Journal of Heat and Mass Transfer Research 10 (2023), Serial Number 20, 245 – 256

Semnan University

# Journal of Heat and Mass Transfer Research

Journal homepage: https://jhmtr.semnan.ac.ir

ISSN: 2383-3068

*Research Article*

# Convective MHD Flow of a Rotating Fluid Past through a Moving Isothermal Plate under Diffusion-Thermo and Radiation Absorption

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**ARTICLE INFO**

***Article history:***

Received: 2023-06-22

Revised: 2023-10-27

Accepted: 2023-10-28

***Keywords:***

Magnetohydrodynamics (MHD);
Radiation absorption;
Rotating fluid;
Dufour effect;
Heat source.

**ABSTRACT**

The current article studies the impact of radiation absorption and diffusion thermo effect or the Dufour effect on a convective MHD flow of a rotating fluid past through a moving vertical isothermal plate under thermal radiation, chemical reaction, and heat source. The equations that govern the flow, are transformed into dimensionless ordinary differential equations(ODEs), which are then solved analytically using the perturbation technique. The pertinent results obtained are illustrated graphically for the various relevant thermophysical parameters involved in the problem. Additionally, we have listed the numerical values showing the changes in the viscous drag, rate of heat transfer and mass transfer rate through tables. In the investigation, we observe that the velocity of the fluid accelerates for increasing Dufour number, radiation absorption, and heat source parameter. On the other hand, the velocity retards due to rotation and chemical reaction parameters. The momentum transfer rate upgrades for the Dufour number and radiation absorption parameter.



## 1. Introduction

Magnetohydrodynamics, abbreviated as MHD, is based on the study of the dynamics of an electrically conducting fluid under the influence of a magnetic field. In the term "magnetohydrodynamics", "magneto" means magnetism, "hydro" means water, and "dynamics" means motion. In 1942, Hannes Afvén first coined the term MHD, for which he won the Nobel Prize in 1970. The combination of Maxwell's equations and Navier Stokes' equation gives rise to the set of governing equations in the field of MHD. Due to the numerous applications of magnetohydrodynamic (MHD) free convective heat and mass transfer flow of an electrically conductive fluid with magnetic impact in various fields of engineering and industrial organizations, such as electric power, gas turbines, geothermal dam, heat transfer, wire drawing, electric pump, MHD electric motor, chemical process, plasma jet, etc., this field of study is currently quite active.

The study of the effect of thermal radiation on an MHD heat and mass transfer flow has attracted significant attention due to its wide-ranging practical applications in numerous engineering and scientific fields, including power industries,

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**Cite this article as:**
Bormudoi, M., Ahmed, N., 2023. Convective MHD Flow of a Rotating Fluid Past through a Moving Isothermal Plate under Diffusion-Thermo and Radiation Absorption. *Journal of Heat and Mass Transfer Research,* 10(2), pp. 245-256.
https://doi.org/10.22075/JHMTR.2023.31013.1454

glass production, boiler design, steel rolling, etc. To construct the proper machinery, such as nuclear power plants, gas turbines, rockets, atomic power plants, etc., it is crucial to have a comprehensive grasp of radiative heat transfer because many industrial processes take place at very high temperatures. Analysis of heat and mass transfer unsteady hybrid nanofluid flow over a stretching sheet with thermal radiation is performed by Sreedevi et al. [1]. Krishna et al. [2] studied the effect of radiation on an MHD flow of Casson hybrid nanofluid over an infinite exponentially accelerated vertical porous plate. A study based on natural convection flow and considering the effects of heat radiation and thermal diffusion is carried out by Reddy, Matao, and Sunzu [3], Bormudoi, Ahmed, and Bordoloi [4]. Also, the field has benefited from the work of researchers such as Bafakeeh et al. [5], Anantha Kumar et al. [6], Prabhakar Reddy and Makinde [7], Lakshmi Devi, Niranjan, and Sivasankaran [8], Popoola [9], Prabhakar Reddy and Sademaki [10], Hakim et al. [11], Goud et al. [12], Bormudoi et al. [13], Bormudoi and Ahmed [14] and Aly et al. [15].

The study of heat and mass transfer in the presence of chemical reactions is of immense importance in many branches of science and technology such as agricultural fields, chemical processing equipment designs, etc. Chemical reactions can be codified as either heterogeneous or homogeneous reactions depending on the situations in which they occur at an interface or a single-phase volume reaction. Reddy [16] studied the effect of chemical reactions on transient MHD flow with mass transfer past an impulsively fixed infinite vertical plate in the presence of thermal radiation. Babu et al. [17] investigated the impact of chemical reactions and radiation on MHD rotating fluid past a moving vertical plate. Recently, Biswal et al. [18] investigated the effects of a chemical reaction and thermal radiation on the flow of a Casson nanofluid past via a stretching sheet with a heat source. The combined effect of heat generation or absorption and first-order chemical reaction on micropolar fluid flows over a uniformly stretched permeable surface is investigated by Magyari and Chamkha [19]. Reddy and Peter [20] studied the effects of chemical reactions on MHD flow past an impulsively started infinite vertical plate with variable temperature and mass diffusion in the presence of a hall current. In the recent past, Reddy et al. [21] researched the effect of heat absorption/generation on MHD heat transfer fluid flow along a stretching cylinder with a porous medium.

