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Exploration of the Impacts of Hall Effect, Dufour Effect, and Heat Source on Parabolic Flow over an Infinite Vertical Plate in the Presence of Rotation, Chemical Reaction, and Radiation in a Porous Medium

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ABSTRACT

The article focuses on the influence of Hall current, radiation, heat source, and Dufour effects on the unsteady magnetohydrodynamic (MHD) natural convective parabolic flow over a vertical plate fixed within a porous medium. The study involves examining the heat transfer and substance accumulation dynamics when an incompressible fluid flows over a vertically oriented plate. The plate is uniformly heated and undergoes increased velocity due to rotational motion. The researcher applied the Laplace Method to find solutions for the relevant mathematical equations. In this analysis, specific parameters were considered, including Prandtl, Schmidt, Grashof values for heat transfer, and the Grashof value for substance accumulation. The results indicated that factors such as heat source, Hall current, permeability, and Grashof values lead to a corresponding increase in fluid velocity. Conversely, an increase in radiation levels is associated with a decrease in fluid velocity. Temperature, on the other hand, rises with a higher heat source and decreases with an increase in radiation levels.

1. Introduction

Examining the movement of fluids plays a pivotal role in understanding heat transfer within reactors. This analysis has applications across a wide array of systems, including biological systems, household and office appliances, commercial and industrial processes, food handling and preparation, cooling of electronic devices, and building heating, ventilation, and air conditioning (HVAC) systems. It also extends to food freezing and refrigeration processes, among numerous other areas. Rajput and Kumar [1, 2], investigated the impact of radiation, rotation in the context of magnetohydrodynamic fluid movement within porous materials. This fluid motion occurs as it passes by a vertically positioned plate that is impulsively started. Prakash *et al.,* [3] explored the impacts of diffusion-thermo and radiation on the unsteady magnetohydrodynamic (MHD) free convection flow along an impulsively started infinite vertical plate. The plate has variable temperature and uniform

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mass diffusion, and the study takes into account the influence of a magnetic field in the presence of a porous medium. Reddy and colleagues [4] explored effects (thermo-diffusion and diffusion thermo) within the context of steady magnetohydrodynamics. This fluid motion occurs alongside a semi-infinite vertically positioned plate that is in motion, all within a porous medium. Internal energy loss due to viscosity is also considered. The study by Dhanalakshmi *et al.,* [5] examined the impacts of thermo-diffusion effect and diffusion thermo efffect in the context of magnetohydrodynamic movement. This motion transpires next to a surface which is vertical and occurs within porous medium. Kesavaiah and Jahagirdar [6] examined the effects of radiation absorption and chemical reactions on the magnetohydrodynamic (MHD) unsteady free convection flow around an inclined porous plate that is being exponentially accelerated. Kesavaiah and Satyanarayana [7] investigated the phenomena of heat and mass transfer in magnetohydrodynamics (MHD) in the context of unsteady flow past an infinite vertical plate that is exponentially accelerated, taking into account chemical reactions and diffusion-thermo effects (Dufour effect). There is a heat source in the system, and the plate displays uniform mass diffusion and variable temperature. Deka and Soundalgekar [8] research observed that the presence of a first-order chemical transformation leads to a reduction in velocity, potentially hindering the separation of the flow near the plate. Soundalgekar [9] explored how the transfer of mass and currents resulting from free convection influences the motion across a vertically oriented plate that has been impulsively started. In 1998, Helmy [10] conducted research into the dynamics of unsteady magnetohydrodynamic (free) flow that takes place over a porous(filtration) plate positioned vertically. Muthucumaraswamy *et al.,* [11-13] analyzed free convection, focusing on the influence of Hall effects on the magnetohydrodynamic flow of a constant temperature vertical plate in motion with a chemical reaction. Their investigation included the analysis of Hall and Rotation Phenomena on Magnetohydrodynamic Flow over a Vertically Oriented Plate experiencing exponential acceleration, coupled with heat and mass transfer consequences. C. Shanthini [14] conducted an analysis of unsteady natural convection flow along a semi-infinite vertical plate through Porosity. Jose and Selvaraj [15] and Sellvaraj *et al.,* [16] examined the influence of rotation on the transfer of thermal and material due to convection, along with the inclusion of a first-order chemical reaction. D. Lakshmikaanth *et al.,* [17, 18] examined the effects of heat source, rotation, and radiation. Aruna *et al.,* [19] explained briefly why the relevance of the magnetic parameter M has increased and the rise of the thermal radiation parameter R has decreased. Selvaraj A and Jyothi [20] have reported the effects of a heat source on magnetohydrodynamics (MHD) and radiation absorption in the flow of a fluid past an exponentially accelerated vertical plate. The study focused on a porous medium, considering a vertically oriented plate with exponential acceleration, temperature variation following an exponential profile, and mass diffusion. Sharma [21] who elucidated that an escalation in the heat source leads to an upward trajectory in both speed and temperature, signifying an augmentation in their respective magnitudes. Alam *et al.,* [22] observed that the utilization of extraction manages the development of hydrodynamic, thermal, and accumulation boundary layers. Prabhakar Reddy *et al.,* [23] investigated the impact of transient natural convective conditions, Soret effect (Sr), and chemical transformations with radiative MHD flow. Prabhakar Reddy and L. Joseph Sademaki [24] examined the influence of Newtonian heating on the time-dependent natural convection of magnetohydrodynamic (MHD) Casson flow. The investigation considers influential factors such as heat sink and internal frictional heating. Prabhakar Reddy and Makinde investigated the flow around a vertically oscillating porous plate situated within porous medium. Noteworthy factors considered in the analysis include thermal radiation, chemical reaction, and heat absorption. Prabhakar Reddy has documented several studies on Ref. [25-31] which reveal that (i) concluded in his study that the rates of both thermal and material transfer decrease with an increase in the rate of a chemical transformation. (ii) concluded from another study that the concentration decreases with an increase in Schmidth number (Sc) and chemical transformation(k), while the opposite trend is observed when Soret number and time are increased. (iii) Examined the flow around a vertically oriented plate that undergoes impulsive motion and oscillation, featuring a temperature that varies and constant mass diffusion. (iv) Examined the flow around a vertically moving porous plate with Newtonian heating in an impulsive manner, considering the impact of hall current. (v) Investigated the impacts of chemical transformation on an unsteady magnetohydrodynamics combined forced and natural convection flow with the accumulation transfer of previously and spontaneously positioned infinite vertical surface. Presentations have been made under the influence of a magnetic field oriented transversely. Prabhakar Reddy and Peter [32] showed that the magnetic parameter has a decelerating effect on the primary fluid velocity, whereas it induces an opposite effect on the secondary fluid velocity. Additionally, the (Pr) Prandtl number tends to reduce the temperature of the fluid. Hetnarski [33, 34] presents an algorithm for the formulas of inverse Laplace transforms.

