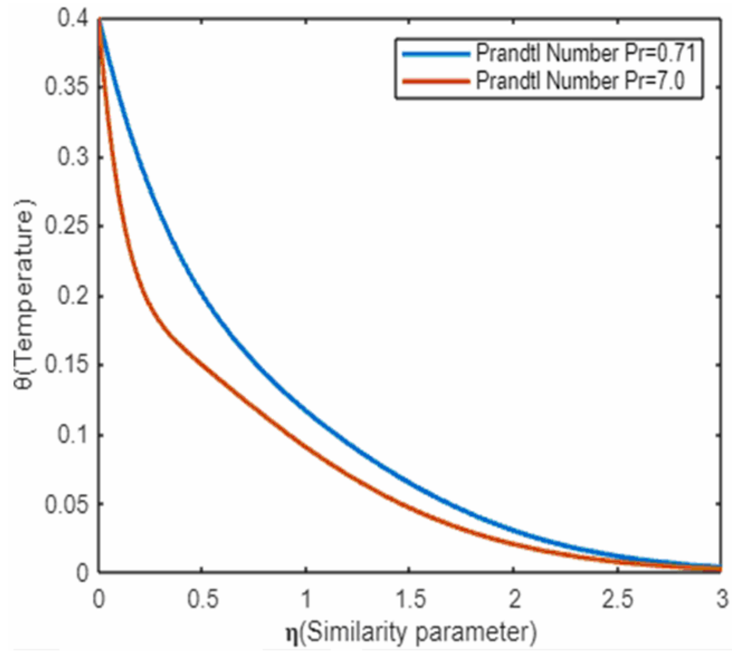

Figure 3. The temperature's behavior concerning the Prandtl number depends on the flow characteristics and boundary conditions. In some scenarios, an increased Prandtl number can result in slower thermal mixing, leading to greater temperature gradients. Conversely, in other instances, it can facilitate quicker heat transfer and a more even temperature distribution.

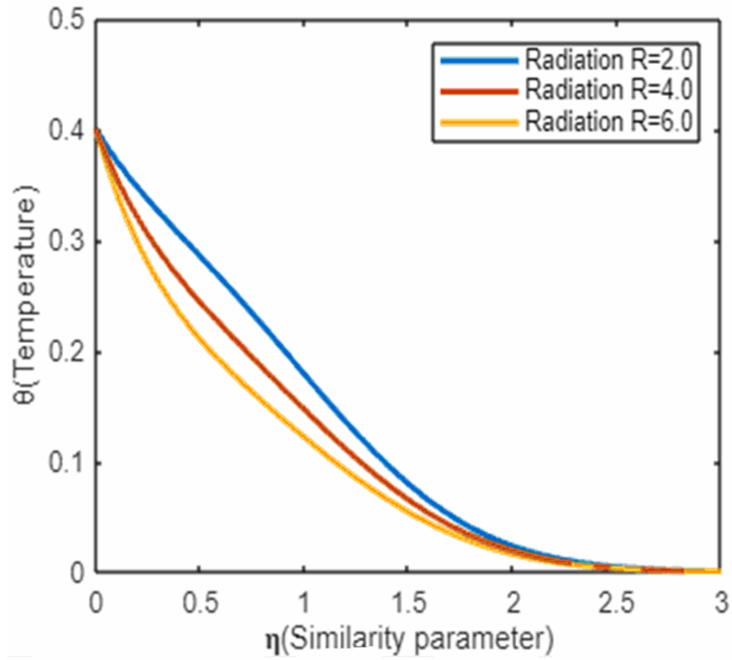

Figure 4. The influence of the radiation parameter on temperature behavior varies according to the particular system and conditions at hand. Typically, an elevation in radiation values might result in a greater influence of radiative heat transfer and could potentially alter the temperature distribution within the system.

