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ANALYSIS OF ROTATIONAL EFFECTS ON FLOW PAST A PARABOLIC ACCELERATED VERTICAL PLATE WITH MASS DIFFUSION IN THE PRESENCE OF THERMAL RADIATION AND CHEMICAL REACTION

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Abstract

A specific theoretical solution of unsteady flow past a Parabolic accelerated isothermal vertical plate with uniform mass diffusion in the presence of Thermal radiation and Chemical reaction of first order homogenous equation has been studied. The non-dimensional governing equations were solved by using the Laplace transform technique. The outcome of plate temperature expanded to T'_w because the thermal radiation parameter (R) is increased, the temperature lowers, whereas the temperature rises as the time is increased and concentration profiles reduces because the effect of flow parameters such as rotational parameter, hall parameter, Chemical reaction parameter, Prandtl number, Schmidt number, the thermal Grashof number, mass Grashof number are studied. It is found that $\Omega = M^2m/(1+m^2)$, the component vanishes in the secondary velocity and the fluid moves along with the plate direction only.

1. Introduction

Magneto hydrodynamics is the study of the magnetic characteristics and behavior of electrically conductive fluids. To detect the magnitude of the

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magnetic field, Hall-effect sensors are utilized. It may be found in a variety of applications, including fluid flow and pressure sensors. A body's temperature causes it to emit thermal radiation, which is an electromagnetic signal. The engineering and scientific industries rely heavily on the investigation of heat and mass transport problems involving chemical processes. The MHD field's influence is critical in a variety of applications, including plasma confinement, nuclear reactor liquid-metal cooling, paper, and the textile sector. Edwin Hall, a physicist, is familiar with the Hall-effect principle. The Sun's heating of the Earth is an example of radiation. Because of the various applications in this subject, such as astrophysics, nuclear power reactors, and geophysics, the analysis of hydromagnetic flow in the presence of thermal radiation, including heat and mass transfer, has attracted many researchers. The engineering and scientific industries rely heavily on the investigation of heat and mass transport problems involving chemical processes.

Dekha et al. [1] investigate the effects of rotation and Hall current on hydromagnetic flow past an accelerated plate moving through a rotating fluid. Selvaraj et al. [2] analyzed the heat and mass transfer effect of rotation on parabolic flow past in a vertical plate. Hall effects on the unsteady free convection flow of a viscous incompressible and electrically conductive fluid were studied by Hossain et al. [3]. In the presence of thermal radiation and the Hall effect, Lakshmi Velu et al. [4] must explore the heat and mass transfer impacts on flow through a parabolic accelerated isothermal vertical plate. Muthucumaraswamy and Sivakumar et al. [5] investigated the effects of Hall current and rotation on MHD flow through an accelerated infinite vertical in the presence of a rotating fluid with variable temperature and uniform mass diffusion with first-order chemical reaction. Muthucumaraswamy et al. [6] investigated MHD flow in the presence of heat radiation using a parabolic beginning motion on an infinite isothermal vertical plate. The MHD flow via a parabolic motion initiated vertical plate with changing temperature, and uniform mass diffusion was studied by Neet et al. [7]. The unsteady MHD free convection flow of viscous incompressible and electrically conductive fluid created by an impulsively moving vertical plate to constant heat flux was investigated by Sacheet et al. [8]. Selvaraj et al. [9]. Studied MHD Parabolic flow past an accelerated isothermal vertical plate with heat and mass diffusion in the presence of rotation. The effects of external plate heating and cooling by free convection currents were studied by Soundalger et al. [10]. In the presence of a magnetic field and Hall currents, this research attempts to investigate the effects of thermal radiation and chemical reactions on flow through a parabolic accelerated isothermal vertical plate. The Laplace transform strategy is utilized to solve the non-dimensional governing equations. The solutions are expressed in terms of a complementary error function and an exponential error function.

2. Mathematical Formulation

The fluid is in a stationary medium and at the same temperature at the start of the plate. Initially, the plate and the fluid rotated at a constant angular velocity Ω' about the Z-axis normal to the plate, which is perpendicular to the X-axis and y' axis, with the X-axis pointing upwards in the vertical plate and y' axis normal to the plate. Consider a viscous incompressible fluid flowing through a parabolic accelerated isothermal vertical plate with uniform mass diffusion. An external magnetic field B_0 of consistent strength is applied to the plate. At time $t' \leq 0,$ the plate and fluid keep the same constant temperature T'_∞ and the fluid concentration is C'_∞. At time $t' > 0,$ the plate is parabolic accelerated with a velocity $u = u_0 t'^2$ in its plane opposite to the gravitational field. At time $t' > 0,$ the temperature of the plate and the concentration level near the plate are increased concerning time. The plate's temperature is increased to T'_w and the concentration level is increased to C'_w.