Furthermore, due to its expanding use in several domains of astrophysics, fluid engineering, and geophysics such as solar and planetary dynamo issues, the structure of magnetic stars, etc., the study of free convective flow with rotating fluid is also very important. Mabood, Ibrahim, and Lorenzini [22] presented how a chemical reaction affects the MHD flow of a rotating fluid across a porous vertical plate when a heat source is present. Prasad, Chaitanya, and Raju [23] investigated how radiation affected the flow of a rotating fluid through an EFGM solution. Ameer Ahamad, Veera Krishna and Chamkha [24], Chand [25], Reddy, Makinde, and Hugo [26], Matao, Reddy, and Sunzu [27], Reddy et al. [28] also considered the concept of rotation in different types of fluid for their study. The diffusion-thermo effect or the Dufour effect is the term used to define the energy flux brought on by the concentration gradient. The diffusion thermal effect, also known as the Dufour effect, was originally experimentally investigated by L. Dufour in the year 1872. Ghaffarpasand [29] characterized the unsteady double-diffusive mixed convection flow with Soret and Dufour effects in a square enclosure with a top moving lid. Some other researchers who analyzed the effect of diffusion-thermo (Dufour effect) under various circumstances are, Meenakshi [30], Jamir and Konwar [31], and Reddy and Chamkha [32].

The main purpose of the current research is to study the effect of diffusion-thermo, and chemical reaction on a MHD free convective flow of a rotating fluid in the presence of radiation absorption and heat source. The chemically reactive fluid considered here passes through a moving vertical isothermal plate. The basic equations involved here are first rehabilitated to a set of non-dimensional partial differential equations by introducing some non-dimensional quantities. After that, these equations are solved using the perturbation method to yield the solutions for the velocity, temperature, and concentration of the fluid. It is envisaged that our findings would be useful in a variety of scientific sectors. This work is an extension of Babu et al. [17]. The main novelty of the article is to examine the impact of diffusion-thermo or the Dufour effect, radiation absorption, and heat source on the fluid, as no work is done on these effects on such problems according to our concern. Our work may have several real applications in many industrial, agricultural, and engineering sectors such as in plasma physics, nuclear reactors, aerospace power generators, food processing, etc. Also, the Dufour effect is used in many heat transfer fields in high atmospheres and the soil due to a moisture gradient at isothermal conditions.

## 2. Mathematical Formulation

In the current issue, a MHD free convective heat and mass transfer flow through a vertical isothermal plate of a rotating fluid that is viscous, incompressible, and electrically conducting is taken into account. Observing the flow on a three-dimensional plane, in which the X-axis is chosen parallel to the plate's direction, the Y-axis is normal to the plate, and the Z-axis is taken along the width of the plate. A consistent magnetic field with a magnetic field strength $\mathbf{B_0}$, generally affects the plate. The fluid and the plate are both rigidly rotated about the Z-axis at a constant angular speed $\boldsymbol{\Omega}^*$. At first, when time $\boldsymbol{t}^* = \mathbf{0}$, the fluid and the plate are both at rest. When time passes, or when $\boldsymbol{t}^* \geq \mathbf{0}$, an impusive force is applied to the plate, and it starts to move in the X-direction. While the plate and fluid are at rest, the temperatures and concentrations are denoted by $\boldsymbol{T}_\infty^*$ and $\boldsymbol{C}_\infty^*$, respectively. The fluid's temperature and concentration, both rise with passing time, reaching $\boldsymbol{T}_w^*$ and $\boldsymbol{C}_w^*$, respectively, and then they remain unchanged. The viscous dissipation and the induced magnetic field are disregarded. All the physical quantities are expressed in terms of of $\boldsymbol{z}^*$ and $\boldsymbol{t}^*$ since an infinite plate is assumed along the X-direction. The magnetic field considered here is not so strong, for which the electron-atom collision becomes very low. As a result of which Hall and ion slip effects are neglected in this study (Krishna and Chamkha [33], Krishna and Chamkha [34], Krishna et al. [35]). We have chosen air to be the solvent or a diffusing medium. As the electrical conductivity and magnetic permeability of air are very small, this makes the magnetic Reynolds number of the flow very small, and so the induced magnetic field is neglected. In the case of free convective flow, both fluid velocity as well as velocity gradient are small. Moreover, the viscous dissipation parameter is small for most of the fluids that exist in nature. As such, the viscous dissipation is neglected in our research work. The fluid flow under consideration is depicted in Figure 1.

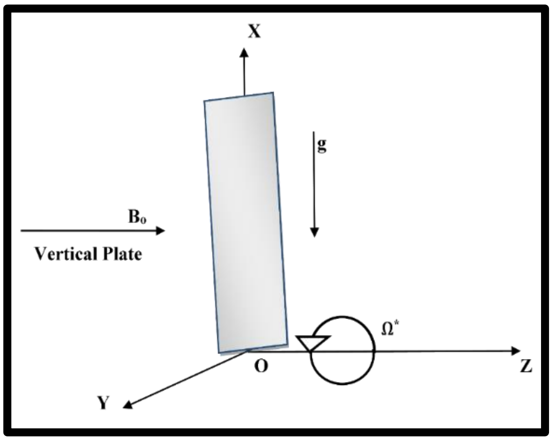


**Fig. 1.** Flow model

The governing equations [Babu et al. [17]] according to our above assumptions are:

Momentum equation:

$$\frac{\partial u^*}{\partial t^*} - 2\Omega^* v^* = g\beta(T^* - T_\infty^*) + g\beta^*(C^* - C_\infty^*) + v\frac{\partial^2 u^*}{\partial z^{*2}} - \frac{\sigma_e{}^* B_o^2}{\rho} u^* \tag{1}$$

$$\frac{\partial v^*}{\partial t^*} + 2\Omega^* u^* = v\frac{\partial^2 v^*}{\partial z^{*2}} - \frac{\sigma^* B_o^2}{\rho} v^* \tag{2}$$

Energy equation:

$$\rho C_p \frac{\partial T^*}{\partial t^*} = \kappa \frac{\partial^2 T^*}{\partial z^{*2}} - \frac{\partial q_r^*}{\partial z^*} + \frac{D_m K_T \rho}{C_s C_p}\frac{\partial^2 C}{\partial z^{*2}} + Q_o^*(T^* - T_\infty^*) + Q_1^*(C - C_\infty) \tag{3}$$

Species continuity equation:

$$\frac{\partial C^*}{\partial t^*} = D\frac{\partial^2 C^*}{\partial z^{*2}} - K^*(C^* - C_\infty^*) \tag{4}$$

The radiative heat flux of an optically thin grey gas is given by

$$\frac{\partial q_r}{\partial z^*} = 4a^*\sigma^*\left({T_\infty^*}^4 - {T^*}^4\right) \tag{5}$$

Now, considering the temperature difference of the flow to be sufficiently small and expanding ${T^*}^4$ with the help of Taylor's series and ignoring the higher order terms in the series, we have

$${T^*}^4 \cong 4{T_\infty^*}^3 T - 3{T_\infty^*}^4$$

$$\therefore \frac{\partial q_r^*}{\partial z^*} = 16a^*\sigma^*{T_\infty^*}^3(T^* - T_\infty^*) \tag{6}$$

Using equation (6) in (3) we get,

$$\rho C_p \frac{\partial T^*}{\partial t^*} = k\frac{\partial^2 T^*}{\partial z^{*2}} - 16a^*\sigma^* {T_\infty^*}^3 (T^* - T_\infty^*) + {Q_o}^*(T^* - T_\infty^*) + Q_1^*(C - C_\infty) \tag{7}$$

The initial and boundary restrictions are

$$\left.\begin{array}{l} t^* \leq 0: \quad u^* = 0, T^* = T_\infty^*, C^* = C_\infty^*, \ \forall\ z^* \\ t^* > 0:\ u^* = u_o,\ T^* = T_w^*,\ C^* = C_w^*, \text{ at } \ z^* = 0 \\ u^* = 0, T^* \to T_\infty^*,\ C^* \to C_\infty^* \text{ as } \ z^* \to \infty \end{array}\right\} \tag{8}$$

The non-dimensional quantities introduced here are:

$$\left.\begin{array}{l} (u,v) = \frac{(u^*,v^*)}{u_o},\ \ t = \frac{t^* u_o^2}{\vartheta},\ z = \frac{z^* u_o}{\vartheta},\ \ \theta = \frac{T^* - T_\infty^*}{T_w^* - T_\infty^*},\ C = \frac{C^* - C_\infty^*}{C_w^* - C_\infty^*}, Gr = \frac{g\beta\vartheta(T_w^* - T_\infty^*)}{u_o^3}, \\ Q_o = \frac{Q_o^*\vartheta}{\rho C_p u_o^2},\ Q_1 = \frac{\vartheta Q_1^*(C_w - C_\infty)}{\rho C_p (T_w - T_\infty) u_o^2}, Sc = \frac{\vartheta}{D},\ \ K = \frac{\vartheta K^*}{u_o^2},\ \ Gm = \frac{\vartheta g \beta^*(C_w^* - C_\infty^*)}{u_o^3}, \\ M = \frac{\sigma B_o^2 \vartheta}{\rho u_o^2},\ \ Pr = \frac{\mu C_p}{K_T}, \Omega = \frac{\Omega^*\vartheta}{u_o^2},\ \ R = \frac{16a^*\vartheta^2\sigma^* {T_\infty^*}^3}{K_T u_o^2},\ \ Du = \frac{D_m K_T (C_w^* - C_\infty^*)}{\kappa C_s C_p (T_w^* - T_\infty^*)} \end{array}\right\} \tag{9}$$

The initial and boundary restrictions are:

$$\left.\begin{array}{l} q = 0, \theta = 0, C = 0, \forall\ z \leq 0\ \&\ t \leq 0 \\ t > 0,\ q = 1, \theta = 1, C = 1, \text{ at } z = 0 \\ q = 0, \theta \to 0, C \to 0, \quad at\ \ z \to \infty \end{array}\right\} \tag{10}$$

Using the above non-dimensional quantities from (9) and introducing the velocity as $q = u + iv$ in the equations (1), (2), (4) and (7), we have the following dimensionless partial differential equations:

$$\frac{\partial q}{\partial t} - (M + 2i\Omega)q = \frac{\partial^2 q}{\partial z^2} + Gr\theta + GcC \tag{11}$$

$$\frac{\partial^2 \theta}{\partial z^2} - Pr\frac{\partial \theta}{\partial t} - (R - Q_o Pr)\theta = -Du\frac{\partial^2 C}{\partial z^2} - Q_1\, Pr\, C \tag{12}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial z^2} - KC \tag{13}$$

