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Effects of Chemical Reaction and Radiation Absorption on Unsteady MHD Free Convection Flow of Jeffery Fluid In Vertical Porous Plate

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Abstract

*In this paper, the investigation on the unsteady MHD free convection flow of Jeffrey fluid in vertical porous plate with chemical reaction and Radiation absorption effects has been carried out.*The governing differential equations of the flow characteristics are evaluated analytically by adoption of the regular perturbation technique. The results obtained for the velocity, temperature and concentration were analysed. The effects of different physical parameters on the flow fields appear on the present situation such as Jeffrey fluid parameter (β), chemical reaction (Kr), Radiation absorption (D), Prandtl number (Pr), Schmidt number (Sc), thermal Grashof number (Gr), mass Grashof number (Gc), magnetic field (M), Heat sink (δ), were illustrated with the aid of graphs in detail. It has been pointed out the fluid velocity significantly deteriorates as the value of Grashof number (Gr), mass Grashof number (Gc), Jeffrey fluid parameter (β), increased, while the opposite trend is noticed for growing values of magnetic field parameter (M), chemical reaction (Kr), Prandtl number (Pr), Radiation absorption (R), Schmidt number (Sc) and Heat sink (δ), respectively.*

Keywords: Free convection, MHD, Jeffrey Fluid, Chemical Reaction, Radiation absorption.

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INTRODUCTION

Chemical engineering strategies usually involve chemical reactions amongst mass and the fluid in which a plate is moving through. Several industrial processes rely on these techniques, such as the production of glass and ceramics, the synthesis of polymers, and food processing. Due to their importance in several processes, the problems of heat and mass transfer associated with chemical reactions have received a lot of attention lately.

Heat and mass transmission happen at the same time in processes including drying, evaporation at a water body's surface, energy transfer in a wet cooling tower, and movement in a desert cooler. This type of flow can be useful in a wide range of sectors (Ramaiah et al., 2016).

The study of liquids that conduct electricity, especially liquid metals, plasma, brackish water, and electrolytes is commonly referred to as magneto-hydrodynamics (MHD).Various applications for this particular type of fluid have emerged in engineering and business, involving MHD sensors, reactor cooling, magnetic drug targeting, power generation, and crystal formation. MHD is affected by magnetic induction strength (Jawad et al., 2021). These days, Magnetohydrodynamics (MHD) has become utilized in an extensive variety of domains of science and engineering, both fundamental and applied. The motion of biological fluids, plastic sheet formation, and lubricant performance has all encouraged interest in the study of non-Newtonian fluids.

The potential applications of the problems of free convective and heat transfer through a porous medium under the influence of a magnetic field in a wide range of scientific and technological fields, including film vaporization in combustion chambers, cross-hatching on ablative surfaces, and transportation cooling of re-entry vehicles and rocket boosters, have drawn the attention of many researchers in recent years. Conversely, flow through a porous material has various geophysical and engineering uses. It can be used, for example, to investigate subsurface water resources in agriculture engineering, filtration and purification processes in chemical engineering, and the flow of water, oil, and natural gas through oil reservoirs in petroleum technology. (Ramana et al., 2016). Mosharrof Hossain et al (2023) explored the effects of chemical reactions on unsteady MHD convective transport on a vertical porous sheet. Kodi et al. (2022) investigated the effects of soret, rotation, hall, and ion slip on the unsteady MHD flow of a Jeffrey fluid through a porous media in the presence of heat absorption and chemical reaction. The variable suction-induced unsteady magneto-hydrodynamic mixed convection Jeffrey fluid flow over an inclined permeable moving plate in the presence of heat generation, thermal radiation, the thermophoresis effect, and identical chemical reactions studied by Gangadhar et al. (2020). Omokhuale et al. (2023) examined the influence of heat absorption on the unstable MHD convective Jeffrey fluid of a viscous, electrically conducting, and incompressible fluid. Prabhakar Reddy (2022) provided an extensive examination of the effects of Newtonian heating on MHD unsteady-free convection boundary layer flow over an oscillating vertical porous plate nested in a porous medium which includes thermal radiation, chemical reactions, and heat absorption.