The unsteady flow of momentum equations is given by

$$\frac{\partial u}{\partial t'} = \upsilon \frac{\partial^2 u}{\partial z'^2} + 2\Omega' v - \frac{\sigma \mu_e^2 B_0^2}{\rho(1+m^2)}(u + mv) + g\beta(T' - T'_\infty) + g\beta^*(C' - C'_\infty) \quad (1)$$

$$\frac{\partial v}{\partial t'} = \upsilon \frac{\partial^2 v}{\partial z'^2} - 2\Omega' u + \frac{\sigma \mu_e^2 B_0^2}{\rho(1+m^2)}(mu - v) \quad (2)$$

Temperature equation

$$\rho C_p \frac{\partial T'}{\partial t'} = k \frac{\partial^2 T'}{\partial z^2} - \frac{\partial q_r}{\partial z} \quad (3)$$

Consider the Mass diffusion Equation

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial z'} - k_l(C' - C'_\infty) \tag{4}$$

Where u is the axial quickness and v is the transverse velocity.

The primary and necessary boundary conditions are

$t' \leq 0 : u = 0,\ v = 0,\ T' = T'_\infty,\ C' = C'_\infty$ for all z

$t' > 0 : u = u_0 t'^2,\ v = 0,\ T' = T'_\infty,\ C' = C'_\infty$ at $z = 0$

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

For the situation of an optically thin grey gas, the local radiant is represented by

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

It is assumed that the temperature differences within the flow are sufficiently small such T'^4 they may be expressed as a linear function of the temperature. This is accomplished by expanding T'^4 n the Taylor series about T' and neglecting higher-order terms, thus

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

By using equations (6), (7) equation (3) reduces to

$$\rho C_p \frac{\partial T'}{\partial t'} = k\frac{\partial^2 T'}{\partial y^2} + 16a^*\sigma T'^3_\infty(T'_\infty - T') \tag{8}$$

On introducing non-dimensional quantities:

$$U = u\left(\frac{u_0}{v^2}\right)^{\frac{1}{3}},\ t = \left(\frac{u_0^2}{v}\right)^{\frac{1}{3}} t',\ Z = z\left(\frac{u_0}{v^2}\right)^{\frac{1}{3}},$$

$$M = \frac{\sigma B_0^2}{\rho}\left(\frac{v}{u_0^2}\right)^{\frac{1}{3}},\ K = k_l\left(\frac{v}{u_0^2}\right)^{\frac{1}{3}},$$

$$R = \frac{16a^{*}\sigma.T_{\infty}^{3}}{k}\left(\frac{v}{u_0}\right)^{\frac{2}{3}},\ C = \frac{C' - C'_{\infty}}{C'_w - C'_{\infty}},\ \theta = \frac{T' - T'_{\infty}}{T'_w - T'_{\infty}},\ \Pr = \frac{\mu C_p}{K},\ Sc = \frac{v}{D'}$$

$$\Omega = \Omega'\left(\frac{v}{u_0^2}\right)^{\frac{1}{3}},\ Gc = \frac{g\beta(C' - C'_{\infty})}{(v,\ u_0)^{\frac{1}{3}}},\ Gr = \frac{g\beta(T - T_{\infty})}{(v,\ u_0)^{\frac{1}{3}}}.$$

Equations (1) to (5) are reduced to the non-dimensional form as:

$$\frac{\partial U}{\partial t} = \frac{\partial^2 U}{\partial z^2} + 2\Omega V - \frac{2M^2}{1 + m^2}(U + mV) + Gr\theta + GcC \tag{9}$$

$$\frac{\partial V}{\partial t} = \frac{\partial^2 V}{\partial z^2} - 2\Omega U + \frac{2M^2}{1 + m^2}(mU - V) \tag{10}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial z^2} - \frac{R}{\Pr}\theta \tag{11}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial z^2} - KC \tag{12}$$

The primal and necessary conditions in the non-dimensional form are

$t' \leq 0 : U = 0,\ V = 0,\ \theta = 0,\ C = 0$ for all Z

$t' > 0 : U = t^2,\ V = 0,\ \theta = 1,\ C = 1$ at $Z = 0$

$$t' > 0 : U \to 0,\ V \to 0,\ \theta \to 0,\ C \to 0 \text{ as } Z \to \infty. \tag{13}$$