2. Numerical Formulation

In this context, we consider a non-conductive vertical plate positioned at z = 0, through which a viscous and incompressible fluid, capable of conducting current, is flowing. The x coordinate is positioned vertically, and the z coordinate is at right angles to a plate with velocity represented by q=t^2. It should be noted that the pressure remains constant across the entire flow field. The obtained results are based on the fulfilment 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:

$$\frac{\partial \mathrm{u}^*}{\partial \mathrm{t}^*} - 2\Omega \mathrm{v}^* = \vartheta \frac{\partial^2 u^*}{\partial z^{*2}} + g\beta(T^* - T_\infty^*) + g\beta(C^* - C_\infty^*) - \frac{\sigma B_0^2 \mu^2 (u^* + m_1 v^*)}{\rho(1+m_1^2)} - \frac{\vartheta u}{k_1} \tag{1}$$

$$\frac{\partial v^*}{\partial t^*} + 2\Omega \mathrm{u}^* = \vartheta \frac{\partial^2 v^*}{\partial z^{*2}} + \frac{\sigma B_0^2 \mu^2 (m_1 u^* - v^*)}{\rho(1+m_1^2)} - \frac{\vartheta v}{k_1} \text{ -} \tag{2}$$

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

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

The conditions are

$$\begin{aligned} &t^* \leq 0 : u^* = 0 \ , \ v^* = 0 , T^* = T_\infty^* , C^* = C_\infty^* \ \forall \, z^* \leq 0. \\ &t^* > 0 : u^* = u_0 (t^*)^2 , v^* = 0, \ \ T^* = T_\infty^* , C^* = C_\infty^* \ at \ \ z^* = 0 \\ &t^* > 0 \text{:} \ u^* \to \ 0, v^* \to 0, T^* \to \ T_\infty^* , C^* \to \ C_\infty^* \ as \, z^* \to \infty. \end{aligned} \tag{5}$$

The consequent dimensionless aggregate is

$$Z = \frac{z^* u_0}{v}, t = \frac{t^* u_0^2}{v}, U = \frac{u}{u_0}, \theta = \frac{T^* - T_\infty^*}{T_W^* - T_\infty^*} \ , C = \frac{C^* - C_\infty^*}{C_W^* - C_\infty^*}$$

$$G_r = \frac{g\beta v (T_W^* - T_\infty^*)}{u_0^3}, G_C = \frac{g\beta^* v (C_W^* - C_\infty^*)}{u_0^3}, M^2 = \frac{\sigma B_0^2}{\rho} \left(\frac{v}{u_0^2}\right)^{1/3} \tag{6}$$

$P_r = \frac{\mu C_p}{k}$, $K = k_1 \left(\frac{v}{u_0^2}\right)^{\frac{1}{3}}$, $S_c = \frac{v}{D}$

Eq. (1) + i × Eq. (2) and putting velocity q = u+iv we get ,

$$\frac{\partial q}{\partial t} = G_r\theta + G_c c + \frac{\partial^2 q}{\partial z^2} - \left(m + \frac{1}{p}\right) q \quad where\ m = \frac{M^2}{(1+\mathrm{h}i)} + 2\Omega i \tag{7}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2} - R\theta + Q\theta + \frac{D_m K_T}{C_s C_p}\frac{\partial^2 C}{\partial z^2} \tag{8}$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial z^2} - kc \tag{9}$$

With conditions,

$$\begin{aligned} &q = \theta = c = 0\ for\ all\ z, t \le 0 \\ &q = t^2, \theta = c = 1\ for\ all\ z\ and\ t = 0 \\ &q \to 0, \theta \to 0, C \to 0\ as\ z \to \infty. \end{aligned} \tag{10}$$

3. Results and Figures

Solving the Eq. (7) $\frac{\partial q}{\partial t} = G_r\theta + G_c c + \frac{\partial^2 q}{\partial z^2} - \left(m + \frac{1}{p}\right) q$,

Using Inverse Laplace technique, we get

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

$$+\frac{G_r}{(P_r-1)}\left\{\begin{array}{l}\frac{e^{bt}}{2b}\left[\begin{array}{l}e^{-2\eta\sqrt{mt+\frac{t}{p}+bt}}erfc\left(\eta-\sqrt{(mt+\frac{t}{p}+bt)}\right)\\ +e^{2\eta\sqrt{mt+\frac{t}{p}+bt}}erfc\left(\eta+\sqrt{(mt+\frac{t}{p}+bt)}\right)\end{array}\right]\\ -\frac{1}{2b}\left[\begin{array}{l}e^{-2\eta\sqrt{mt+\frac{t}{p}}}erfc\left(\eta-\sqrt{mt+\frac{t}{p}}\right)\\ +e^{2\eta\sqrt{mt+\frac{t}{p}}}erfc\left(\eta+\sqrt{mt+\frac{t}{p}}\right)\end{array}\right]\end{array}\right\}$$

$$-\frac{G_c}{c(S_c-1)}\left\{\begin{array}{l}\frac{e^{ct}}{2}\left[\begin{array}{l}e^{-2\eta\sqrt{mt+\frac{t}{p}+ct}}erfc\left(\eta-\sqrt{mt+\frac{t}{p}+ct}\right)\\ +e^{2\eta\sqrt{mt+\frac{t}{p}+ct}}erfc\left(\eta+\sqrt{mt+\frac{t}{p}+ct}\right)\end{array}\right]\\ -\frac{1}{2}\left[\begin{array}{l}e^{-2\eta\sqrt{mt+\frac{t}{p}}}erfc\left(\eta-\sqrt{mt+\frac{t}{p}}\right)\\ +e^{2\eta\sqrt{mt+\frac{t}{p}}}erfc\left(\eta+\sqrt{mt+\frac{t}{p}}\right)\end{array}\right]\end{array}\right\}$$

$$+\frac{G_r}{(P_r-1)}\left\{\frac{P_rD_fS_c}{(S_c-P_r)}\left[\begin{array}{r}\left[\frac{k}{2ab}\left[e^{-2\eta\sqrt{mt+\frac{t}{p}}}erfc\left(\eta-\sqrt{mt+\frac{t}{p}}\right)+e^{2\eta\sqrt{mt+\frac{t}{p}}}erfc\left(\eta+\sqrt{mt+\frac{t}{p}}\right)\right]\right]\\ +\frac{e^{at}(a+k)}{2a^2-2ab}\text{-}\left[\begin{array}{l}e^{2(-\eta)\sqrt{mt+\frac{t}{p}+at}}erfc\left(\eta-\sqrt{mt+\frac{1}{p}t+at}\right)\\ +e^{2\eta\sqrt{mt+\frac{t}{p}+at}}erfc\left(\eta+\sqrt{mt+\frac{1}{p}t+at}\right)\end{array}\right]\\ -\frac{e^{bt}(b+k)}{2ba-b^2}\left[\begin{array}{l}e^{2(-\eta)\sqrt{mt+\frac{t}{p}+bt}}erfc\left(\eta-\sqrt{mt+\frac{1}{p}t+bt}\right)\\ +e^{2\eta\sqrt{mt+\frac{t}{p}+bt}}erfc\left(\eta+\sqrt{mt+\frac{1}{p}t+bt}\right)\end{array}\right]\end{array}\right]\right\}$$