The PDE's given in (11-13) are converted to a new set of ODEs to find the solutions analytically. For this, we assume

$$\left.\begin{array}{l} q(z,t) = q_o(z) + \epsilon e^{nt} q_1(z) + O(\epsilon^2) \\ \theta(z,t) = \theta_o(z) + \epsilon e^{nt}\theta_1(z) + O(\epsilon^2) \\ C(z,t) = C_o(z) + \epsilon e^{nt} C_1(z) + O(\epsilon^2) \end{array}\right\} \tag{14}$$

Now substituting the above values in equations (11-13) and equating the harmonic and non-harmonic parts, we have the following differential equations.

$$\left.\begin{array}{l} q_o'' - A_6\, q_o = -Gr\theta_o - GmC_o \\ q_1'' - A_6\, q_1 = nq_1 - Gr\theta_1 - GmC_1 \\ \theta_o'' - R\theta_o + Q_o Pr\, \theta_o = -Du\, C_o'' - Q_1 Pr\, C_o \\ \theta_1'' - \text{Pr}\ n\, \theta_1 + (Q_o Pr - R)\, \theta_1 = -Du\, C_1'' - Q_1 Pr\, C_1 \\ C_o'' - K\, Sc\, C_o = 0 \\ C_1'' - (K + n)Sc\, C_1 = 0 \end{array}\right\} \tag{15}$$

The boundary restrictions are:

$$\left.\begin{array}{l} q = 0,\ \theta = 0,\ C = 0,\ \forall\, z,\ t \leq 0 \\ \text{When } t > 0, \\ q_o = 1,\ \theta_o = 1,\ C_o = 1,\ q_1 = 0,\ \theta_1 = 0, C_1 = 0 \text{ at } z = 0, \\ q_o \to 0,\ \theta_o \to 0, C_o \to 0,\ q_1 \to 0, \theta_1 \to 0,\ C_1 \to 0 \text{ as } z \to \infty \end{array}\right\} \quad (16)$$

Using the above boundary conditions in (16) and solving the ordinary differential equations in (15), we have the following zeroth order and first orders solutions

$$\left.\begin{array}{l} q_o = A_{11}e^{-\sqrt{A_6}z} + A_7e^{-\sqrt{A_2}z} + A_{10}e^{-\sqrt{A_1}z}, q_1 = 0 \\ \theta_o = (1 - A_5)e^{-\sqrt{A_2}z} + A_5e^{-\sqrt{A_1}z}, \theta_1 = 0 \\ C_o = e^{-\sqrt{A_1}z}, C_1 = 0 \end{array}\right\} \quad (17)$$

Now, putting these values in (14), we have the ultimate solutions for the fluid's velocity, temperature and concentration are as follows:

$$q(z,t) = A_{11}e^{-\sqrt{A_6}z} + A_7e^{-\sqrt{A_2}z} + A_{10}e^{-\sqrt{A_1}z} \quad (18)$$

$$\theta(z,t) = (1 - A_5)e^{-\sqrt{A_2}z} + A_5e^{-\sqrt{A_1}z} \quad (19)$$

$$C(z,t) = e^{-\sqrt{A_1}z} \quad (20)$$

**SKIN-FRICTION ($\tau_x$):**

$$\tau_x = \left.\frac{\partial q}{\partial z}\right]_{z=0} = -A_{11}\sqrt{A_6} - A_7\sqrt{A_2} - A_{10}\sqrt{A_1} \quad (21)$$

**NUSSELT NUMBER (Nu):**

$$\mathrm{Nu} = -\left.\frac{\partial \theta}{\partial z}\right]_{z=0} = (1 - A_5)\sqrt{A_2} + A_5\sqrt{A_1} \quad (22)$$

**SHERWOOD NUMBER (Sh):**

$$\mathrm{Sh} = -\left.\frac{\partial C}{\partial z}\right]_{z=0} = \sqrt{A_1} \quad (23)$$

## 3. Results and Discussions

This section includes a visual representation that illustrates how the influence of various non-dimensional parameters appeared in the governing equations under usual boundary conditions in velocity, temperature, and concentration field of the fluid. For graphical representation, some fixed values of the parameters are considered such as Prandtl number Pr = 0.71, which represents air at 200°C, Schmidt number Sc = 0.22 (for Hydrogen) and 0.6 (for water vapor), thermal Grashof number Gr = 5, solutal Grashof number Gm = 5, Chemical reaction ($K$) = 1, Hartmann number ($M$) = 1, heat source parameter ($Q_o$)= 0.2, radiation absorption parameter ($Q_1$), rotation parameter ($\Omega$) = 0.2, thermal radiation parameter ($R$)= 1 , Dufour number Du = 2. In the last part of this section, the numerical values that reveal the change in skin friction, Nusselt number, and Sherwood number are tabulated and discussed.

Figures(2-9) give a view of the impact of different parameters on the velocity field of the considered flow.

The Dufour number Du enhances the fluid velocity which is noticed in Figure 2. It shows that as the Dufour number increases, the thermal boundary layer also increases. With the upliftment in the Dufour effect, the thermal buoyancy force within the velocity field rises, due to which the velocity rises.

Figure 3 and Figure 4 show the influence of thermal Grashof number Gr and solutal Grashof number Gm on the fluid velocity. It is seen that both these parameters raise the fluid velocity. As the Grashof number is the ratio of buoyancy force and viscous diffusivity, with the increase in Gr and Gm, the viscosity of the fluid decreases and the buoyancy force increases which speeds up the velocity. Also, it can be noticed that the fluid motion is accelerated near the plate and it drops asymptotically thereafter. This is because the buoyancy force is very strong near the hot plate, but the impact of the buoyancy force away from the plate vanishes.