The study of non-Newtonian fluids has several applications in engineering and sector, particularly for the extraction of crude oil from petroleum products. Despite most models of fluids, which incorporate convected derivatives, Jeffrey fluids use a comparatively simpler linear model based on time derivatives. One of the rate-type materials is Jeffrey fluid. It demonstrates the fluid's linear viscoelastic effect, which has multiple applications in polymers. (Yale *et al.*, 2019). Fluids are classified as Newtonian and non-Newtonian fluids for the most part. Non-Newtonian fluids, which include blood, greases, oils, and honey, offer a wide range of practical and industrial uses. Biological systems, textile, polymer, and irrigation issues all include Fluid flows through porous mediums that are non- Newtonian those are subject to magnetic effects (Noor et al., 2020). The effects of chemical reactions on the Unstable MHD flow of Jeffrey fluid in a porous enclosure discussed by Shukla et al. (2023). Omokhuale et al. (2023) investigated the effect of heat absorption on the magnetohydrodynamic (MHD) flow of Jeffery fluid in an infinite vertical plate. The theoretical study of a chemically reactive fluid in an MHD natural convection flow with heat source and sink effects was presented by Ojemeri and Hamza in 2022. Gambo & Gambo (2020) presented an extensive examination of the impacts of a fully developed natural convective flow of a heat-generating or absorbing fluid in an open-ended vertical concentric annulus with a magnetic field effect. Chu et al. (2020) investigated the nonlinear thermal radiation and heat sink/source of a bidirectional, periodically moving surface-driven flow in a rate-type nanofluid containing a gyrotactic microbe. The effects of radiative heat flux, joule heating, dissipation, and heat generation/absorption on the mixed convective entropy-optimized nanomaterial MHD flow of Ree-Eyring fluid created by two rotating disks highlighted by Zhao et al. (2021). Unsteady MHD flow of a Jeffery fluid through a porous medium in the presence of chemical reaction and heat absorption investigated by Raghunath et al. (2022). A computational study on the magnetohydrodynamic (MHD) squeezing flow of Jeffrey fluid through two parallel plates in a porous medium including thermal radiation, heat generation/absorption, as well as chemical reaction conducted by Noor et al. (2020) . The work by Shukla et al. (2023) looked at how a chemical reaction affected the unsteady MHD flow of the jeffrey fluid in a porous enclosure covered by a vertically oscillating surface. The impact of radiation absorption and chemical reactions on the magneto hydrodynamic (MHD) flow of Jeffrey fluid in an infinite vertical plate studied by Omokhuale and Dange (2023). The impacts on heat absorption and magnetohydrodynamics (MHD) on the flow of Jeffrey fluid across a vertical porous plate with varying suction were investigated by Salisu et al. (2022). MHD Casson fluid flow across an infinite vertical plate with chemical reaction and heat generation was studied by Omokhuale et al. (2019). Kodi et al. (2022) examined the effects of Soret, Rotation, Hall, and Ion slip on unsteady MHD flow of a Jeffrey fluid through a porous material in the presence of heat absorption and a chemical reaction. MHD flow of a second-grade fluid with heat absorption and chemical reaction was investigated by Ramzan et al. (2022). Thermal radiation effect of unstable magneto-convective heat and mass spread by micropolar binary mixture of fluid moving over a continuous permeable surface researched by Hossain et al. (2022) . The roles of radiation and viscous dissipation on the flow of an unstable magnetically heat-conductive mass across a vertically porous sheet have been studied by Hasanuzzaman et al. (2022). The influence of radiation and chemical reactions on an unstable two-dimensional laminar flow covering a viscous fluid over a rapidly traveling, semi-infinite vertical absorbent surface investigated by Appidi et al. (2023). The Newtonian heating, heat absorption, and chemical reaction of MHD free convective Casson hybrid nanofluids moving through an indefinitely oscillating vertical porous plate studied by Krishna (2022). Impact of heat generation and absorption on natural convection flow in a vertical annulus with time-periodic boundary conditions, investigated by Oni et al. (2019).

