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# CHEMICAL REACTION EFFECT ON UNSTEADY MHD FLOW THROUGH POROUS MEDIUM PAST AN EXPONENTIALLY ACCELERATED INCLINED PLATE WITH VARIABLE TEMPERATURE AND MASS DIFFUSION IN THE PRESENCE OF HALL CURRENT

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***ABSTRACT***

*Chemical reaction effect on unsteady MHD flow through porous medium past an exponentially accelerated inclined plate with variable temperature and mass diffusion in the presence of Hall current is studied here The fluid taken is electrically conducting. The Governing equations involved in the present analysis are solved by the Laplace-transform technique. The velocity profile is discussed with the help of graphs drawn for different parameters like thermal Grashof number, mass Grashof Number, Prandtl number, chemical parameter, Hall current parameter, permeability parameter, phase angle, the magnetic field parameter and Schmidt number; and the numerical values of skin-friction and sherwood number have been tabulated.*

***Keywords:*** *MHD flow exponentially accelerated plate, variable temperature, mass diffusion, Hall current.*

## INTRODUCTION

MHD flow with heat and mass transfer plays important role in different areas of science and technology, like chemical engineering, mechanical engineering, biological science, petroleum engineering, biomechanics, irrigation engineering and aerospace technology. In addition, the influence of magnetic field on viscous, incompressible and electrically conducting fluid is of great importance. It has many applications in magnetic material processing, glass manufacturing control processes and purification of crude oil. The response of laminar skin friction and heat transfer to fluctuations in the stream velocity was studied by Lighthill [1]. Raptis [2] has analyzed heat transfer in flow through a porous medium bounded by an infinite vertical plate under the action of magnetic field. Further Raptis and Perdikis [3] have considered flow of a viscous fluid through a porous medium bounded by a vertical surface. Singh and Kumar [4] have worked on free convection flow past an exponentially accelerated vertical plate. Mass transfer effects on the flow past an exponentially accelerated vertical plate with constant heat flux was investigated by Basant *et al.* [5]. Muthucumaraswamy *et al.* [10] have presented heat transfer effect on flow past an exponentially accelerated vertical plate with variable temperature. Further Muthucumaraswamy *et al.* [11] have considered mass transfer effect on exponentially accelerated isothermal vertical plate. Heat and mass transfer in MHD boundary layer flow past an inclined plate with viscous dissipation in porous medium was analyzed by Singh [15]. Chemical reaction effect on MHD flow is also significant in many cases. Some such problems already studied are mentioned here. Muthucumarswamy and Ganesan [6] have investigated first order chemical reaction on flow past an Impulsively started vertical plate with uniform heat and mass flux. Viscous flow over a non-linearly stretching sheet in the presence of a chemical reaction and magnetic field was studied by Raptis and Perdikis [9]. Effects of chemical reaction, heat and mass transfer and radiation on the MHD flow along a vertical porous wall in the presence of induced magnetic field was considered by Sahin and Chamkha [12]. Mahdy [13] has worked on effect of chemical reaction and heat generation or absorption on double-diffusive convection from a vertical truncated cone in porous media with variable viscosity. Rajput and Sahu [14] have presented combined effects of chemical reactions and heat generation or absorption on unsteady transient free convection MHD flow between two long vertical parallel plates through a porous medium with constant temperature and mass diffusion. Some papers related with Hall effect are also mention here. Attia[7] has considered the effect of variable properties on the unsteady Hartmann flow with heat transfer considering the Hall effect. The Hall effect on unsteady MHD Couette flow with heat transfer of a Bingham fluid with suction and injection was analyzed by Attia and Sayed[8]. Unsteady MHD flow through porous medium past an impulsively started inclined oscillating plate with variable temperature and mass diffusion in the presence of Hall current was studied by us [17]. Srinivas and Naikoti [16] have investigated Hall effect on unsteady MHD free convection flow over a stretching sheet with variable viscosity and viscous dissipation. We are considering chemical reaction effect on unsteady MHD flow through porous medium past an exponentially accelerated inclined plate with variable temperature and mass diffusion in the presence of Hall current. The results are shown with the help of graphs and table.