$$-\frac{G_r}{(S_c-1)}\frac{P_rD_fS_c}{(S_c-P_r)}\begin{bmatrix} \left[\frac{k}{2ac}\left[mt+\frac{t}{p}\right]\right] \\ +\frac{e^{at}(a+k)}{2a^2-2ab}\begin{bmatrix} e^{-2\eta\sqrt{mt+\frac{t}{p}+at}}erfc\left(\eta-\sqrt{mt+\frac{1}{p}t+at}\right) \\ +e^{2\eta\sqrt{mt+\frac{t}{p}+at}}erfc\left(\eta+\sqrt{mt+\frac{1}{p}t+at}\right) \end{bmatrix} \\ -\frac{e^{ct}(c+k)}{2ac-2c^2}\begin{bmatrix} e^{-2\eta\sqrt{mt+\frac{t}{p}+ct}}erfc\left(\eta-\sqrt{mt+\frac{1}{p}t+ct}\right) \\ +e^{2\eta\sqrt{mt+\frac{t}{p}+ct}}erfc\left(\eta+\sqrt{mt+\frac{1}{p}t+ct}\right) \end{bmatrix} \end{bmatrix}$$

$$+\frac{G_r}{(S_c-1)}\frac{P_rD_fS_c}{(S_c-P_r)}\begin{bmatrix} \left[\frac{k}{2ac}\begin{bmatrix} e^{-2\eta\sqrt{S_ckt}}erfc\left(\eta\sqrt{S_c}-\sqrt{kt}\right) \\ +e^{2\eta\sqrt{S_ckt}}erfc\left(\eta\sqrt{S_c}+\sqrt{kt}\right) \end{bmatrix}\right] \\ +\frac{a+k}{a(a-c)}\frac{e^{at}}{2}\begin{bmatrix} e^{-2\eta\sqrt{S_c}\sqrt{kt+at}}erfc\left(\eta\sqrt{S_c}-\sqrt{kt+at}\right) \\ +e^{2\eta\sqrt{S_c}\sqrt{kt+at}}erfc\left(\eta\sqrt{S_c}+\sqrt{kt+at}\right) \end{bmatrix} \\ -\frac{c+k}{c(a-c)}\frac{e^{ct}}{2}\begin{bmatrix} e^{-2\eta\sqrt{S_c}\sqrt{kt+ct}}erfc\left(\eta\sqrt{S_c}-\sqrt{kt+ct}\right) \\ +e^{2\eta\sqrt{S_c}\sqrt{kt+ct}}erfc\left(\eta\sqrt{S_c}+\sqrt{kt+ct}\right) \end{bmatrix} \end{bmatrix}$$

$$-\frac{G_r}{(P_r-1)}\left\{\begin{array}{c} \frac{e^{bt}}{2b}\begin{bmatrix} e^{-2\eta\sqrt{P_r}\sqrt{bt+Rt-Qt}}erfc\left(\eta\sqrt{P_r}-\sqrt{bt+Rt-Qt}\right) \\ +e^{2\eta\sqrt{P_r}\sqrt{bt+Rt-Qt}}erfc\left(\eta\sqrt{P_r}+\sqrt{bt+Rt-Qt}\right) \end{bmatrix} \\ -\frac{1}{2b}\begin{bmatrix} e^{-2\eta\sqrt{P_r}\sqrt{Rt-Qt}}erfc\left(\eta\sqrt{P_r}-\sqrt{Rt-Qt}\right) \\ +e^{2\eta\sqrt{P_r}\sqrt{Rt-Qt}}erfc\left(\eta\sqrt{P_r}+\sqrt{Rt-Qt}\right) \end{bmatrix} \\ +\frac{P_rD_fS_c}{(S_c-P_r)}\begin{bmatrix} \left[\frac{k}{2ab}\begin{bmatrix} e^{-2\eta\sqrt{P_r}\sqrt{Rt-Qt}}erfc\left(\eta\sqrt{P_r}-\sqrt{Rt-Qt}\right) \\ +e^{2\eta\sqrt{P_r}\sqrt{Rt-Qt}}erfc\left(\eta\sqrt{P_r}+\sqrt{Rt-Qt}\right) \end{bmatrix}\right] \\ +\frac{a+k}{a(a-b)}\frac{e^{at}}{2}\begin{bmatrix} e^{-2\eta\sqrt{P_r}\sqrt{at+Rt-Qt}}erfc\left(\eta\sqrt{P_r}-\sqrt{at+Rt-Qt}\right) \\ +e^{2\eta\sqrt{P_r}\sqrt{at+Rt-Qt}}erfc\left(\eta\sqrt{P_r}+\sqrt{at+Rt-Qt}\right) \end{bmatrix} \\ -\frac{b+k}{b(a-b)}\frac{e^{bt}}{2}\begin{bmatrix} e^{-2\eta\sqrt{P_r}\sqrt{bt+Rt-Qt}}erfc\left(\eta\sqrt{P_r}-\sqrt{bt+Rt-Qt}\right) \\ +e^{2\eta\sqrt{P_r}\sqrt{bt+Rt-Qt}}erfc\left(\eta\sqrt{P_r}+\sqrt{bt+Rt-Qt}\right) \end{bmatrix} \end{bmatrix} \end{array}\right\}$$

$$-\frac{G_c}{c(S_c-1)}\left\{\begin{matrix}\frac{e^{ct}}{2}\left[\begin{matrix}e^{-2\eta\sqrt{S_c}\sqrt{kt+ct}}erfc\left(\eta\sqrt{S_c}-\sqrt{kt+ct}\right)\\+e^{2\eta\sqrt{S_c}\sqrt{kt+ct}}erfc\left(\eta\sqrt{S_c}+\sqrt{kt+ct}\right)\end{matrix}\right]\\-\frac{1}{2}\left[\begin{matrix}e^{-2\eta\sqrt{S_c}\sqrt{kt}}erfc\left(\eta\sqrt{S_c}-\sqrt{kt}\right)\\+e^{2\eta\sqrt{S_c}\sqrt{kt}}erfc\left(\eta\sqrt{S_c}+\sqrt{kt}\right)\end{matrix}\right]\end{matrix}\right\} \tag{11}$$