The main aim of the present study is to investigate the effects of chemical reaction and radiation absorption on unsteady MHD free convection flow of Jeffery fluid in vertical porous plate using the regular perturbation technique. The study is an extension to the work done by Salisu et al. (2022).

METHODOLOGY

Mathematical Formulations

We investigated an incompressible Jeffrey fluid with electrical conductivity in two dimensions flowing in an unstable way over a vertical porous plate. The physical variables, given the plate's vertical extent, can be represented as functions of y' and t', where x' is the vertical upward direction along the plate where the fluid sink and applied magnetic field at the plate's surface, and y' is the plate's normal. Compared to the fluid's own temperature and the surrounding air temperature, the fluid is heated to $T_w{}'$ and its concentration is raised to $C_w{}'$,, respectively. Furthermore, the effect of heat and chemical absorption, radiation absorption, and Soret effects are all taken into consideration. The induced magnetic field is thought to be insignificant. The subsequent fundamental equations govern the problem, further assuming the reliability of the boundary-layer and Boussinesq approximations:

Continuity equation

$$\frac{\partial v'}{\partial y'} = 0 \tag{1}$$

Momentum equation

$$\frac{\partial u'}{\partial t'} + v' \frac{\partial u'}{\partial y'} = -\frac{1}{\rho}\frac{\partial p'}{\partial x'} + \frac{v}{(1+\beta_1)}\frac{\partial^2 u'}{\partial y'^2} + gB_T(T' - T'_\infty) + gB_C(C' - C'_\infty) - \frac{\sigma\beta_0^2 u'}{\rho} - \nu\frac{u'}{K'} \tag{2}$$

Energy equation

$$\frac{\partial T'}{\partial t'} + v' \frac{\partial T'}{\partial y'} = \frac{K}{\rho C_P}\frac{\partial^2 T'}{\partial y'^2} - \frac{Q_0}{\rho C_P}(T' - T'_\infty) + Q_1(C' - C'_\infty) \tag{3}$$

Mass Concentration/Diffusion equation

$$\frac{\partial c'}{\partial t'} + v' \frac{\partial c'}{\partial y'} = D_m \frac{\partial^2 c'}{\partial y'^2} - R_m(C' - C'_\infty) \tag{4}$$

The dimensional distances along and perpendicular to the plate and dimensional time are represented by the variables x', y', and t', respectively. The components of dimensional velocities along the x' and y' axes are, respectively, u' and v'. The dimensional temperature is T', the dimensional concentration is C', and the temperature and concentration at the wall are, respectively, C_w and T_w. The temperature and dimensional concentration of the free stream are denoted by C_∞ and T_∞, respectively. The variables that are represented in this equation are the fluid density (ρ), kinematic viscosity (v), specific heat at constant pressure c_ρ, fluid electrical conductivity (σ), magnetic induction B_0, porous medium permeability K', and dimensional heat absorption Q^0 coefficient, the mass diffusivity is D_m, the gravitational acceleration is g, the thermal expansion coefficient is B_T, the concentration expansion coefficient is B_C, and the chemical reaction parameter is R_m. Q_1 is the coefficient of proportionality for radiation absorption. It is assumed that the permeable plate travels with a variable velocity in the direction of the fluid flow and that the temperature and concentration at the wall, along with the suction velocity, fluctuate exponentially with time.

The above assumptions show that the appropriate boundary conditions for the fields of temperature, concentration, and velocity are

*

$$\left\{\begin{matrix} u = U_0\left(1+\in e^{int}\right), & T = T_w+\in (T_w - T_\infty)e^{int} & C = C_w+\in (C_w - C_\infty)e^{int} & at\ y = 0 \\ u \to 0, & T \to T_\infty\ , & C \to C_\infty & as\ y \to \infty \end{matrix}\right\} \tag{5}$$