**MATHEMATICAL ANALYSIS**

MHD flow between two parallel electrically non conducting plates inclined at an angle $\alpha$ from vertical is considered. x axis is taken along the plate and $z$ normal to it. A transverse magnetic field $B_0$ of uniform strength is applied on the flow. Initially it has been considered that the plate as well as the fluid is at the same temperature $T_\infty$. The species concentration in the fluid is taken as $C_\infty$. At time $t > 0$, the plate starts exponentially accelerating in its own plane with velocity $u=u_0 e^{bt}$, and temperature of the plate is raised to $T_w$. The concentration $C$ near the plate is raised linearly with respect to time. The flow modal is as under:

$$\frac{\partial u}{\partial t} = \upsilon\frac{\partial^2 u}{\partial z^2} + g\beta Cos\alpha(T-T_\infty) + g\beta^* Cos\alpha(C-C_\infty) - \frac{\sigma B_0^2(u+mv)}{\rho(1+m^2)} - \frac{\upsilon u}{K}, \tag{1}$$

$$\frac{\partial v}{\partial t} = \upsilon\frac{\partial^2 v}{\partial z^2} + \frac{\sigma B_0^2(mu-v)}{\rho(1+m^2)} - \frac{\upsilon v}{K}, \tag{2}$$

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial z^2} - K_c(C-C_\infty), \tag{3}$$

$$\rho C_p\frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial z^2}. \tag{4}$$

The corresponding initial and boundary conditions are

$$\left.\begin{array}{l} t\le 0: u=0, v=0, T=T_\infty, C=C_\infty, \text{ for all } z \\ t>0: u=u_0 e^{bt}, v=0, T=T_\infty+(T_w-T_\infty)\dfrac{u_0^2 t}{\upsilon}, C=C_\infty+(C_w-C_\infty)\dfrac{u_0^2 t}{\upsilon}, \text{ at } z=0 \\ u\to 0, v\to 0, T\to T_\infty, C\to C_\infty \text{ as } z\to 0. \end{array}\right\} \tag{5}$$

Here u is the primary velocity, v -the secondary velocity, g-the acceleration due to gravity, $\beta$ -volumetric coefficient of thermal expansion, b-acceleration parameter, t-time, $m(=\omega_e\tau_e)$ is the Hall parameter with $\omega_e$ -cyclotron frequency of electrons and $\tau_e$ -electron collision time, K-the permeability parameter, T-temperature of the fluid, $\beta^*$ -volumetric coefficient of concentration expansion, C-species concentration in the fluid, $\nu$ -the kinematic viscosity, $\rho$ -the density, $C_p$ -the specific heat at constant pressure, k-thermal conductivity of the fluid, *D*-the mass diffusion coefficient, $T_w$ -temperature of the plate at z= 0, $C_w$ -species concentration at the plate z= 0, $B_0$ -the uniform magnetic field, $K_c$ -chemical reaction, $\sigma$ - electrical conductivity.

The following non-dimensional quantities are introduced to transform equations (1), (2), (3) and (4) into dimensionless form:

$$\left.\begin{array}{l} \bar{z}=\dfrac{zu_0}{\upsilon}, \bar{u}=\dfrac{u}{u_0}, \bar{v}=\dfrac{v}{u_0}, \theta=\dfrac{(T-T_\infty)}{(T_w-T_\infty)}, S_c=\dfrac{\upsilon}{D}, \mu=\rho\upsilon, P_r=\dfrac{\mu c_p}{k}, G_r=\dfrac{g\beta\upsilon(T_w-T_\infty)}{u_0^{\,3}}, \\ M=\dfrac{\sigma B_0^2\upsilon}{\rho u_0^2}, G_m=\dfrac{g\beta^*\upsilon(C_w-C_\infty)}{u_0^{\,3}}, \overline{C}=\dfrac{(C-C_\infty)}{(C_w-C_\infty)}, \bar{t}=\dfrac{tu_0^2}{\upsilon}, \overline{K}=\dfrac{u_0}{\upsilon^2}K, \bar{b}=\dfrac{b\upsilon}{u_0^2}, \end{array}\right\} \tag{6}$$