Solving Eq. (8) and Eq. (9) we get Temperature θ and Concentration C as

$$\theta=\frac{1}{2}\left[\begin{matrix}e^{-2\eta\sqrt{P_rRt-PrQt}}\,erfc\left(\eta\sqrt{Pr}-\sqrt{Rt-Qt}\right)\\+e^{2\eta\sqrt{P_rRt-PrQt}}\,erfc\left(\eta\sqrt{Pr}+\sqrt{Rt-Qt}\right)\end{matrix}\right]$$

$$+\frac{P_rD_fS_c}{S_c-P_r}\left[\begin{matrix}\frac{a+k}{a}\frac{e^{at}}{2}\left[\begin{matrix}e^{-2\eta\sqrt{P_rat+P_rRt-PrQt}}\,erfc\left(\eta-\sqrt{at+Rt-Qt}\right)\\+e^{2\eta\sqrt{P_rat+P_rRt-PrQt}}\,erfc\left(\eta+\sqrt{at+Rt-Qt}\right)\end{matrix}\right]\\-\frac{k}{2a}\left[\begin{matrix}e^{-2\eta\sqrt{P_rRt-PrQt}}\,erfc\left(\eta\sqrt{P_r}-\sqrt{Rt-Qt}\right)\\+e^{2\eta\sqrt{P_rRt-PrQt}}\,erfc\left(\eta\sqrt{P_r}+\sqrt{Rt-Qt}\right)\end{matrix}\right]\end{matrix}\right] \tag{12}$$

$$-\frac{P_rD_fS_c}{S_c-P_r}\left[\begin{matrix}\frac{a+k}{a}\frac{e^{at}}{2}\left[\begin{matrix}e^{-2\eta\sqrt{S_cat+S_ckt}}\,erfc\left(\eta\sqrt{S_c}-\sqrt{at+kt}\right)\\+e^{2\eta\sqrt{S_cat+S_ckt}}\,erfc\left(\eta\sqrt{S_c}+\sqrt{at+kt}\right)\end{matrix}\right]\\-\frac{k}{2a}\left[\begin{matrix}e^{-2\eta\sqrt{S_ckt}}\,erfc\left(\eta\sqrt{S_c}-\sqrt{kt}\right)\\+e^{2\eta\sqrt{S_ckt}}\,erfc\left(\eta\sqrt{S_c}+\sqrt{kt}\right)\end{matrix}\right]\end{matrix}\right]$$

$$C=\frac{1}{2}\left[e^{-2\eta\sqrt{Sckt}}\,erfc\left(\eta\sqrt{Sc}-\sqrt{kt}\right)+e^{2\eta\sqrt{Sckt}}\,erfc\left(\eta\sqrt{Sc}+\sqrt{kt}\right)\right] \tag{13}$$

$$where\ \eta=\frac{z}{2\sqrt{t}}\ ,a=\frac{Pr(R-Q)-S_ck}{S_c-Pr}\ \ ,b=\frac{m+\frac{1}{p}-P_rR+P_rQ}{P_r-1}\,and\ c=\frac{m+\frac{1}{p}-S_ck}{S_c-1}$$

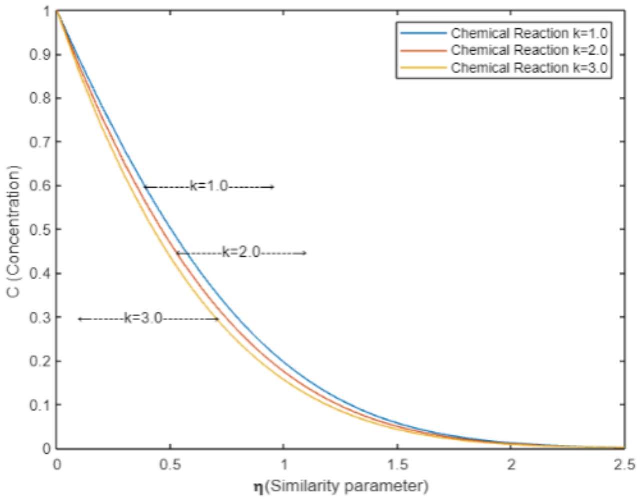

Fig. 1. Concentration profile for different values for chemical reaction

A rate equation connecting the reactant and product concentrations' rate of change to their respective concentrations illustrates the steps of a chemical reaction in Figure 1. The exact form of this rate equation varies depending on the reaction mechanism and is inferred through experimental methods. Sometimes, an increase in the reaction constant, or 'k,' results in an increase in the reaction rate. Reactant depletion is accelerated by Eq. (13), which causes a decrease in reactant concentrations over time.

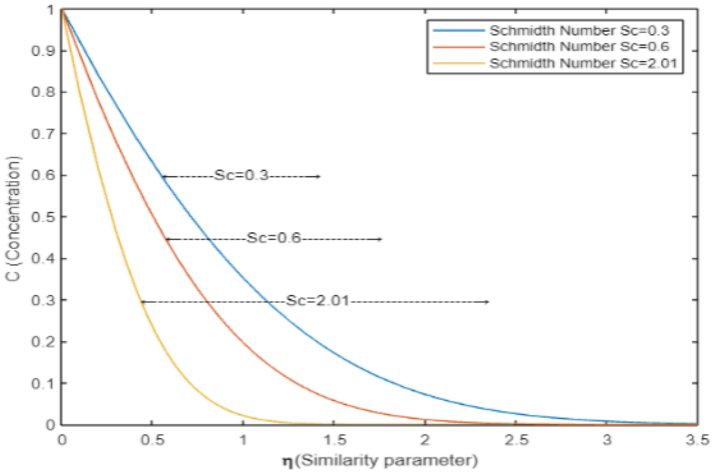

Fig. 2. Concentration profile for different values for Schmidth Number

An increase in the Schmidt number (Sc) in Figure 2 indicates a lower diffusivity of the species when compared to momentum transfer. This suggests that the fluid—such as the solute concentration in a liquid—is more effective at carrying momentum than the particular species being studied. According to Eq. (13) the fluid tends to disperse more quickly than the species it is carrying, which lowers the concentration levels.

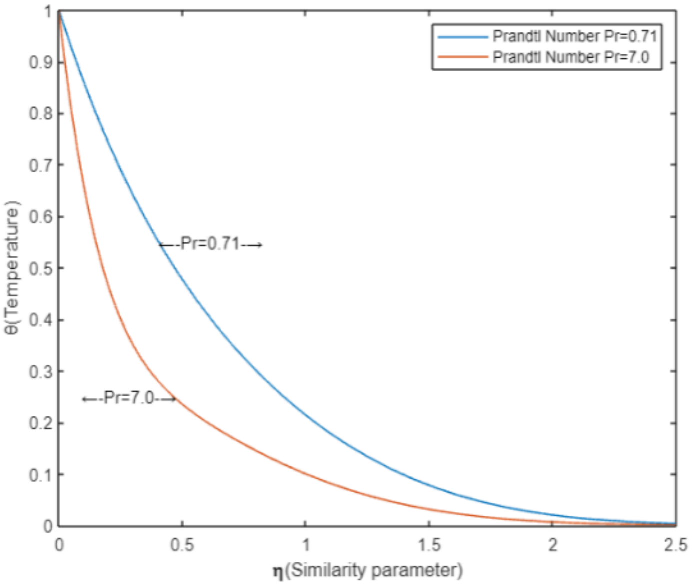

Fig. 3. Temperature profile for different values for Prandtl number

Figure 3 illustrates how flow dynamics and boundary conditions affect the temperature response in relation to the Prandtl number. In some cases, a greater Prandtl number can result in less thermal mixing, which makes temperature gradients steeper. On the other hand, in certain situations, it may promote faster heat transfer and a more uniform temperature distribution from Eq. (12).