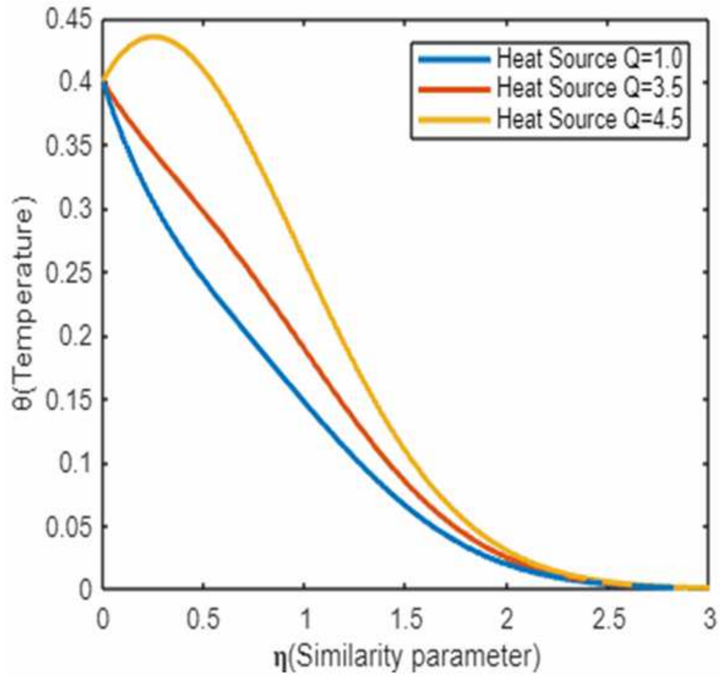

Figure 5. The heat source, denoted as "*Q*", signifies the quantity of thermal energy introduced into a system. This energy input can take the form of external heating, like that from a burner or electrical heating element, or it can originate internally within the system through chemical reactions or other processes. When heat is introduced into a system, it is dispersed among its individual particles, leading to an elevation in their kinetic energy, which, in turn, results in a rise in temperature.

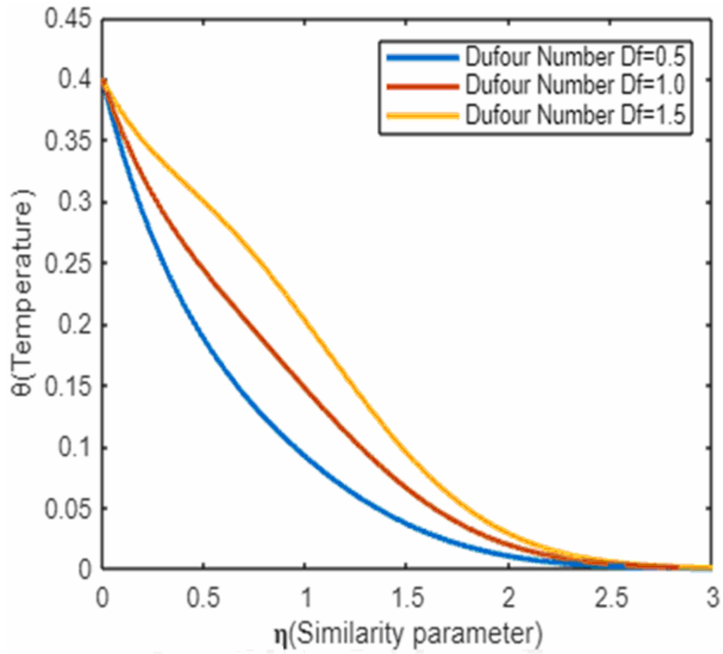

Figure 6. A raise in the Dufour (Df) number suggests a higher relative significance of mass diffusion and thermal diffusion contributions. While this may affect the overall heat transfer characteristics of the flow, it does not influence the direction of the temperature profile, meaning it does not cause either a decrease or increase in temperature.