where $\bar{u}$ is the dimensionless primary velocity, $\bar{v}$ -the secondary velocity, $\bar{b}$ -dimensionless acceleration parameter, $\bar{t}$ -dimensionless time, $\theta$ -the dimensionless temperature, $\overline{C}$ - the dimensionless concentration, $\overline{K}$ - the dimensionless permeability parameter, $G_r$ -thermal Grashof number, $G_m$ -mass Grashof number, $K_0$ -chemical reaction parameter, $\mu$ -the coefficient of viscosity, $P_r$ -the Prandtl number, $S_c$ -the Schmidt number, *M*-the magnetic parameter.

Thus the model becomes

$$\frac{\partial\bar{u}}{\partial\bar{t}} = \frac{\partial^2\bar{u}}{\partial\bar{z}^2} + G_r Cos\alpha\theta + G_m Cos\alpha\overline{C} - \frac{M(\bar{u}+m\bar{v})}{(1+m^2)} - \frac{1}{\overline{K}}\bar{u}, \tag{7}$$

$$\frac{\partial\bar{v}}{\partial\bar{t}} = \frac{\partial^2\bar{u}}{\partial\bar{z}^2} + \frac{M(m\bar{u}-\bar{v})}{(1+m^2)} - \frac{1}{\overline{K}}\bar{v}, \tag{8}$$

$$\frac{\partial \overline{C}}{\partial \bar{t}} = \frac{1}{S_c}\frac{\partial^2 \overline{C}}{\partial \bar{z}^2} - K_0\overline{C}, \tag{9}$$

$$\frac{\partial \theta}{\partial \bar{t}} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial \bar{z}^2}. \tag{10}$$

The boundary conditions become

$$\left.\begin{array}{ll} \bar{t} \le 0 : \bar{u} = 0, \bar{v} = 0, \theta = 0, \overline{C} = 0, & \text{for all } \bar{z}, \\ \bar{t} > 0 : \bar{u} = e^{\bar{b}\bar{t}}, \bar{v} = 0, \theta = \bar{t}, \overline{C} = \bar{t}, & \text{at } \bar{z} = 0, \\ \bar{u} \to 0, \bar{v} \to 0, \theta \to 0, \overline{C} \to 0 & \text{as } \bar{z} \to \infty \end{array}\right\}. \tag{11}$$

Dropping bars in the above equations, we get

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial z^2} + G_r Cos\alpha\theta + G_m Cos\alpha C - \frac{M(u+mv)}{(1+m^2)} - \frac{1}{K}u, \tag{12}$$

$$\frac{\partial v}{\partial t} = \frac{\partial^2 v}{\partial z^2} + \frac{M(mu-v)}{(1+m^2)} - \frac{1}{K}v, \tag{13}$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial z^2} - K_0 C, \tag{14}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2}. \tag{15}$$

The boundary conditions will become

$$\left.\begin{array}{ll} t \le 0 : u = 0, v = 0, \theta = 0, C = 0, & \text{for all z}, \\ t > 0 : u = e^{bt}, v = 0, \theta = t, C = t, & \text{at z=0}, \\ u \to 0, v \to 0, \theta \to 0, C \to 0, & \text{as } z \to \infty. \end{array}\right\} \tag{16}$$

Combining equations (15) and (16), the model becomes

$$\frac{\partial q}{\partial t} = \frac{\partial^2 q}{\partial z^2} + G_r Cos\alpha\theta + G_m Cos\alpha C - qa, \tag{17}$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial z^2} - K_0 C, \tag{18}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2}. \tag{19}$$

The boundary conditions are transformed as

$$\left.\begin{array}{ll} t \le 0 : q = 0, \theta = 0, C = 0, & \text{for all z}, \\ t > 0 : q = e^{bt}, \theta = t, C = t, & \text{at z=0}, \\ q \to 0, \theta \to 0, C \to 0, & \text{as } z \to \infty \end{array}\right\}. \tag{20}$$

Here q= u + i v, $a = \dfrac{M(1-im)}{1+m^2} + \dfrac{1}{K}.$

The dimensionless governing equations (17) to (19), subject to the boundary conditions (20), are solved by the usual Laplace - transform technique.