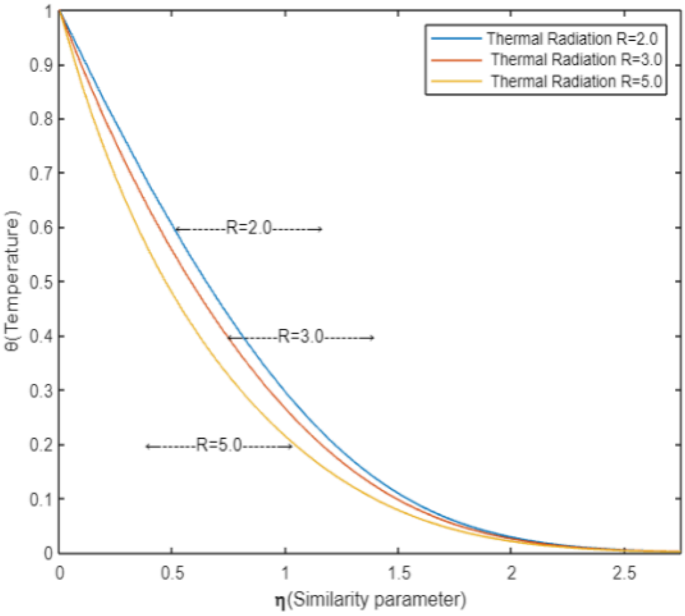

Fig. 4. Temperature profile for different values for thermal radiation

The investigation of radiation's effect on temperature in Figure 4 is contingent upon the specific system and conditions being studied. Radiative heat transfer generally has a greater effect when radiation levels rise. In the example above, a rise in radiation values causes the temperature to decline according to Eq. (12).

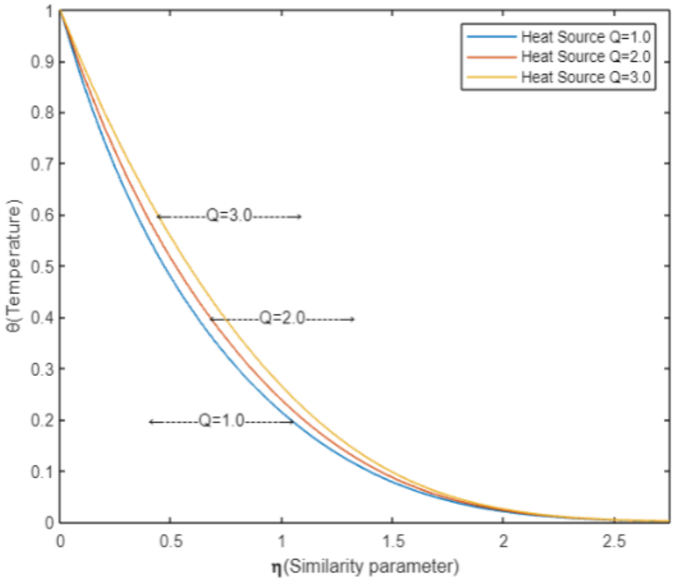

Fig. 5. Temperature profile for different values for heat source

The Heat Source, represented by Q in Figure 5, measures the amount of thermal energy added to a system. This energy can be produced internally by chemical reactions or other mechanisms, or it can come from external sources such as burners or electrical heating elements. When heat is added to a system, the thermal energy is distributed among its constituents, increasing particle motion and kinetic energy. A rise in temperature is correlated with this increased kinetic energy. An increase in the heat source's quantity (Q), as determined by Eq. (12), usually causes the temperature to rise.

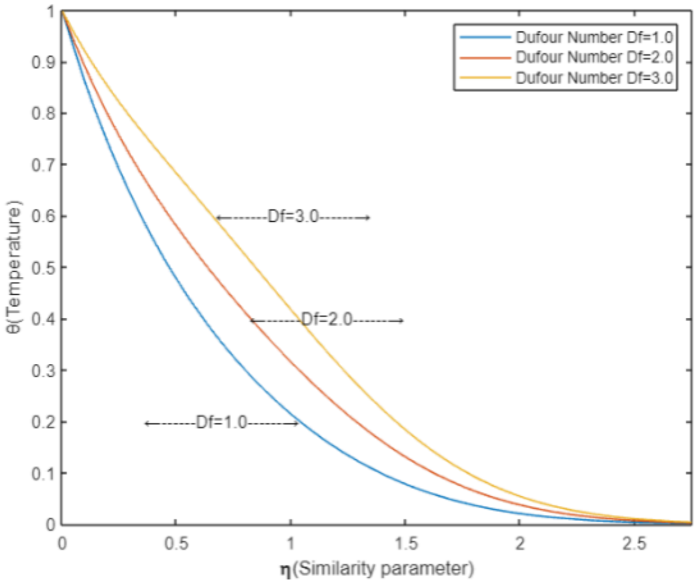

Fig. 6. Temperature profile for different values for Dufour number

An elevation in the Dufour number, using Eq. (12), typically indicates a rise in temperature. In Figure 6, the analysis focuses on the Dufour number, denoted as Df. Df is a dimensionless number used in fluid mechanics to describe the ratio of heat transfer due to molecular diffusion to heat transfer due to mass flow. When Df is low, mass diffusion is dominant.

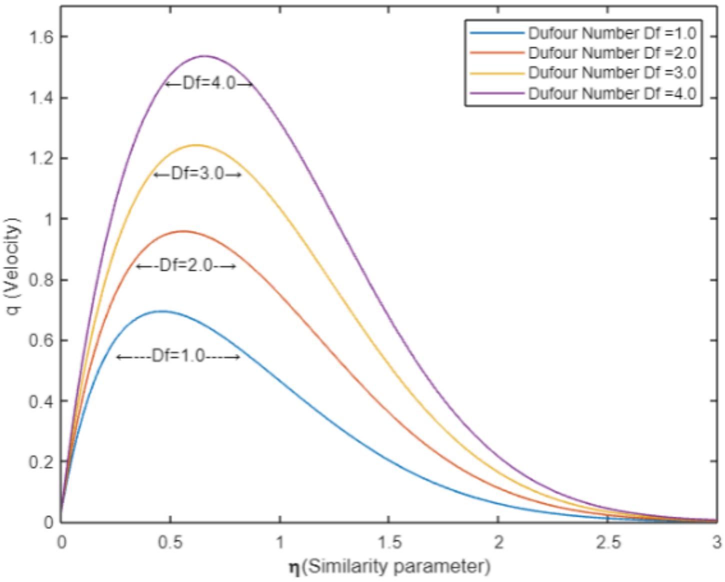

Fig. 7. Velocity profile for different values for Dufour number

From Eq. (11) stating that an increase in the Dufour number causes an increase in fluid velocity does not apply to the indirect and complex relationship between the two variables shown in Figure 7. The particular behaviour would be contingent upon the fluid's properties and the specifics of the system under examination. An elevated Dufour number is indicated in the diagram above as leading to increased velocity.