Where T_w and C_w are are the wall dimensional temperature and concentration, respectively, TT_∞ and $C_\infty$are the free stream dimensional temperature and concentration, respectively, and n is the constant. Where U_0 is the plate velocity Eq. (1) demonstrates abundantly evident that the suction velocity at the plate surface is only controlled by time. Considering that it takes the following exponential form:

$$v' = -v_0 \tag{6}$$

Where V_0 is the constant suction velocity normal to the plate. To describe the governing equations and the boundary condition in dimensionless form, the following non-dimensional quantities are introduced.

$$\left\{\begin{matrix} x = \frac{x'}{a}, \quad y = \frac{y'}{a}, \quad u = \frac{u'}{U}, \quad p = \frac{ap'}{\rho v u}, \quad t = \frac{t'u}{a}, \quad \theta = \frac{T' - T_\infty'}{T_w' - T_\infty'} \text{ and } C = \frac{(C' - C_\infty')}{(C_w' - C_\infty')} \\ Re = \frac{ua}{v}, \quad \alpha = 1 + \beta_1, \quad v' = -v_0, \quad \gamma = \frac{v_0 a}{v} \quad Pr = \frac{v\rho C_p}{k} \quad \delta = \frac{vQ_T}{a^2 \rho c_p} \end{matrix}\right\} \tag{7}$$

The following dimensionless form is obtained by reducing equations (2) to (4) with regard to of the non-dimensional quantities (7) and equation (6).

$$Re\frac{\partial u}{\partial t} - \gamma\frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} + \frac{1}{(1+\beta_1)}\frac{\partial^2 u}{\partial y^2} + G_r T + G_c C - mu - \frac{1}{k}u \tag{8}$$

$$Re\frac{\partial T}{\partial t} - \gamma\frac{\partial T}{\partial y} = \frac{1}{Pr}\frac{\partial^2 T}{\partial y^2} + \lambda c - \delta T \tag{9}$$

$$Re\frac{\partial c}{\partial t} - \gamma\frac{\partial c}{\partial t} = \frac{1}{sc}\frac{\partial^2 c}{\partial y^2} - \xi c \tag{10}$$

While the boundary and initial dimensionless conditions are:

$$\left.\begin{matrix} u = 1 + \in e^{int}, \ \theta = 1 + \in e^{int}, \ \emptyset = 1 + \in e^{int} & at\ y = 0 \\ u \to 0, \ \theta \to T_\infty, \ \emptyset \to C_\infty & as\ y \to \infty \end{matrix}\right\} \tag{11}$$

METHOD OF SOLUTION

We employ the perturbation approach to solve the equations (8) to (10) subject to the boundary conditions (11). Let the fields of concentration, temperature, and velocity as

$$\mathrm{U(y,t)} = U_0(y) + U_1(y)\varepsilon e^{int}$$
$$\mathrm{T(y,t)} = T_0(y) + T_1(y)\varepsilon e^{int}$$
$$\mathrm{C(y,t)} = C_0(y) + C_1(y)\varepsilon e^{int} \qquad \ldots (12)$$

The thermal Grash of number, solutal Grash of number, magnetic parameter, Jeffrey fluid parameter, Prandtl number, heat absorption parameter, radiation absorption parameter, Schmidt number, and chemical reaction parameter are, respectively, *Gr, Gm, M*, β_1, Pr, *δ, λ, Sc* and *Kr.* Where ∈ is a small quantity (∈ << 1).

Assume that $-\frac{\partial p}{\partial x} = \lambda[e^{int} + e^{-int}]$ and $\alpha = (1 + \beta_1)$