The solution obtained is as under:

$$\theta = t\left\{(1+\frac{z^2P_r}{2t})erfc[\frac{\sqrt{P_r}}{2\sqrt{t}}] - \frac{z\sqrt{P_r}}{\sqrt{\pi\sqrt{t}}}e^{-\frac{z^2}{4t}}P_r\right\},$$

$$C = \frac{e^{-z\sqrt{S_cK_0}}}{4\sqrt{K_0}}\left\{erfc[\frac{z\sqrt{S_c}-2t\sqrt{K_0}}{2\sqrt{t}}](-z\sqrt{S_c}+2t\sqrt{K_0}) + e^{2z\sqrt{S_cK_0}}erfc[\frac{z\sqrt{S_c}+2t\sqrt{K_0}}{2\sqrt{t}}](z\sqrt{S_c}+2t\sqrt{K_0})\right\}$$

$$q = \frac{1}{2}e^{bt-\sqrt{a+bz}}A_{15} + \frac{G_rCos\alpha}{4a^2}\left[zA_{11} + 2e^{-\sqrt{a}z}A_2P_r + 2A_{14}A_4(1-P_r)\right] + \frac{G_mCos\alpha}{4(a-K_0S_c)^2}[zA_{11}$$

$$+ 2A_{13}A_5(1-S_c) + 2e^{-\sqrt{a}z}A_2S_c(1-tK_0) - \frac{ze^{-\sqrt{a}z}A_3K_0S_c}{\sqrt{a}}] + \frac{G_rCos\alpha}{2a^2\sqrt{\pi}}[2zae^{\frac{-z^2P_r}{4t}}\sqrt{tP_r}$$

$$+ \sqrt{\pi}A_{14}(A_6 + A_7P_r) + \sqrt{\pi}A_{12}(az^2P_r - 2 + 2at + 2P_r)] + \frac{G_mCos\alpha}{4\sqrt{\pi}(a-K_0S_c)^2}[\frac{e^{-\sqrt{K_0S_c}}\sqrt{\pi}A_9\sqrt{S_c}}{2\sqrt{K_0}}$$

$$(S_cK_0 - az) + A_{13}\sqrt{\pi}A_{10}(S_c - 1) + e^{-\sqrt{K_0S_c}}\sqrt{\pi}A_8(1 - at - S_c + tK_0S_c)]$$

The expressions for the constants involved in the above equations are given in the appendix.

## SKIN FRICTION

The dimensionless skin friction at the plate z=0:

$$\left(\frac{dq}{dz}\right)_{z=0} = \tau_x + i\tau_y,$$

Separating real and imaginary part in $\left(\frac{dq}{dz}\right)_{z=0}$, the dimensionless skin – friction components $\tau_x = \left(\frac{du}{dz}\right)_{z=0}$ and $\tau_y = \left(\frac{dv}{dz}\right)_{z=0}$ can be computed.

## SHERWOOD NUMBER

The dimensionless Sherwood number at the plate z=0 is given by

$$S_h = \left(\frac{\partial C}{\partial z}\right)_{z=0} = erfc[-\sqrt{tK_0}](-\frac{1}{4\sqrt{K_0}}\sqrt{S_c} - \frac{t\sqrt{S_cK_0}}{2}) + \sqrt{S_c}erfc[\sqrt{tK_0}](\frac{1}{4\sqrt{K_0}} + t\sqrt{K_0}) - \frac{e^{-tK_0}\sqrt{tS_cK_0}}{\sqrt{\pi K_0}},$$