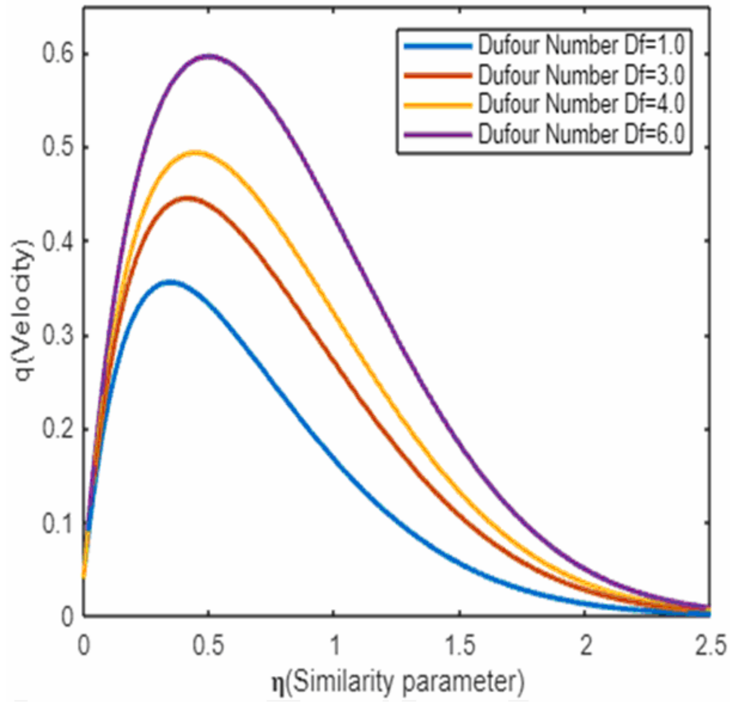

Figure 7. The influence of the Dufour (Df) number on velocity is contingent on the specific flow conditions, boundary conditions, and system geometry in question. The connection between the Dufour number and velocity is more intricate and varies according to the particular flow scenario under consideration.

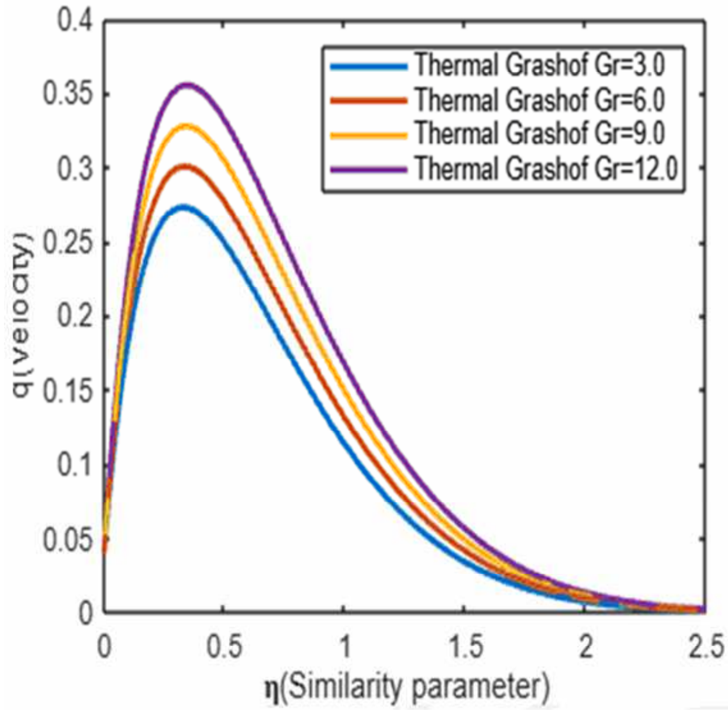

Figure 8. A raise in the thermal Grashof (Gr) number can lead to more vigorous convective motion and result in higher flow velocities. This occurs because higher values of the thermal Grashof (Gr) number indicate a more pronounced buoyancy-driven flow, often due to larger temperature differences or more significant variations in fluid properties, such as density.