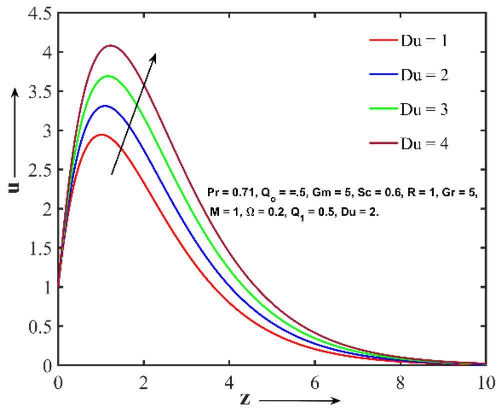


**Fig. 2.** Observed change in primary velocity for *Du*

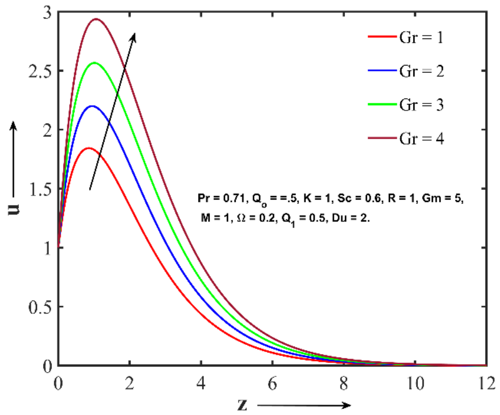


**Fig. 3.** Observed change in primary velocity for *Gr*

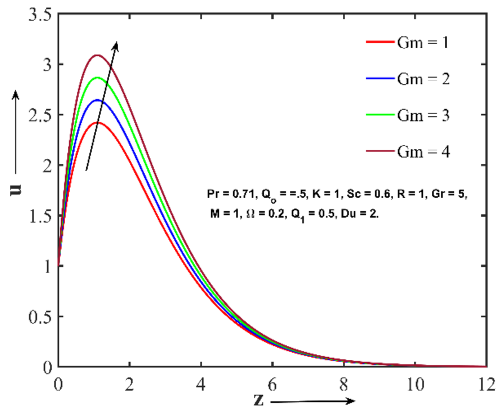


**Fig. 4.** Observed change in primary velocity for *Gm*

The chemical reaction parameter $K$ reduces the fluid velocity which is visualized in Figure 5. In this study, only destructive case of chemical reaction ($K > 0$) is investigated. Rise in chemical reaction implies low diffusivity which, in turn, causes a decrement in the velocity field of the flow.

The Hartmann number $M$ lowers the fluid velocity as depicted in Figure 6. The reason for this is that applying a magnetic field to an electrically conducting fluid generates the Lorentz force, which is a resistive force that acts in the direction opposite to the flow of the fluid, and it reduces the fluid velocity.

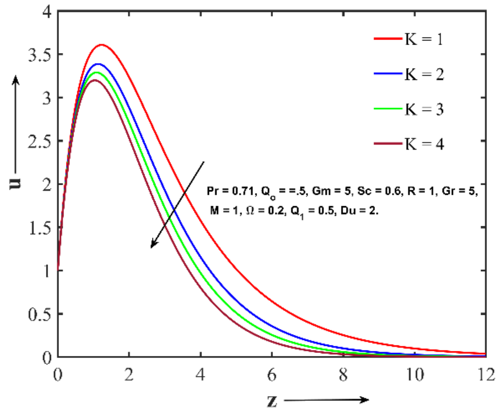


**Fig. 5.** Observed change in primary velocity for K

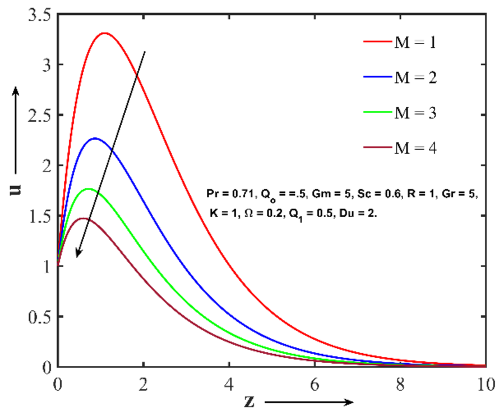


**Fig. 6.** Observed change in primary velocity for M

Figure 7 demonstrates that the increment in the rotation parameter Ω drops the fluid velocity. This shows that rotation causes a restriction in the flow.

Figure 8 shows that the hike in heat source $Q_o$ parameter raises the fluid velocity. In the presence of a heat source or heat generation, the heat is generated in the flow, for which the buoyancy force improves, as a result of which the flow rate and the velocity profile are enhanced.

Figure 9 demonstrates that with the increment in radiation absorption parameter $Q_1$, the fluid velocity also upgrades. The radiation absorption parameter absorbs the heat which in turn accelerates the flow.