## RESULT AND DISCUSSIONS

The velocity profile for different parameters like, thermal Grashof number (*Gr*), magnetic field parameter (*M*), Hall parameter (*m*), Prandtl number (*Pr*), chemical reaction parameter($K_0$), acceleration parameter (*b*) and time (t) is shown in figures 1.1 to 2.10. The concentration profile for different parameters like, chemical reaction parameter, Schmidt number and time are shown in figure 3.1 to 3.3. It is observed from figures 1.1 and 2.1 that the primary and secondary velocities of fluid decrease when the angle of inclination ($\alpha$) is increased. It is observed from figure 1.2 and 2.2, when the mass Grashof number *Gr* is increased then the velocities are increased. From figures 1.3 and 2.3 it is deduced that velocities increases with thermal Grashof number *Gr*. If Hall current parameter *m* is increased then u increases, while *v* gets decreased (figures 1.4 and 2.4). Also, it is observed from figures 1.5 and 2.5 that the effect of increasing values of the parameter *M* results in decreasing u and increasing v. It is deduced that when chemical reaction parameter $K_0$ is increased then the velocities are decreased (figures 1.6 and 2.6). It is observed from figures 1.7 and 2.7 that acceleration parameter *b* is increased then the velocities are increased. It is deduced that when permeability parameter *K* is increased then the velocities are increased (figures 1.8 and 2.8). Further, it is observed that velocities decrease when Prandtl number and Schmidt number are increased (figures 1.9, 2.9, 1.10 and 2.10). Further, from figures 1.11 and 2.11, it is observed that velocities increase with time.

 

Skin friction is given in table1. The value of $\tau_x$ increases with, thermal Grashof Number, the mass Grashof number, Hall current parameter, Schmidt number and time, and it decreases with the increase in the angle of inclination of plate, chemical reaction parameter, acceleration parameter, the magnetic field parameter, permeability parameter and Prandtl number. However, similar effect is observed with $\tau_y$, except in the case of chemical reaction parameter, Hall parameter, the magnetic field parameter and acceleration parameter, in which case effect is reversed.

Sherwood number is given in table 2. The value of $S_h$ decreases with chemical reaction parameter, Schmidt number and time