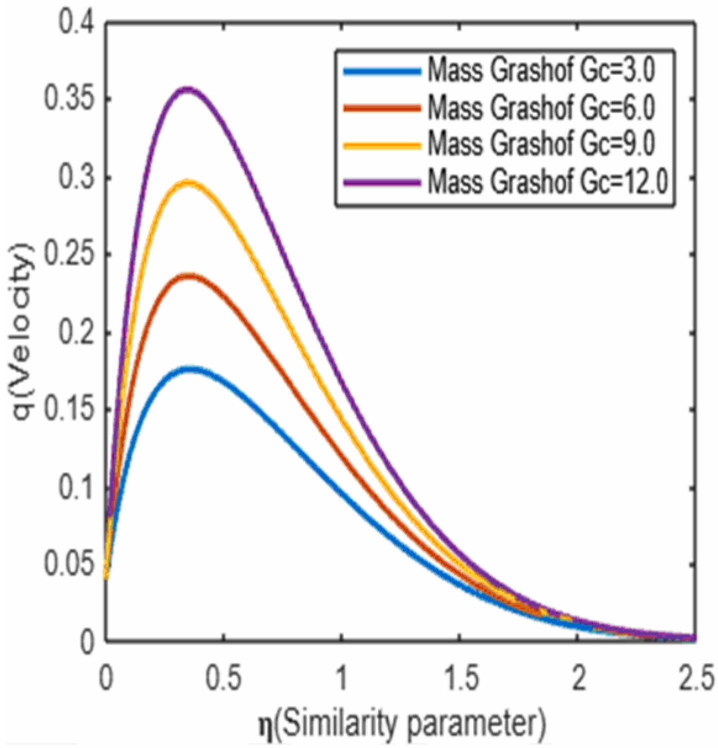

Figure 9. The mass Grashof number is frequently employed to study natural convection flows associated with mass transfer, especially diffusion-driven flows. An increase in the mass Grashof number signifies a more robust buoyancy-driven flow, often caused by greater disparities in density or variations in fluid properties, such as diffusivity. In these scenarios, a higher mass Grashof number encourages more vigorous convective motion and leads to elevated velocity levels. The buoyant forces prompt the fluid to move more swiftly, resulting in higher flow velocities.

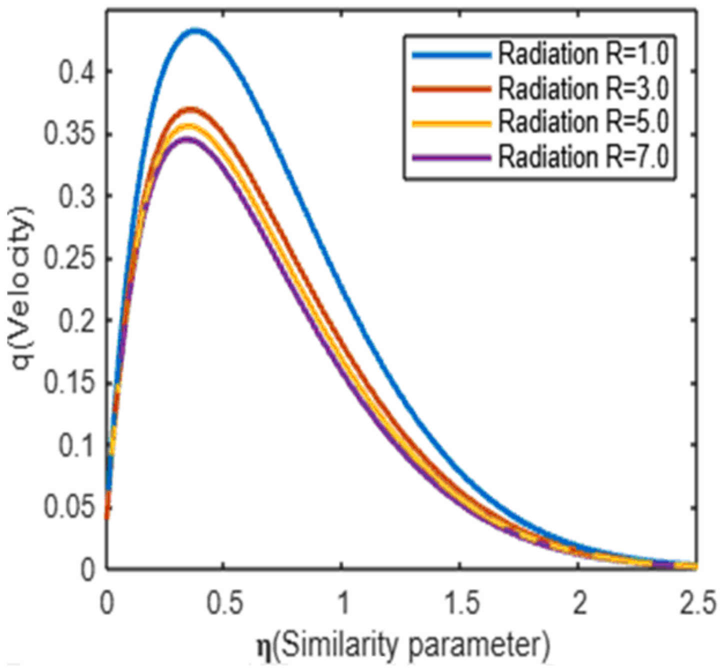

Figure 10. The thermal radiation is commonly linked to radiative transfer of heat which encompasses the transfer of heat through electromagnetic waves, particularly infrared radiation. Typically, the radiation parameter serves as an indicator of the significance of radiative heat transfer in relation to other heat transfer modes like conduction or convection. Although radiative heat transfer can impact the temperature distribution within a system, it does not have a direct effect on the velocity of fluid flow. Velocity is mainly determined by factors such as pressure gradients, fluid properties, and the characteristics of the flow regime (e.g., laminar or turbulent).