The above equations (9)-(12) and the boundary conditions (13) can be combined as

$$\frac{\partial F}{\partial t} = \frac{\partial^2 F}{\partial z^2} - aF + Gr\theta + GcC \tag{14}$$

$$\frac{\partial \theta}{\partial T} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial z^2} - \frac{R}{\Pr}\theta \tag{15}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 \theta}{\partial z^2} - KC \tag{16}$$

Where $a = \frac{2M^2}{1+m^2} + 2i\left[\Omega - \frac{M^2 m}{1+m^2}\right]$

With boundary conditions

$t' \le 0 : F = 0, \theta = 0, C = 0$ for all Z

$t' > 0 : F = t^2, \theta = 1, C = 1$ at $z = 0$

$t' > 0 : F \to 0, \theta \to 1, C \to 1$ as $Z \to \infty$. (17)

Where $F = U + iV$, U represents the axial velocity (primary velocity), V represents the transverse velocity (secondary velocity), all the physical variables are defined in the terminology.

3. Solution Procedure

$$\theta = \frac{1}{2}[e^{-2\eta\sqrt{Rt}} erfc(\eta\sqrt{\Pr} - \sqrt{bt}) + e^{2\eta\sqrt{Rt}} erfc(\eta\sqrt{\Pr} + \sqrt{bt})]$$

$$C = \frac{1}{2}[e^{-2\eta\sqrt{Sc\cdot Kt}} erfc(\eta\sqrt{Sc} - \sqrt{Kt}) + e^{2\eta\sqrt{Sc\cdot Kt}} erfc(\eta\sqrt{Sc} + \sqrt{Kt})]$$

$$F = \frac{\eta^2 tS}{a} + t^2 S + \frac{\eta\sqrt{t}}{2a} T - 2\eta t^{\frac{3}{2}} T - \frac{\eta}{a\sqrt{\pi}} e^{-(\eta^2 + at)} + (e+f)l_1 - e\exp(Ct)l_7$$

$$-f\exp(dt)l_3 - el_4 + e\exp(Ct)l_5 - fl_6 + f\exp(dt)l_7$$

Where, $S = \frac{1}{2}[e^{-2\eta\sqrt{at}} erfc(\eta - \sqrt{at}) + e^{2\eta\sqrt{at}} erfc(\eta + \sqrt{at})]$

$$T = \frac{1}{2\sqrt{a}}[e^{-2\eta\sqrt{at}} erfc(\eta - \sqrt{at}) + e^{2\eta\sqrt{at}} erfc(\eta + \sqrt{at})]$$

$$l_1 = [e^{-2\eta\sqrt{at}} erfc(\eta - \sqrt{at}) + e^{2\eta\sqrt{at}} erfc(\eta + \sqrt{at})]$$

$$l_2 = [e^{-2\eta\sqrt{(a+c)t}} erfc(\eta - \sqrt{(a+c)t}) + e^{2\eta\sqrt{(a+c)t}} erfc(\eta + \sqrt{(a+c)t})]$$

$$l_3 = [e^{-2\eta\sqrt{(a+d)t}} erfc(\eta - \sqrt{(a+d)t}) + e^{2\eta\sqrt{(a+d)t}} erfc(\eta + \sqrt{(a+d)t})]$$

$$l_4 = [e^{-2\eta\sqrt{\Pr\cdot bt}} erfc(\sqrt{\Pr}\eta - \sqrt{bt}) + e^{2\eta\sqrt{\Pr\cdot bt}} erfc(\sqrt{\Pr}\eta - \sqrt{bt})]$$

$$l_5 = [e^{-2\eta\sqrt{\Pr(b+c)t}} erfc(\sqrt{\Pr}\eta - \sqrt{(b+c)t}) + e^{2\eta\sqrt{\Pr(b+c)t}} erfc(\sqrt{pr}\eta - \sqrt{(b+c)t})]$$

$$l_6 = [e^{-2\eta\sqrt{Sc\cdot Kt}} erfc(\sqrt{Sc}\eta - \sqrt{Kt}) + e^{2\eta\sqrt{Sc\cdot Kt}} erfc(\sqrt{Sc}\eta - \sqrt{Kt})]$$

$$l_7 = [e^{-2\eta\sqrt{Sc(K+d)t}} erfc(\sqrt{Sc}\eta - \sqrt{(K+d)t})$$

$$+ e^{2\eta\sqrt{Sc(K+d)t}} erfc(\sqrt{Sc}\eta - \sqrt{(K+d)t})]$$

$$b = \frac{R}{\Pr}, \ c = \frac{a - \Pr\cdot b}{\Pr - 1}, \ d = \frac{a - Sc\cdot K}{Sc - 1}, \ e = \frac{Gr}{2c(1-\Pr)}, \ f = \frac{Gc}{2d(1-Sc)} \text{ and}$$

$$\eta = \frac{z}{2\sqrt{t}}.$$

4. Results and Interpretation

To analyse and studied the outcome of this problems is better understand also numerical calculations are carried out of different parameters $Gr, Gc, Sc, \Pr, M, m, t, K,$ and Ω. To plot profiles, it is assumed and considered that the Prandtl number is 0.71.