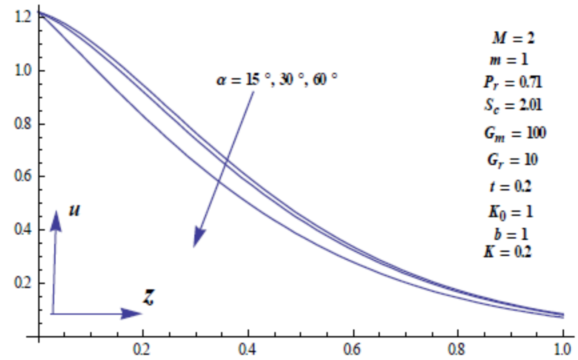


**Figure-1.1:** Velocity u for different values of $\alpha$

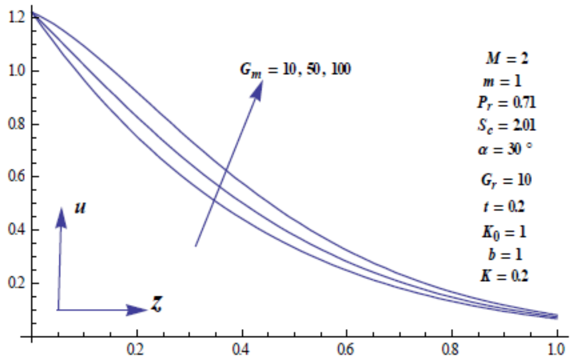


**Figure-1.2:** Velocity u for different values of *Gm*

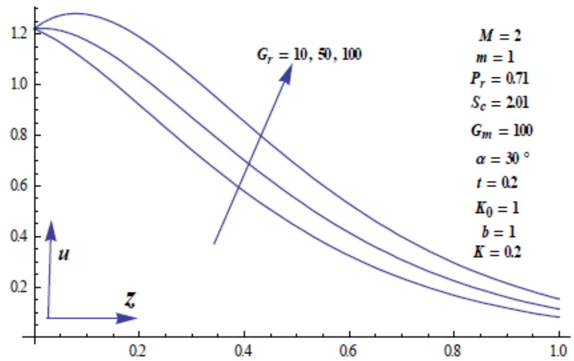


**Figure-1.3:** Velocity u for different values of *Gr*

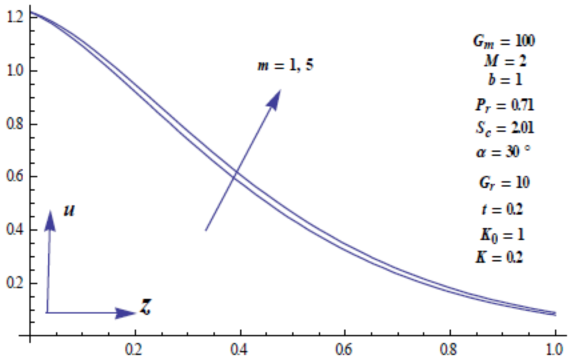


**Figure-1.4:** Velocity u for different values of *m*

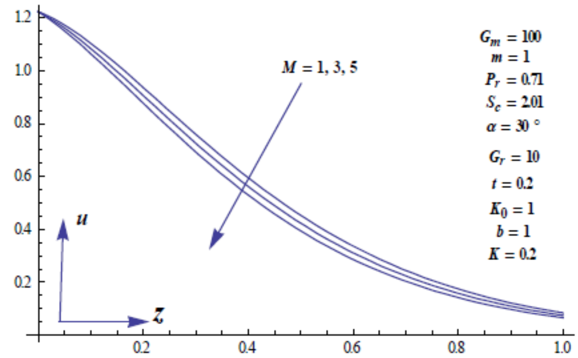


**Figure-1.5:** Velocity u for different values of *M*

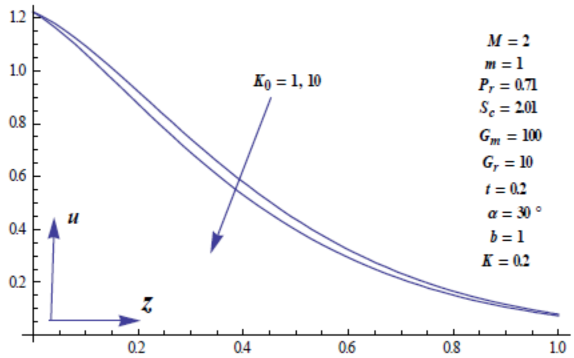


**Figure-1.6:** Velocity u for different values of $K_0$

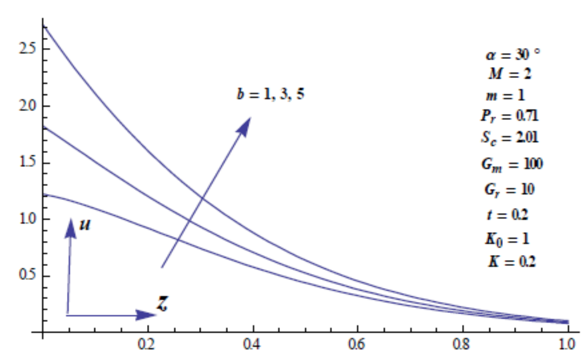