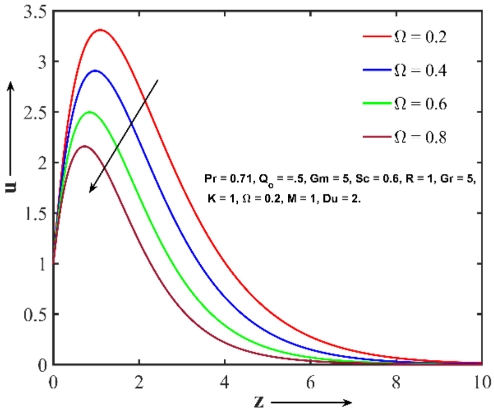


**Fig. 7.** Observed change in primary velocity for Ω

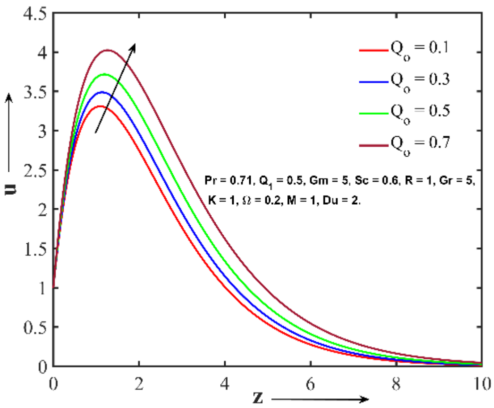


**Fig. 8.** Observed change in primary velocity for $Q_o$

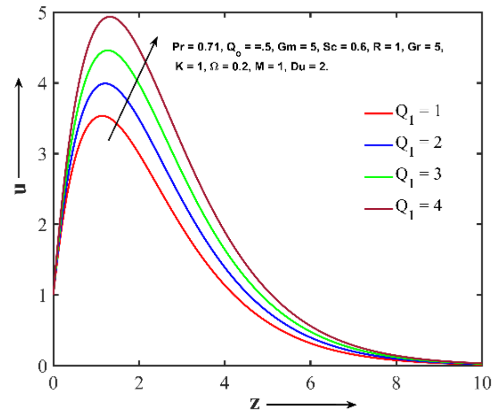


**Fig. 9.** Observed change in primary velocity for $Q_1$

The effects of several parameters on the fluid's temperature are displayed in Figures (10–13).

The fluid temperature escalates with an increase in Dufour number Du. As the Dufour number increases, the thickness of the thermal boundary layer amplifies and the fluid temperature goes up. Intensification in the fluid temperature with the increase in radiation absorption parameter $Q_1$ is revealed in Figure 11.

The graph sketched in Figure 12 shows that the fluid temperature increases as the heat source parameter $Q_o$ rises. The heat source parameter generates heat in the flow, which increases the fluid temperature.

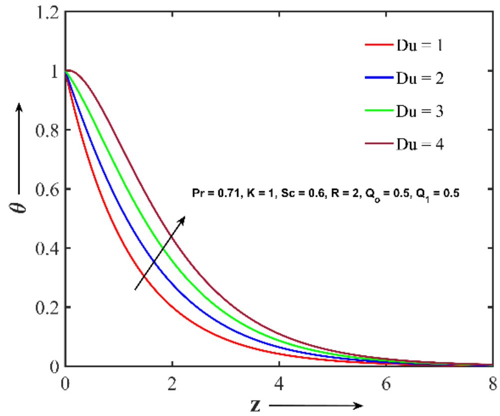


**Fig. 10.** Observed change in θ for *Du*

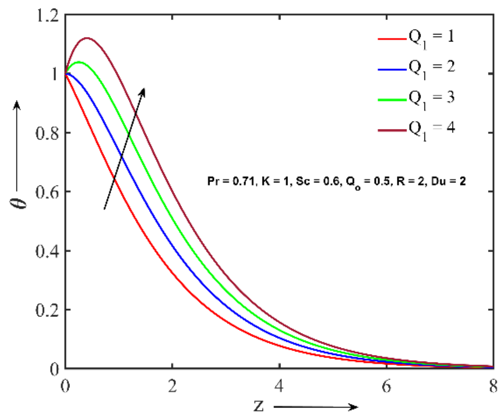


**Fig. 11.** Observed change in θ for $Q_1$

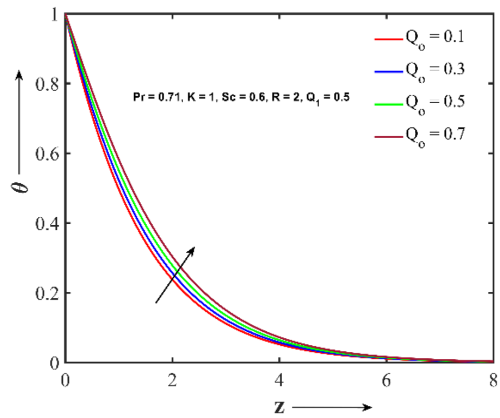


**Fig. 12.** Observed change in θ for $Q_o$

Figure 13 illustrates how the expansion in the thermal radiation parameter R causes the fluid temperature to decrease. The effect of radiation decreases the rate of energy transport to the fluid, which lowers the temperature of the fluid.

Figures (14–15) illustrate how the fluid's concentration varies in response to the chemical reaction parameter K and Schmidt number Sc. Figure 14 shows that the species concentration declines with an increase in chemical reaction parameter K. As the chemical reaction intensifies, the concentration boundary layer gets thinner, and so the species concentration falls. Figure 15 demonstrates how the fluid's concentration reduces as Sc increases. The fluid's molecular diffusivity falls with an increase in Sc, hence lowering the fluid concentration, as the ratio of kinematic viscosity to molecular diffusivity is determined by Schmidt number. Schmidt number, $Sc = 0.6$, represents water vapor and the increasing Schmidt number in air and water causes a decrease in concentration distribution over the boundary layer.