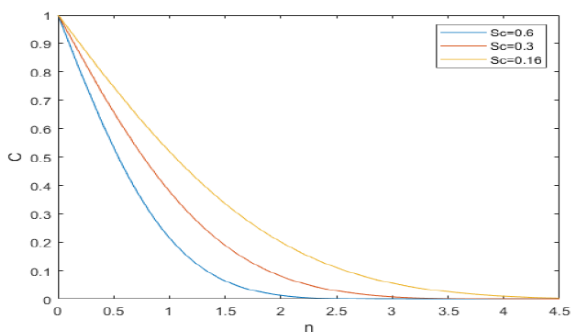

Figure 1. Concentration profiles for different of Sc.

Figure 1 suggest the impact of Schmidt number $(Sc = 0.6, 0.3, 0, 16)$, $t = 0.2, k = 0.2$ on the concentration field. It is discovered that the Schmidt number decreases, and the fluid's concentration value also increases.

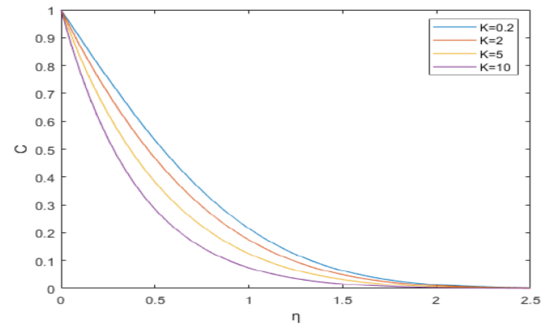

Figure 2. Concentration profiles for different of K.

Figure 2 shows the effects of $K(K = 0.2, 2, 5, 10)$. When $t = 0.2$, $Sc = 0.6$ on the concentration profile, we found the chemical parameter (K) values increases, the concentration of the fluid will decrease.

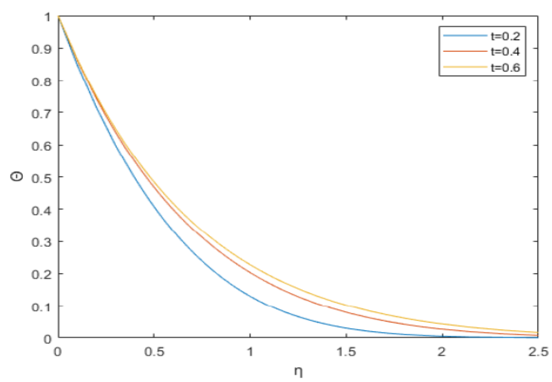

Figure 3. Temperature profiles for different of t.

Figure 3 shows the different values of time $t(t = 0.2, 0.4, 0.6)$ when $r = 2$, $pr = 0.71$ on the temperature profile, it is noticed that an increase in time t, results in also increase in the plate temperature.

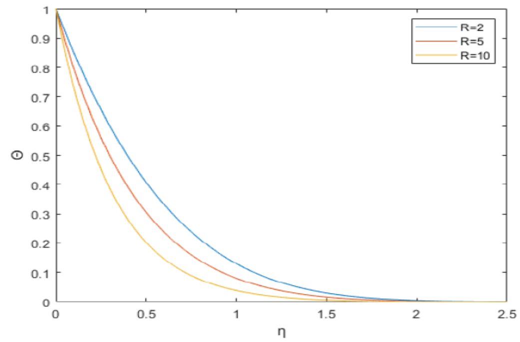

Figure 4. Temperature pattern for different of R.

Figure 4 shows that the temperature profiles are calculated for other thermal radiation parameters $R(R = 2, 5, 10)$. When $pr = 0.71$, $t = 0.2$, it is observed that the importance of thermal radiation is an increase in temperature will decrease.