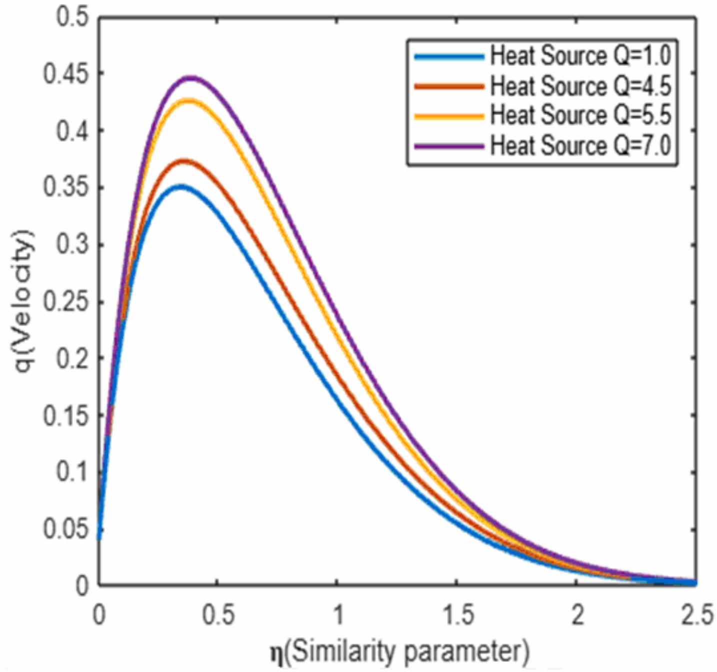

Figure 11. Introducing a heat source into a fluid system has the potential to influence fluid flow and may bring about alterations in velocity. Nonetheless, the precise relationship between the heat source and velocity is intricate. In certain situations, an augmentation of the heat source can indeed result in an elevation of velocity. For instance, in a forced convection system where a fluid is compelled to move through external means like a pump or a fan, augmenting the heat input can lead to an increased flow rate and higher velocities.

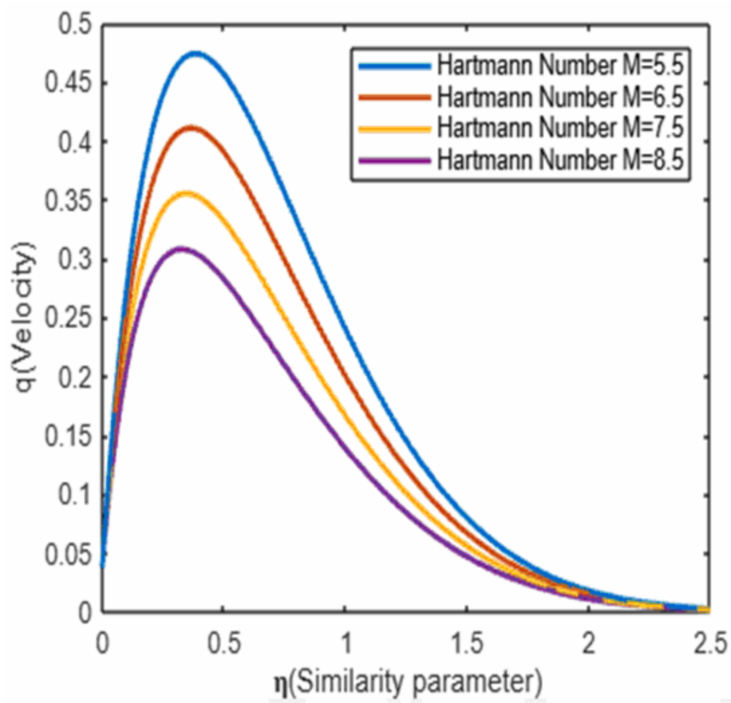

Figure 12. An increase in Hartmann numbers generally leads to a higher magnetic field strength relative to viscous forces. This, in turn, can bring about changes in flow characteristics, like the damping of turbulence or modifications in flow patterns.