By equating the harmonic and non-harmonic terms and substituting equation (12) into equations (8), (9) and (10) while neglecting the terms of $\in^2$, we obtain

$$u_1'' + \gamma\alpha u_1' - \left(Rein + m + \frac{1}{k}\right)\alpha u_1 = -\alpha GrT_1 - \alpha Gcc_1 - \alpha\lambda \tag{13}$$

$$u_0'' + \gamma\alpha u_0' - \left(m + \frac{1}{k}\right)\alpha u_0 = -\alpha GrT_0 - \alpha Gcc_0 - \alpha\lambda \tag{14}$$

$$T_1'' + \gamma prT_1' - (Rein + \delta)prT_1 = -prc_1 \tag{15}$$

$$T_0'' + \gamma prT_0' - \delta prT_0 = -prc_0 \tag{16}$$

$$c_1'' + \gamma scc_1' - (Rein + \xi)scc_1 = 0 \tag{17}$$

$$c_0'' + \gamma scc_0' - sc\xi c_0 = 0 \tag{18}$$

The corresponding boundary conditions are

$$\left.\begin{matrix} u = u_0 = 1, \theta_1 = \theta_0 = 1, \quad c_0 = c_1 = 1, \quad at\ \ y = 0 \\ u_0 = 0, \ u_1 = 0, \ \theta_0 = 0, \ \theta_1 = 0, \ c_0 = 0, \ c_1 = 0 \quad as\ \ y \to \infty \end{matrix}\right\} \tag{19}$$

In light of (19), we obtain the following equations after solving equation (13) – (18).

$$U_0(y) = B_{12}e^{-n_{10}y} + B_{13}e^{-n_6y} + B_{14}e^{-n_2y} + B_{15} \tag{20}$$
$$U_1(y) = B_{17}e^{-n_{12}y} + B_{18}e^{-n_8y} + B_{19}e^{-n_4y} + B_{20} \tag{21}$$
$$T_0(y) = B_6e^{-n_6y} + B_7e^{-n_2y} \tag{22}$$
$$T_1(y) = B_9e^{-n_8y} + B_{10}e^{-n_4y} \tag{23}$$
$$C_0(y) = e^{-n_2y} \tag{24}$$
$$C_1(y) = e^{-n_4y} \tag{25}$$

On substituting the expressions of U_0, U_1, T_0, T_1, C_0, and C_1. The velocity, temperature, and concentration expressions in equations (12) are

$$U(y,t) = (B_{12}e^{-n_{10}y} + B_{13}e^{-n_6y} + B_{14}e^{-n_2y} + B_{15}) + \varepsilon(B_{17}e^{-n_{12}y} + B_{18}e^{-n_8y} + B_{19}e^{-n_4y} + B_{20})e^{int} \tag{26}$$
$$T(y,t) = (B_6e^{-n_6y} + B_7e^{-n_2y}) + \varepsilon(B_9e^{-n_8y} + B_{10}e^{-n_4y})e^{int} \tag{27}$$
$$C(y,t) = (e^{-n_2y}) + \varepsilon(e^{-n_4y})e^{int} \tag{28}$$

The skin-friction, Nusselt number, and Sherwood number constitute vital physical parameters for this particular kind of boundary layer flow.

Skin-Friction

With only*the velocity field known, the Skin-friction at the plate in the non-dimensional form can be obtained.

$$\tau = -\left(\frac{\partial u}{\partial y}\right)_{y=0} = n_{10}B_{12} + n_6B_{13} + n_2B_{14} + \varepsilon(n_{12}B_{17} + n_8B_{18} + n_4B_{19})e^{int} \tag{29}$$

Nusselt Number

The rate of heat transfer on the well in terms of the Nusselt number can be obtained from the temperature field as follows:

$$N_u = -\left(\frac{\partial T}{\partial y}\right)_{y=0} = (n_6B_6 + n_2B_7) + \varepsilon(n_8B_9 + n_4B_{10})e^{int} \tag{30}$$

Sherwood Number

The rate of mass transfer on the surface in terms of Sherwood number Sh is given by the concentration field.

$$Sh = -\left(\frac{\partial c}{\partial y}\right)_{y=0} = n_2 + \varepsilon n_4e^{int} \tag{31}$$

RESULTS AND DISCUSSION

The current research investigates unstable flow of an incompressible Jeffery fluid over a vertical porous plate, analyzing the effects of chemical reactions and radiation absorption. The regular perturbation technique is used to solve partial differential equations with non-linear coupling. The results illustrate the impacts on various fundamental parameters, particularly the heat sink, radiation absorption, thermal, magnetic, and Jeffrey fluid parameters (β, S, and M) mass and Grashof number Gr Computation of the flow fields is done using the Grashof number (Gc), Prandtl number (Pr), Schmidt number (Sc), and chemical reaction parameter (Kr) on the flow behaviors. The current study's computations make use of the following default parameter values: The Prandtl number Pr value is chosen to represent air. Pr = 0.71, $\beta = 0.1$,S=1,M=1,$\delta = 1$,Ra=1,Gr=1,Gc=1,Sc=0.22 and Kr=1.