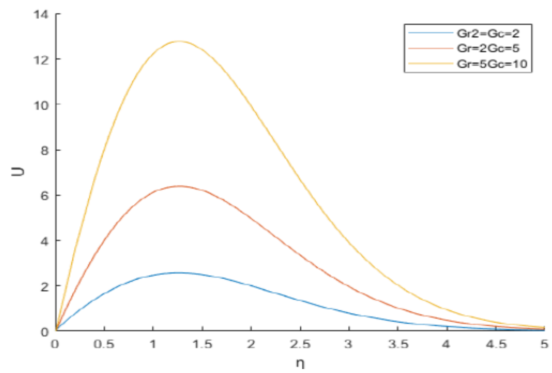

Figure 5. Velocity pattern for different of Gr, Gc.

Figure 5 clearly shows that the velocity profiles of different values of thermal and Mass Grashof numbers Gr and Gc values $(Gr = Gc = 2, Gr = Gc = 5, Gr = 10, Gc = 10)$ when $t = 0.2$, $pr = 0.71$, $Sc = 0.16$, $M = 2$, $m = 0.5$, $\Omega = 0.1$ increase the mass buoyancy effect of Gr and Gc.

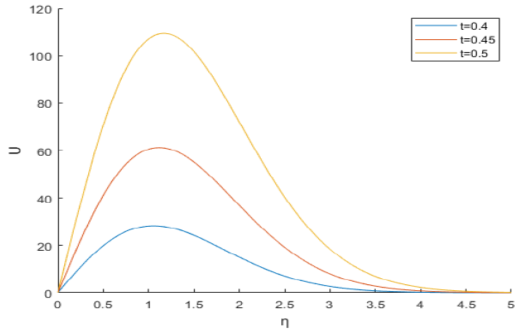

Figure 6. Velocity pattern for different of t.

Figure 6 shows that the effect of time $t(t = 0.4, 0.45, 0.5)$ on the velocity profile, when $Gr = 2, Gc = 2, pr = 0.71, Sc = 0.6, M = 2, m = 0.5, \Omega = 0.2, R = 2, K = 2,$ it is observed that the time t increases the results in plate velocity also increases.

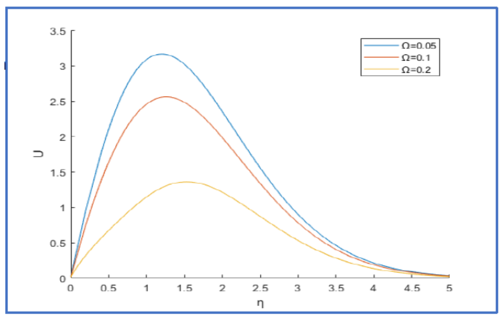

Figure 7. Velocity pattern for different of Ω.

Figure 7 shows that angular velocity $\Omega(\Omega = 0.05, 0.1, 0.2)$ on the velocity profile, when the values $Gr = 2, Gc = 2, pr = 0.71, Sc = 0.16, M = 2, m = 0.2, t = 0.2, R = 2, K = 2,$ the rotational parameter Ω will increase, velocity of the plate will decrease.

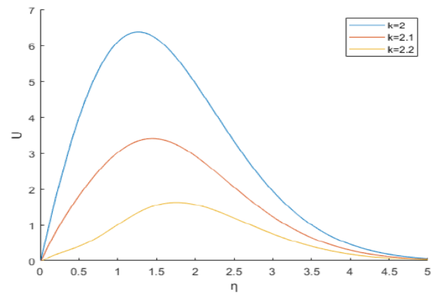

Figure 8. Velocity pattern for different of K.

Figure 8 shows the chemical reaction $K(K = 2, 2.1, 2.2)$ on the velocity profile, when the values are $Gr = 2, Gc = 5, pr = 0.71, Sc = 0.16, M = 2, m = 0.5, \Omega = 0.1, t = 0.2, R = 2,$ the values of chemical parameter K the values are increase and the results in the plate velocity will decreases.

5. Conclusion

In thermal radiation and chemical reaction process get the definite solution of Hall effects and MHD flow past through the parabolic accelerated vertical plate has been researched. The Laplace transform strategy is utilized to solve non-dimensional governing equations. Graphically, the influence of different physical parameters such as the thermal Grashof number, mass Grashof Advances and number, hall parameter, thermal radiation parameter, chemical reaction parameter, magnetic field parameter, and time are investigated.

An analytical study for the concentration, temperature and velocity profiles follows.

- As the thermal radiation parameter (R) is increased, the temperature brings down, through the temperature rises as the time is increased (t).
- As the Schmidt number (Sc) lowers, the concentration increases, and as the chemical reaction parameter increases, the concentration reduces (K).
- As time (t) passes, the velocity values esteemed in high.
- The velocity increases as the thermal Grashof number (Gr) and the mass Grashof number (Gr) increase.

- As the rotational parameter (Ω) and the chemical reaction parameter (K) are increased, the velocity drops.

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