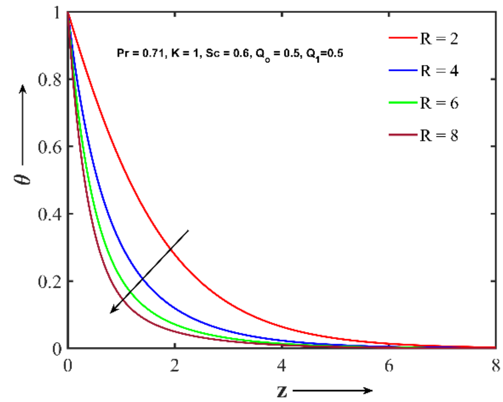


**Fig. 13.** Observed change in θ for *R*

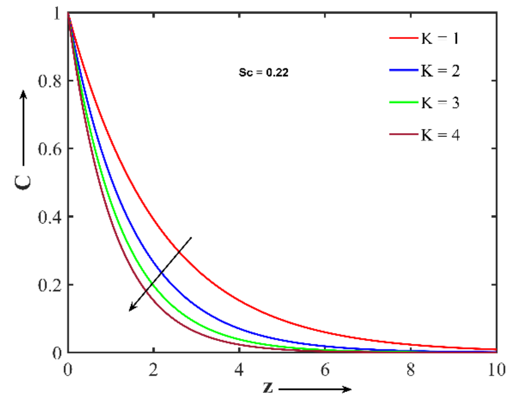


**Fig. 14.** Observed change in C for *K*

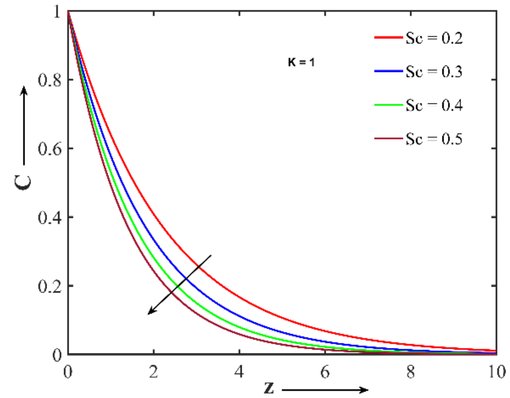


**Fig. 15.** Observed change in C for *Sc*

Table 1 depicts the effect of Dufour number Du, radiation absorption parameter $Q_1$ and rotation parameter Ω on the skin friction $\tau_x$. It is seen that the Dufour number and radiation absorption parameter enhances the skin friction and on the other hand the rotation parameter $\Omega$ reduces the viscous drag of the fluid.

**Table 1.** Observed change in $\tau_x$ for $Du$, $Q_1$ and **Ω**

| Du | $Q_1$ | Ω | Skin-friction($\tau_x$) |
|---|---|---|---|
| 1 | 0.5 | 0.2 | 5.5111 |
| 2 | 0.5 | 0.2 | 5.7725 |
| 3 | 0.5 | 0.2 | 6.0340 |
| 2 | 0.6 | 0.2 | 5.8569 |
| 2 | 0.7 | 0.2 | 5.9413 |
| 2 | 0.8 | 0.2 | 6.0256 |
| 2 | 0.5 | 0.3 | 5.5238 |
| 2 | 0.5 | 0.4 | 5.2336 |
| 2 | 0.5 | 0.5 | 4.9297 |

The impact of Dufour number Du, radiation absorption parameter $Q_1$ and heat source $Q_o$ on the rate of heat transfer in terms of Nusselt number is shown in Table 2. Here, it is seen that all of these mentioned parameters reduce the Nusselt number simultaneously.

**Table 2.** Observed change in Nu for Du, $Q_1$ and $Q_o$

| Du | $Q_1$ | $Q_o$ | Nusselt no(Nu) |
|---|---|---|---|
| 1 | 0.5 | 0.2 | 0.5142 |
| 2 | 0.5 | 0.2 | 0.3565 |
| 3 | 0.5 | 0.2 | 0.1989 |
| 2 | 0.6 | 0.2 | 0.3056 |
| 2 | 0.7 | 0.2 | 0.2548 |
| 2 | 0.8 | 0.2 | 0.2039 |
| 2 | 0.5 | 0.3 | 0.3009 |
| 2 | 0.5 | 0.4 | 0.2417 |
| 2 | 0.5 | 0.5 | 0.1782 |

The influence of chemical reaction parameter $K$ and Schmidt number Sc on the rate of mass transfer is revealed in Table 3. Both these parameters uplift the mass transfer rate. That is, the Sherwood number hikes with the rise in chemical reaction parameters $K$ and Schmidt number Sc.

**Table 3.** Observed change in Sh for K and Sc

| K | $Sc$ | Sherwood no(Sh) |
|---|---|---|
| 1 | 0.22 | 0.4690 |
| 2 | 0.22 | 0.6633 |
| 3 | 0.22 | 0.8124 |
| 1 | 0.2 | 0.4472 |
| 1 | 0.3 | 0.5477 |
| 1 | 0.4 | 0.6325 |

## 4. Comparison

To validate our present results, a comparison table is formed which is labeled as Table 4. It is noticed that, in the work of Babu et al. [17], the skin friction gets reduced due to an increment in the rotation parameter $\Omega$, which is similar to our result. Also, Figure 2 of Babu et al. [17] illustrates that with the rise in rotation parameter $\Omega$, the fluid velocity depletes, which is the same as our result depicted in Figure 7. Also, we have compared Figure 7 of Babu et al. [17] with Figure 13 of this current study. Both these figures represent the impact of thermal radiation on the fluid's temperature. It is observed that in both cases the thermal radiation lowers the temperature of the fluid.