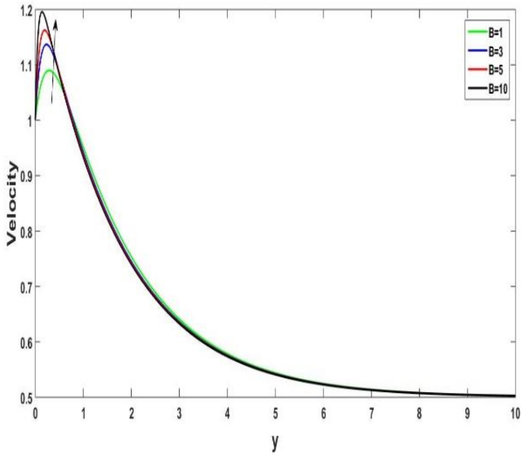

Figure 1: Jeffrey fluid parameter's effect on gradient of velocity

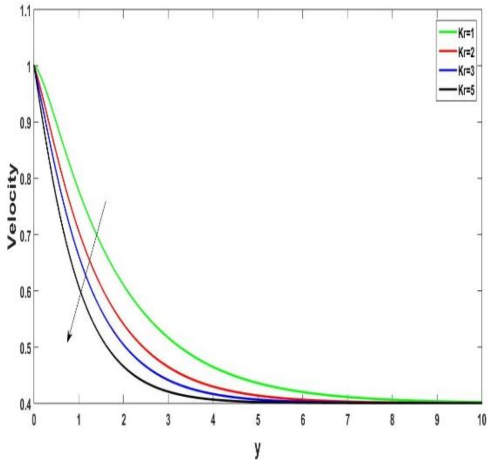

Figure 2: chemical reaction parameter's effect on velocity gradient

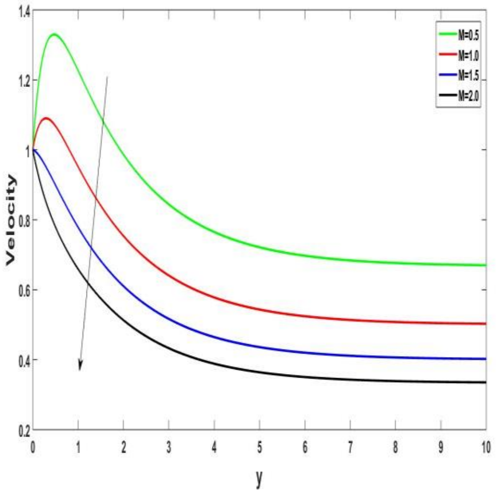

Figure 3: Velocity gradient impacted by The magnetic parameter (Hartmann number)

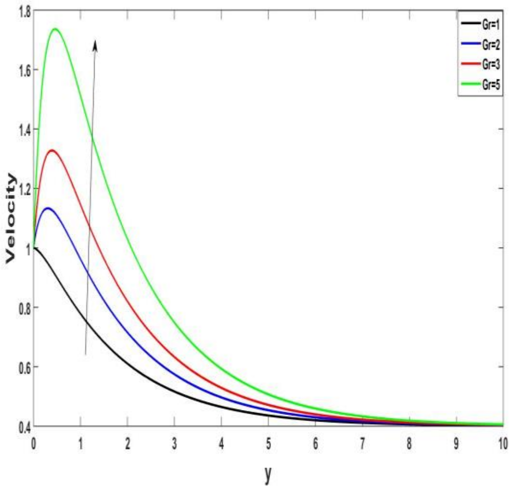

Figure 4: The impact of the thermal Grashof number on the gradient in velocity*

Figure 1 illustrates the effect of the Jeffrey fluid parameter on velocity profiles. It is clear that velocity profiles increase along with the Jeffrey fluid parameter. Conversely, Figures 2 and 3 illustrated the reverse occurrence, showing that for a fixed value of other parameters, the fluid velocity increased with growing levels of the chemical reaction and magnetic parameter (Hartmann number).