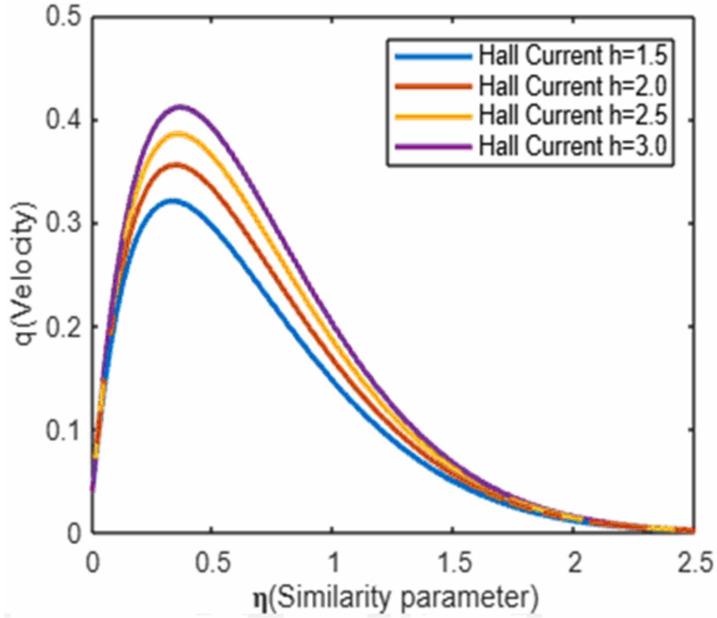

Figure 13. When the Hall current, denoted as ‘*h*’, increases, there is a direct association with an elevation in velocity. As ‘*h*’ increases, speed similarly exhibits a corresponding upward trend. The influence of the Hall current on speed is established through intricate interactions involving the Lorentz force, the electric field, and the magnetic field. These interactions can result in alterations in flow patterns, the stability of the flow, or the emergence of intricate plasma phenomena. However, the precise connection between the Hall current and velocity necessitates a detailed analysis of the particular system in question.

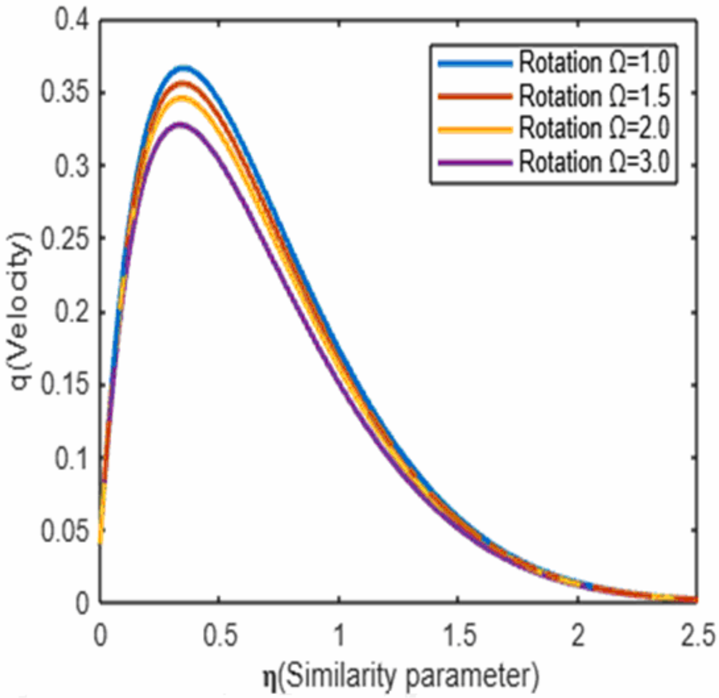

Figure 14. In the realm of fluid dynamics, the existence of rotation can exert a noteworthy impact on flow characteristics. As the rotation parameter escalates, it signifies a more pronounced rotation or angular velocity within the system. This rotational motion can provoke alterations in flow patterns and bring about heightened flow velocities. In specific scenarios, an augmentation in the rotation parameter can amplify circulation or streamline curvature, ultimately resulting in increased velocities. This phenomenon is particularly conspicuous in rotating flows, including swirling flows or flows occurring within rotating machinery.