**Table 4.** Comparison table for Skin-friction, where $R = 1, K = 1, Sc = 0.6, Gr = 5, Gm = 5, M = 1$.

| **Ω** | $\tau_x$ **(Babu et al. 2021)** | $\tau_x$ **(present result)** |
|---|---|---|
| 0.2 | 4.5845 | 4.1887 |
| 0.4 | 4.3000 | 3.8793 |
| 0.6 | 3.7985 | 3.5115 |
| 0.8 | 3.5472 | 3.1518 |

## 5. Conclusions

In the present study, the effect of radiation absorption and diffusion-thermo on an MHD free convective flow of a rotating fluid under chemical reaction and heat source is investigated. After investigation, we conclude the following vital results:

1. Fluid velocity falls with the hike in chemical reaction parameter and rotation parameter.
2. Growth in Dufour number, radiation absorption, and heat source, enhances the fluid velocity gradually.
3. Thermal buoyancy force and concentration buoyancy force tend to accelerate the flow velocity throughout the boundary layer region.
4. A comprehensive fall in the fluid temperature takes place with the escalation in the thermal radiation parameter. On the other hand, the fluid temperature boosts up with the upliftment in radiation absorption parameter, thermal diffusion parameter, and heat source parameter.
5. Enlargement in Schmidt number and chemical reaction parameter, causes the fluid concentration to fall asymptotically.
6. The rate of momentum transfer surge with the impact of diffusion-thermo and radiation absorption parameters. It shows a reverse effect with the rise in rotation parameter.
7. Diffusion-thermo, radiation absorption, and heat source parameter deplete the rate of heat transfer.
8. The mass transfer rate boosts due to the influence of Schmidt number and chemical reaction parameters.

## Nomenclature

| | |
|---|---|
| $B_o$ | *Component of magnetic field (A.m$^{-1}$)* |
| $u^*$ | *Velocity component towards the x-axis (m/s)* |
| $v^*$ | *Velocity component towards the z-axis (m/s)* |
| $C_\infty$ | *Concentration outside the plate (kg.m$^{-3}$)* |
| $C_w$ | *Plate concentration(kg.m$^{-1}$).* |
| $T_\infty$ | *Temperature outside the plate(K)* |
| $T_w$ | *Plate temperature(K).* |
| $t^*$ | *Dimensional time(s)* |
| $\Omega^*$ | *Angular velocity (Hz)* |
| $g$ | *Acceleration due to gravity (m.s$^{-2}$)* |
| $\beta^*$ | *Co-efficient of thermal expansion due to concentration ($K^{-1}$)* |
| $T^*$ | *Fluid's temperature (with dimension) (K)* |
| $T$ | *Fluid's temperature (without dimension) (K).* |
| $\nu$ | *Kinematic viscosity ($m^2 s^{-1}$).* |
| $\sigma^*$ | *Stefan-Boltzmann constant* |
| $\sigma_e^*$ | *Electrical conductivity ($\Omega^{-1}\ m^{-1}$)* |
| $\rho$ | *Density (kg $m^{-3}$).* |
| $C_p$ | *Specific heat (J.kg$^{-1}$. K)* |
| $\kappa$ | *Thermal conductivity ($m^2 s^{-1}$)* |
| $Q_o^*$ | *Dimensional heat source parameter* |
| $Q_1^*$ | *Dimensional radiation absorption* |
| $D$ | *Co-efficient of mass diffusivity* |
| $q_r$ | *Radiation heat flux (W.m$^{-2}$)* |
| $D_m$ | *Mass diffusivity* |
| $K_T$ | *Thermal diffusion ratio* |
| $c_s$ | *Concentration susceptibility* |
| $M$ | *Magnetic parameter* |
| $Gr$ | *Thermal Grashof number* |
| B | *Co-efficient of thermal expansion* |
| Ω | *Dimensionless rotation parameter* |
| $Gm$ | *Solutal Grashof number* |
| $\theta$ | *Fluid temperature.* |
| $R$ | *Radiation parameter* |

$Q_o$ *Dimensionless heat source parameter*

$Q_1$ *Dimensionless radiation absorption parameter*

$K$ *Chemical reaction parameter (m.s^-1^).*

$Sc$ *Schmidt number*

$Pr$ *Prandtl number.*

## Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article. In addition, the authors have entirely observed the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

## Appendixes

$A_1 = KSc,$

$A_2 = R - Q_o Pr,$

$A_3 = \frac{-DuA_1}{A_1 - A_2},$

$A_4 = \frac{-Q_1 Pr}{A_1 - A_2},$

$A_5 = A_3 + A_4,$

$A_6 = M + 2i\Omega,$

$A_7 = \frac{-Gr(1 - A_5)}{A_2 - A_6},$

$A_8 = \frac{-GrA_5}{A_1 - A_6},$

$A_9 = \frac{-Gm}{A_1 - A_6},$

$A_{10} = A_8 + A_9,$

$A_{11} = 1 - A_7 - A_{10}$

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