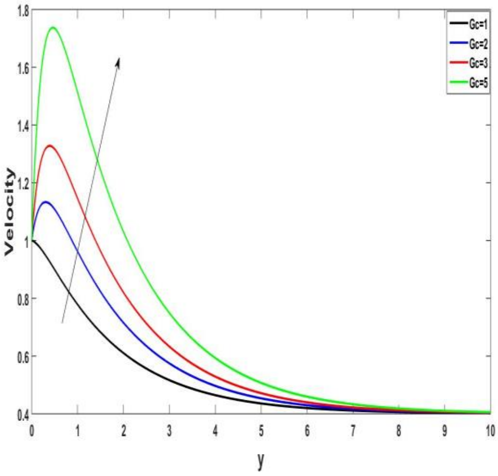

Figure 5: Mass Grashof number effect on The velocity gradient.

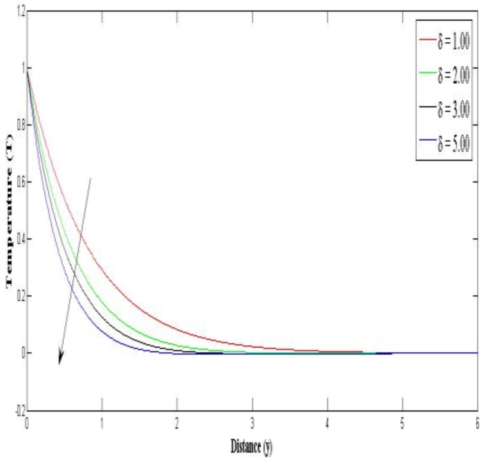

Figure 6: The heat sink parameter's influence The on temperature gradient

Figures 4 and 5 above illustrate the effects of mass and thermal Grashof numbers (Gr = Gc =1.0, 2.0, 3.0, and 5.0) on the velocity profiles. It is demonstrated that the thermal buoyant force boost produces a velocity increase. Furthermore, the peak velocity increases rapidly nearer the porous plate and progressively falls for free steam velocity. Additionally, It is noted that when the species buoyancy force grows, the fluid velocity increases and the peak value becomes more noticeable. Thus, before accurately dropping to a free stream value, In the vicinity of the plate, the velocity distribution observable achieves its highest value.