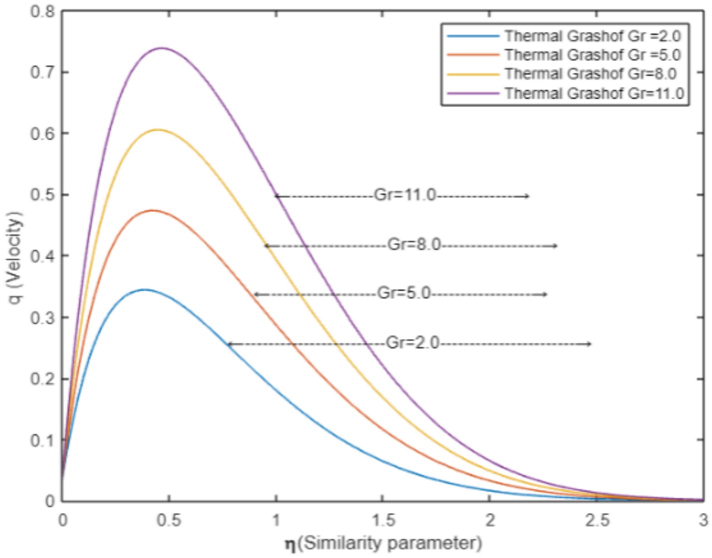

Fig. 8. Velocity profile for different values for Thermal Grashof

As seen in Figure 8, an increase in the thermal Grashof number can stimulate more vigorous convective motion, which could result in higher flow velocities. Higher thermal Grashof numbers indicate stronger buoyancy-driven flow, which can result from wider temperature differences or more variations in fluid properties like density. This is why this phenomenon happens. An increase in the thermal Grashof number from Eq. (11) can promote more robust convective motion and possibly lead to higher flow velocities.

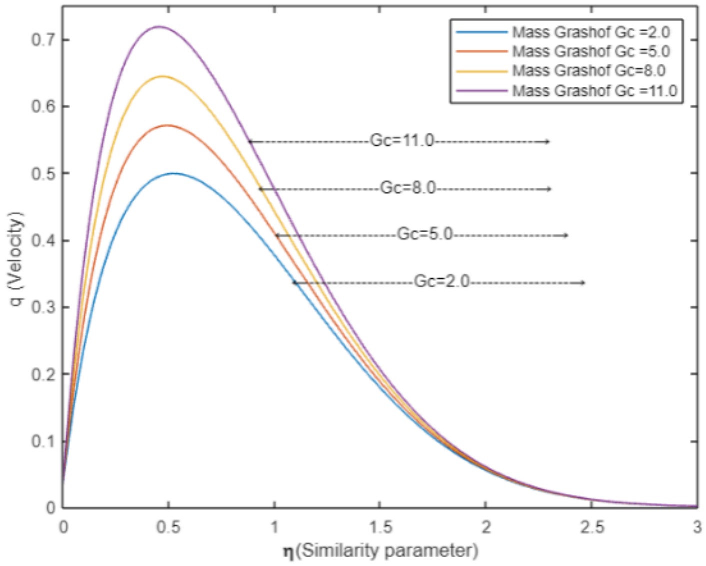

Fig. 9. Velocity profile for different values of Mass Grashof

The Accumulation Grashof number is commonly used to analyse natural convection flows that involve mass transfer, such as diffusion-driven flows. It is derived from the result of Eq. (11) and Figure 9. Greater buoyancy-driven flow is indicated by a higher Mass Grashof number, which can be attributed to larger density differences or increased fluid property variations like diffusivity. Higher Mass Grashof numbers in these situations promote stronger convective motion, which raises velocity levels as buoyant forces cause the fluid to move faster.

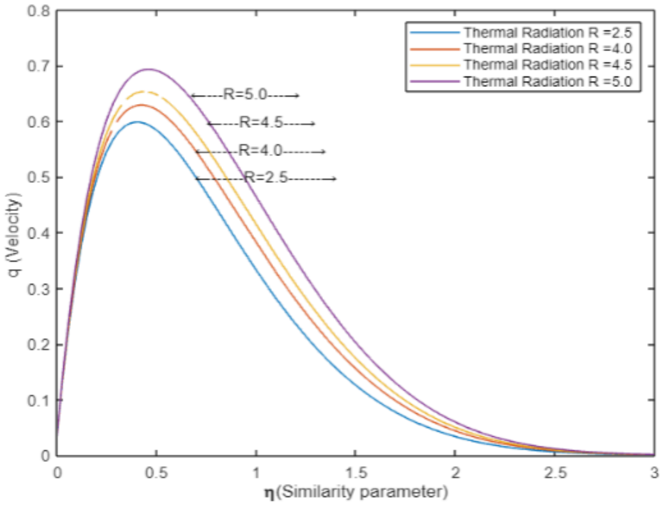

Fig. 10. Velocity profile for different values for thermal radiation

Radiative heat transfer in Figure 10 usually has no direct effect on fluid flow velocity, but it can affect the temperature distribution within a system. On the other hand, the data in Eq. (11) indicates that a rise in velocity is correlated with an increase in radiation values.

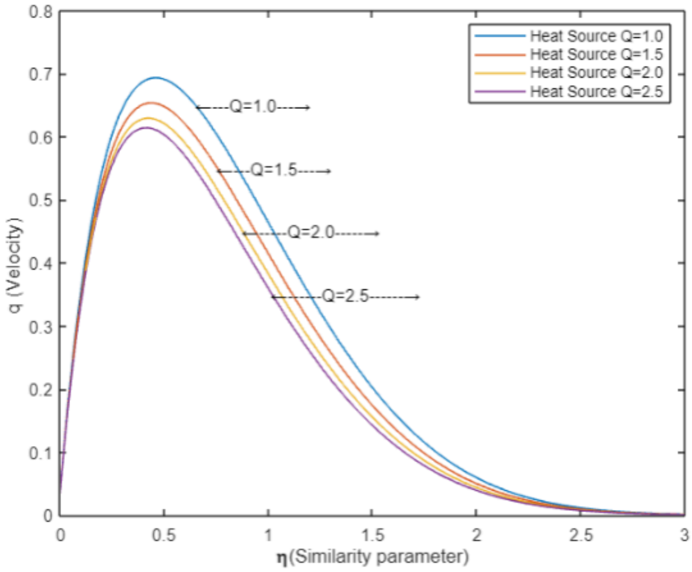

Fig. 11. Velocity profile for different values for heat source

According to Eq. (11) an increase in the heat source can lead to an elevated velocity. For example, in a forced convection setup where external factors like pumps or fans compel fluid movement, augmenting the heat input can lead to an upsurge in flow rate and, consequently, higher velocities. In Figure 11, the introduction of a heat source into a fluid system can indeed influence fluid flow dynamics and potentially induce changes in velocity. However, the precise relationship between the heat source and velocity is complex.