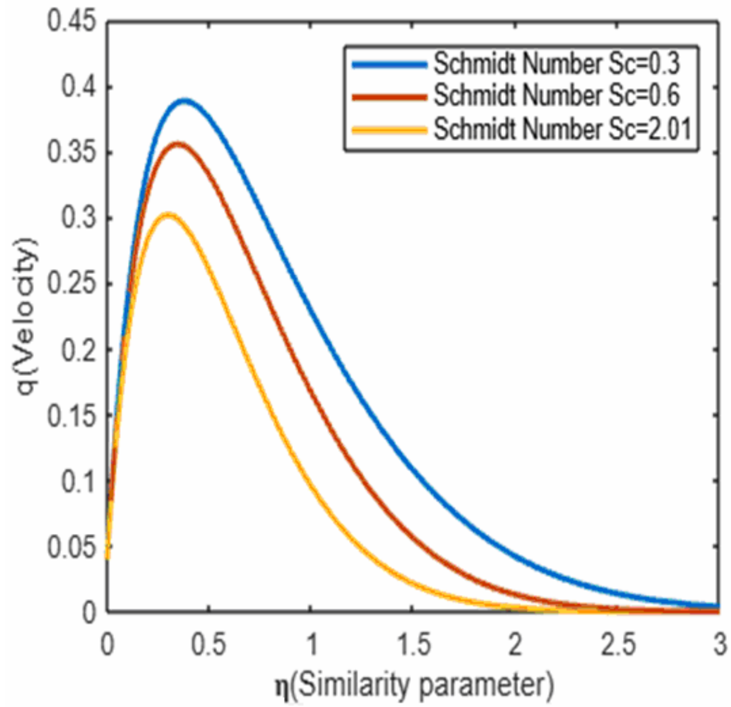

Figure 15. The impact of Schmidt numbers on velocity depends on the specific flow regime, boundary conditions, and the attributes of the mass transfer process. In some cases, an increase in the Schmidt number can indeed result in a reduction in velocity. This situation arises when the mass diffusivity is relatively low compared to the momentum diffusivity, implying that the species being transported (e.g., the concentration of a solute) diffuse at a slower rate than the fluid momentum, thereby causing reduced velocities.