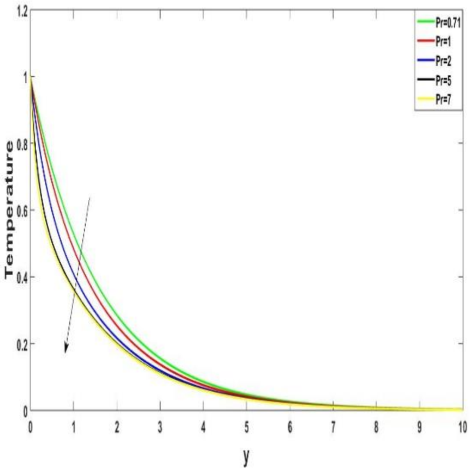

Figure 7: impact of Prandlt number on temperature gradient

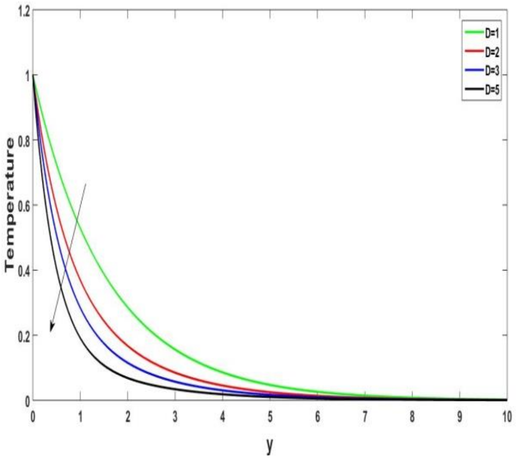

Figure 8: temperature gradient impact due to radiation absorption

Figure 6 shows that temperature and velocity diminish as heat sink δ increases. This is due to the fact that when heat absorption occurs, buoyant forces decrease, which delays flow rate and lowers temperature profile. Figure 7 depicts the impacts of changing the Prandtl number (Pr = 0.71, 1.0, 2.0, 5.0, 7.0) on the temperature gradient. The graph displays that temperature drops as the Prandtl number rises.*Figure 8 demonstrates that the temperature decreases*as radiation absorption (D) grows. This is because the buoyant forces reduce as a result of heat absorption, reducing the flow rate and lowering the temperature profile.

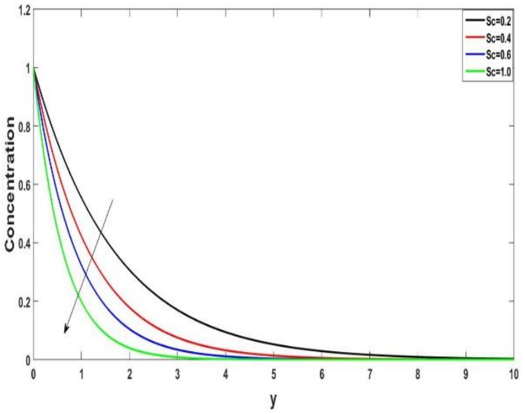

Figure 9: Scmidlt number's number impact On the gradient of concentration

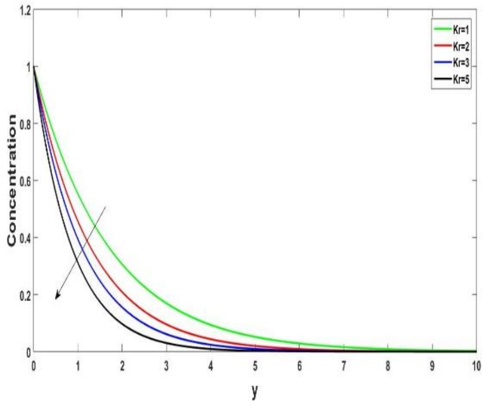

Figure 10: Concentration gradient is impacted by a chemical reaction parameter on

In the same spirit, see Figure 9. The concentration and Schmidt number (Sc) have a clear relationship; the concentration drops as the Schmidt number increases. As the Schmidt number increases, the fluid tends to transfer momentum more effectively than mass (concentration). Therefore, as less mass is effectively moved through the fluid, the concentration decreases. However, Figure 10 depicts a similar process, showing that the fluid's concentration lowers as the rate of chemical reaction increases.

CONCLUSION

The effects of radiation absorption, and chemical reactions on unstable MHD free convection flow of Jeffrey fluid on vertical porous plates are examined in this work. The mass diffusion/concentration, temperature, and velocity governing equations of the flow are solved by the regular perturbation approach. The pressure term parameter, thermal Grashof number, mass Grashof number, Prandtl number, Schmidt number, Jeffrey fluid parameter β, suction parameter, magnetic parameter, heat sink, radiation absorption, and chemical reaction parameter were among the parameters that were examined graphically. The following conclusions were drawn by the investigation: It has been found that the velocity profile accelerates as the Jeffrey fluid parameter increases. It is discovered that as the chemical reaction and magnetic parameters increase, the fluid's velocity decreases. By raising the Grashof number (Gr) and the Grashof number for mass transfer (Gm), the fluid velocity is accelerated. The results of the experiment showed that temperature and velocity drop in proportion to an increase in heat sink δ. As the radiation absorption (D) and prandtl number (Pr) rise, the fluid's temperature falls. As the chemical reaction and Schmidt number Sc increase, the concentration diminishes.

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