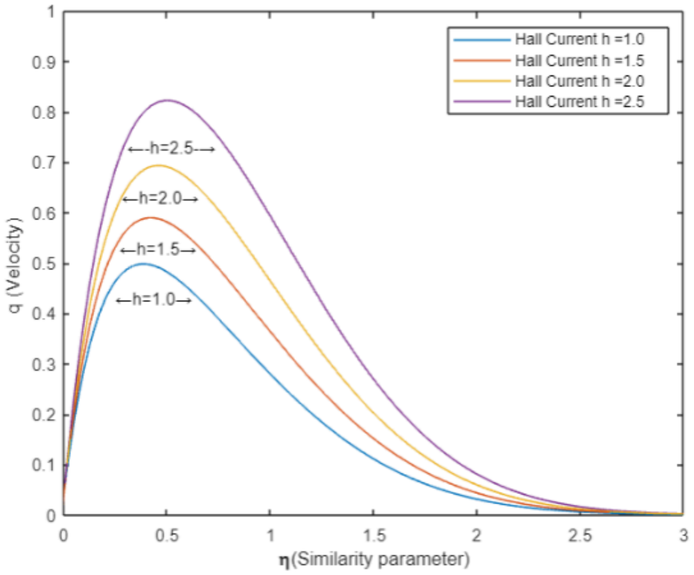

Fig. 12. Velocity profile for different values for hall current

As per Eq. (11) and illustrated in Figure 12, the influence of a magnetic field on fluid motion can be quantified using Hartmann values. These values accurately gauge the reduction in velocity variations caused by the Lorentz force induced by the magnetic field. It's essential to note that these values specifically indicate changes in velocity magnitude rather than the direction or speed. In magnetohydrodynamic configurations, elevated Hartmann values typically signify a more potent magnetic field compared to viscous forces. Consequently, this may result in alterations to flow dynamics, such as turbulence reduction or adjustments in flow patterns.

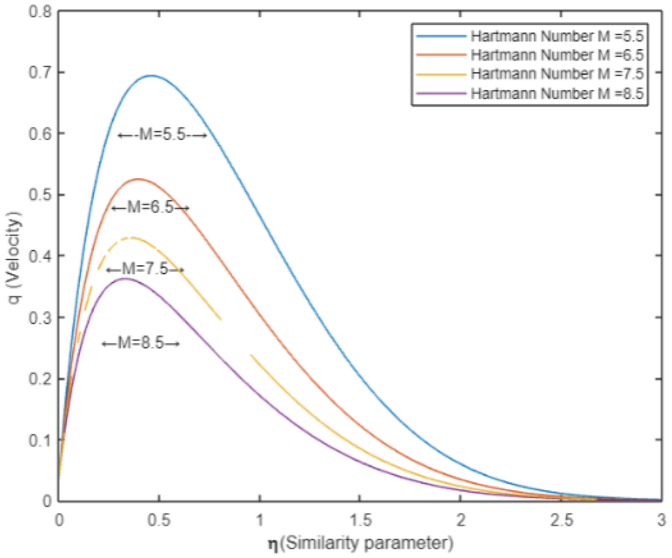

Fig. 13. Velocity profile for different values for Hartmann number

In Figure 13, as the Hall current (h) is raised using Eq. (11), there is a corresponding increase in velocity that results in higher velocities.

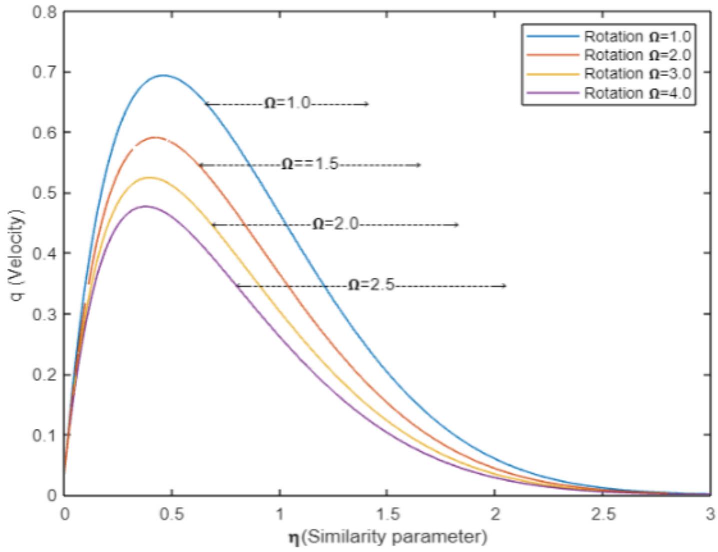

Fig. 14. Velocity profile for different values for rotation

As shown in Figure 14, within the field of fluid dynamics, rotation has a major effect on flow properties. Rotation parameters can change flow patterns and lead to increased flow speeds when they rise, signifying a more prominent rotation or angular velocity within the system. An increase in the rotation parameter can enhance circulation or streamline curvature, which will ultimately result in higher velocities, according to Eq. (11). This phenomenon is especially noticeable in flows that rotate, like swirling flows or flows inside of rotating machinery.

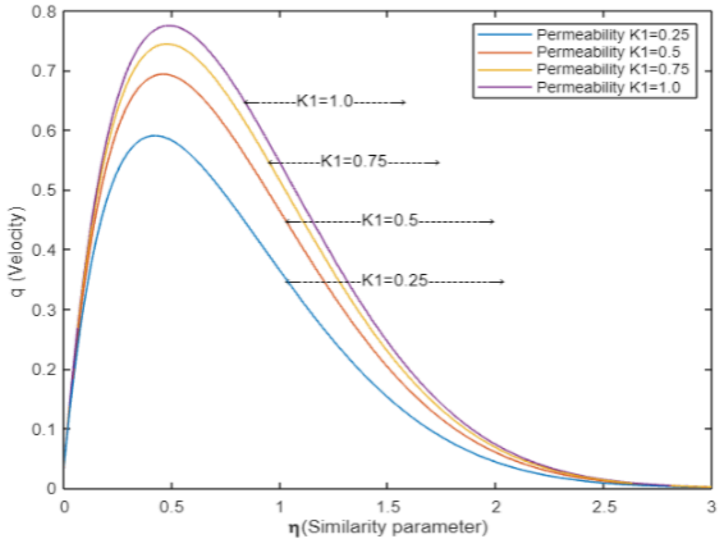

Fig. 15. Velocity profile for different values for permeability

The idea of Steady-State Flow is demonstrated in Figure 15. When fluid flow reaches a steady state, it exhibits a consistent velocity that doesn't change over time. The velocity is constant in this state and is not affected by changes that occur later in time.Conversely, Unsteady Flow is also illustrated. Eq. (11) Fluid flows exhibit unsteadiness in many real-world situations, meaning that the velocity changes over time. Think about a sudden fluid release from a pipe, for example. The fluid's velocity varies over time until it settles into a new equilibrium. The particular conditions and variables affecting the fluid flow determine how quickly the velocity changes over time.