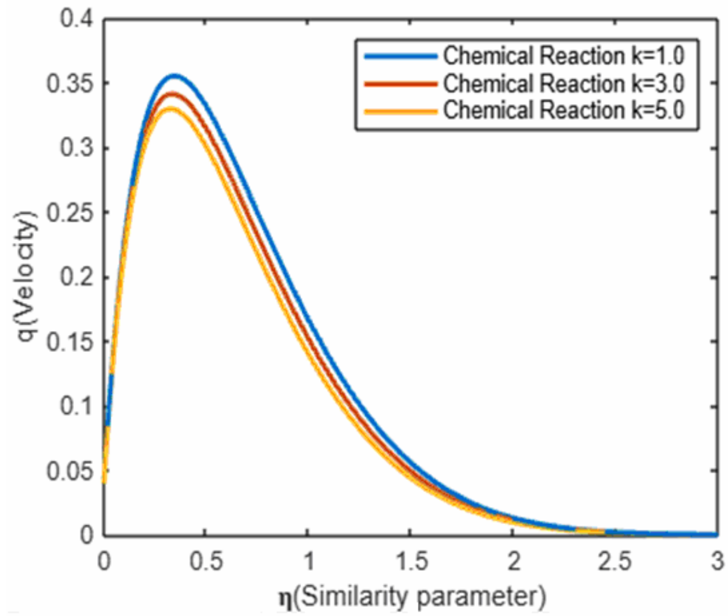

Figure 16. There is no direct and universally applicable connection between the chemical reaction rate (k) and the velocity in fluid flow systems. The chemical reaction rate signifies the pace at which a chemical reaction occurs and is generally independent of the fluid flow velocity. In fluid dynamics, the flow velocity is primarily governed by factors like pressure gradients, boundary conditions, flow geometry, and the nature of the fluid itself. While chemical reactions can impact fluid properties and behavior, their direct influence on velocity is contingent on the specific characteristics of the system and the coupling between chemical reactions and fluid dynamics. In certain scenarios, specific chemical reactions may yield products that influence flow behavior, such as modifying viscosity or altering fluid properties. These alterations can indirectly impact flow velocity.

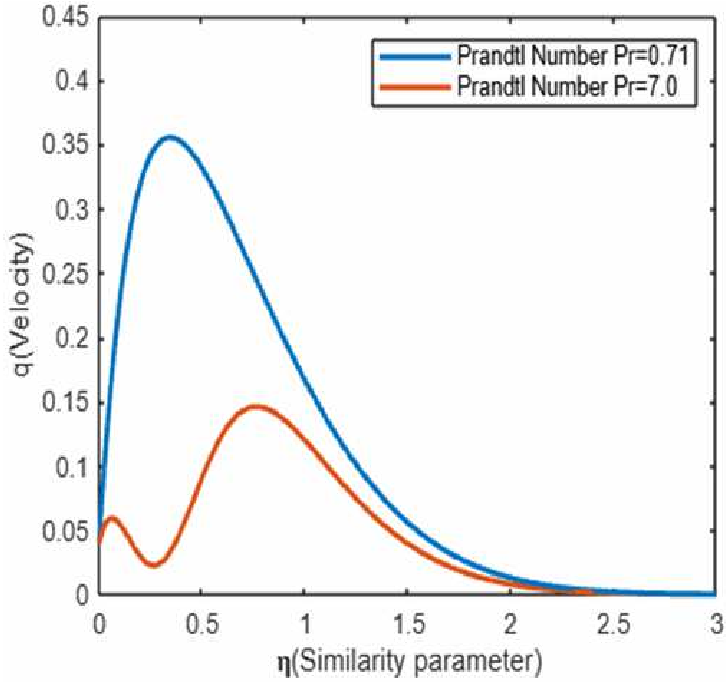

Figure 17. The influence of the Prandtl number on velocity is contingent upon the specific flow regime and the heat transfer mechanisms in play. In specific cases, particularly in forced convection flows where heat transfer plays a significant role, a rise in the Prandtl number may lead to a reduction in velocity. This phenomenon occurs because higher Prandtl numbers are linked to slower thermal diffusion, which leads to larger thermal boundary layers and reduced velocity gradients near solid boundaries.

5. Conclusion

We provide a convenient and captivating framework for computational analysis, with a specific emphasis on the swift isothermal flow along a vertical plate which involves heat and mass transfer. From these calculations, various essential relationships are deduced:

(i) A rise in velocity corresponds to a rise in radiation. The Hartmann number, M, and the Dufour (Df) number lead to a decrease in velocity. Higher Grashof numbers indicate greater fluid velocities, signifying a more significant impact of buoyancy-driven flow. Velocity also rises with the expansion of the heat source, Q, and with the increase in Hall current, h.

(ii) With an increase in radiation (R), temperature decreases. Temperature, on the other hand, rises with an increase in heat source, Q.

(iii) As the rate of chemical reaction, denoted by k, rises, the species' concentration involved tends to decrease. This relationship suggests that a higher reaction rate results into a more rapid conversion of reactants into products, leading to a reduction in their concentrations over time.

In summary, the incorporation of various factors into our research has led to a comprehensive list of findings. Continual additions to our study will allow us to further refine and deepen our understanding.

Acknowledgements

The authors thank the anonymous referees for their valuable suggestions and comments which improved the paper.

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