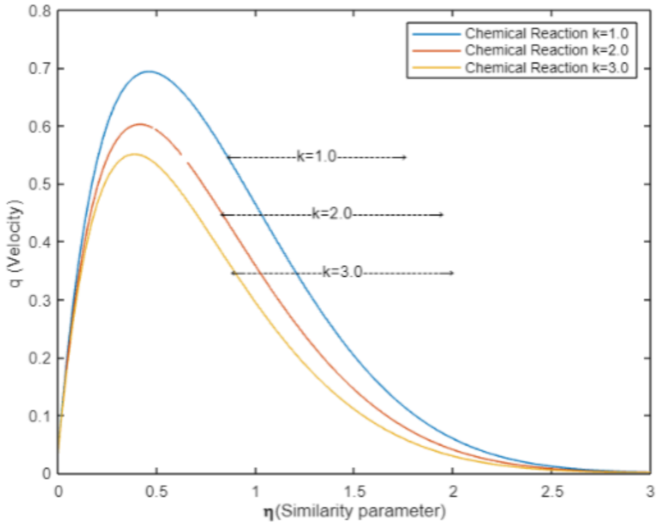

Fig. 16. Velocity profile for different values of chemical reaction

Figure 16 the relationship between the chemical reaction rate (k) and fluid flow speed is not clear-cut or generally applicable, as shown by Eq. (11). The rate at which a chemical reaction happens is known as the chemical reaction rate, and it is typically unrelated to the fluid flow velocity. The primary determinants of flow speed in fluid dynamics are pressure gradients, boundary conditions, flow geometry, and the intrinsic properties of the fluid. Chemical reactions can affect the behaviour and properties of fluids, but they have a direct impact on velocity only in certain situations and when fluid dynamics and chemical reactions interact. Under some conditions, certain chemical reactions may produce products that change the viscosity or fluid properties, either by increasing or lessen. Changes in flow velocity may result indirectly from these adjustments.

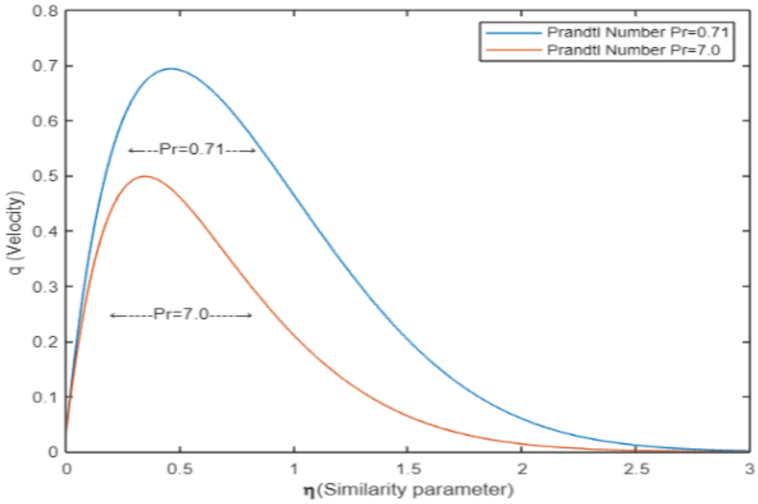

Fig. 17. Velocity profile for different values of Prandtl number

The Prandtl number's effect on speed in Figure 17 is contingent upon the pertinent flow conditions and thermal transfer mechanisms. In some circumstances, a decrease in velocity may follow an increase in the Prandtl number, especially in forced convection flows where heat transfer plays a major role. This is so because larger thermal boundary layers develop as a result of slower thermal diffusion, which is linked to higher Prandtl numbers. Velocity gradients near solid boundaries decrease as a result of Eq. (11), which ultimately contributes to a decrease in velocity.

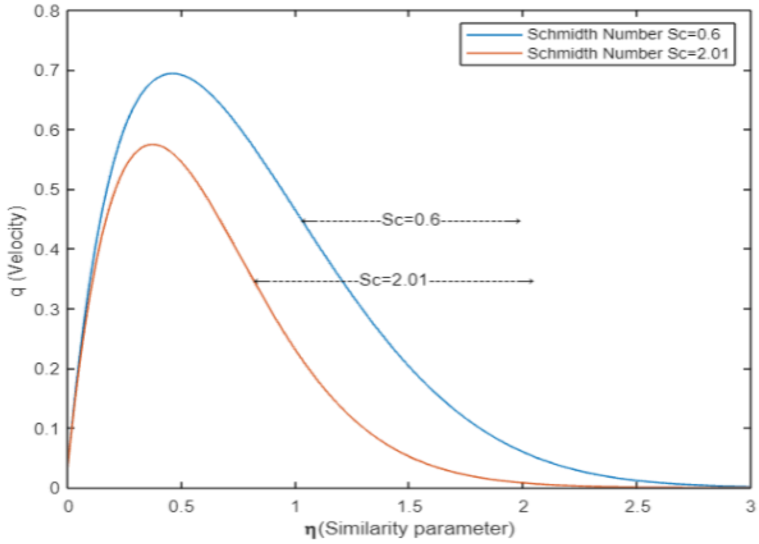

Fig. 18. Velocity profile for different values for Schmidth number

The influence of Schmidt (Sc) values on velocity in Figure 18 is contingent upon particular flow conditions, boundary conditions, and the features of the mass transfer process. There are situations where a decrease in velocity can be caused by the increasing Schmidt numbers in Eq. (11). This happens when the momentum diffusivity is higher than the mass diffusivity. This means that the species being transported (like a solute's concentration) diffuses more slowly than the fluid momentum, which eventually results in lower velocities.

4. Conclusion

This provides a favorable and attractive framework for computational analysis, adopting a dynamic research approach that specifically focuses on a rapidly responding isothermal vertical plate. The plate exhibits notable characteristics related to heat and the accumulation of transferred elements. Through these computations, we can establish the following relationships:

i. As velocity increases, radiation also increases, while the Hartmann number (M) and Dufour number (Df) contribute to a decrease in velocity
ii. Elevated Grashof numbers are associated with higher fluid velocities, indicating a more pronounced impact of buoyancy-driven flow.
iii. Velocity scales up in tandem with the increase in the heat source (Q).
iv. Furthermore, velocity expands with the increase in Hall current (h).
v. With an increase in radiation (R), there is a corresponding decrease in temperature. Conversely, temperature rises with a growing heat source (Q).
vi. With an increase in the chemical reaction rate (k), there is a tendency for the concentration of the relevant species to decrease. This correlation indicates that a higher reaction rate accelerates the consumption or conversion of reactants into products, resulting in a swifter decrease in their concentrations over time.

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