**Figure-1.7:** Velocity u for different values of *b*

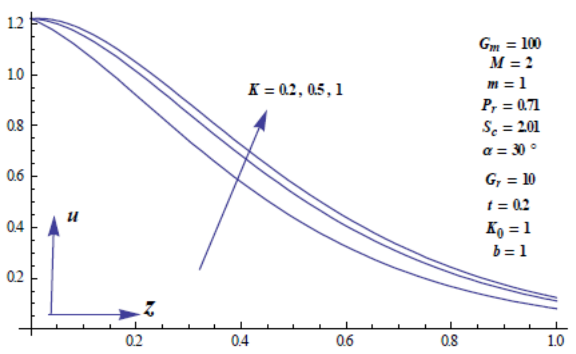


**Figure-1.8:** Velocity u for different values of *K*

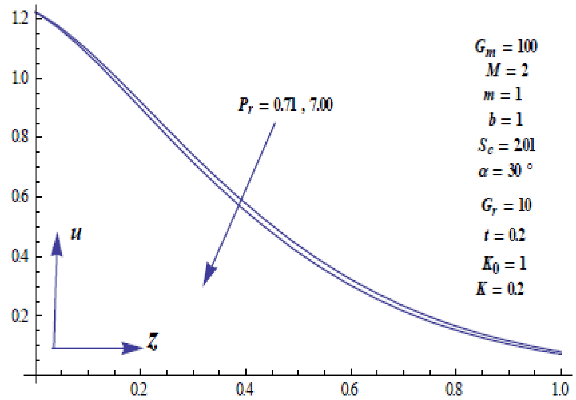


**Figure-1.9:** Velocity u for different values of *Pr*

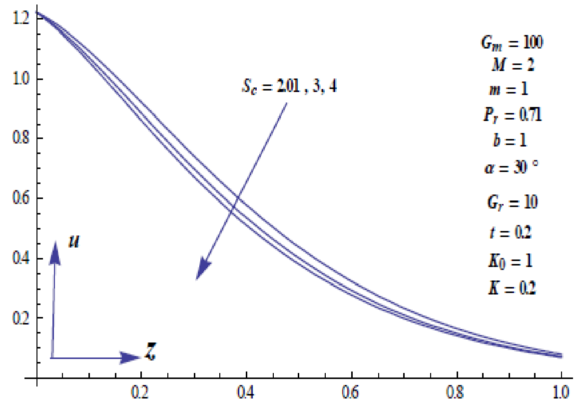


**Figure-1.10:** Velocity u for different values of *Sc*

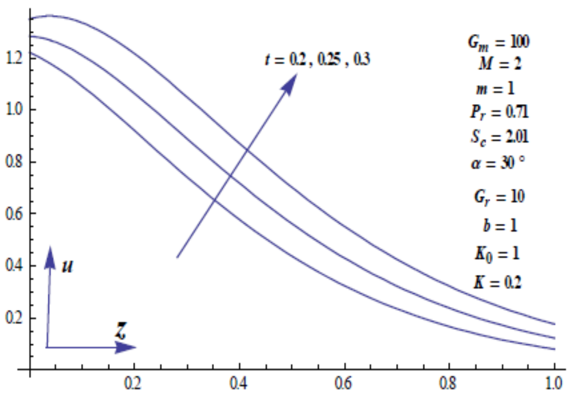


**Figure-1.11:** Velocity u for different values of *t*

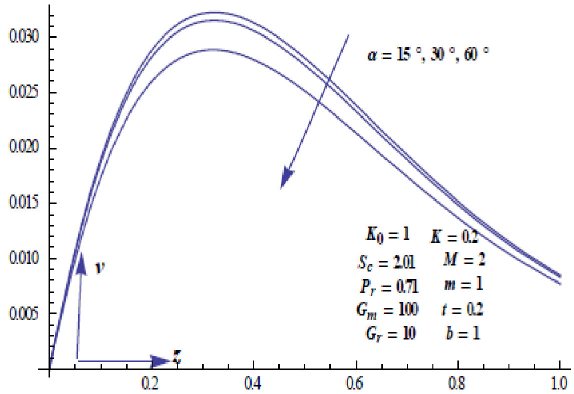


**Figure-2.1:** Velocity v for different values of $\alpha$

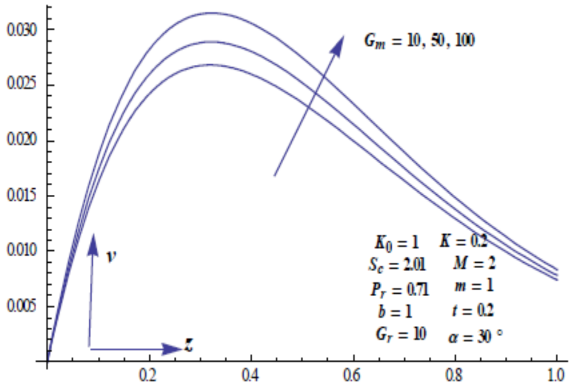


**Figure-2.2:** Velocity v for different values of *Gm*

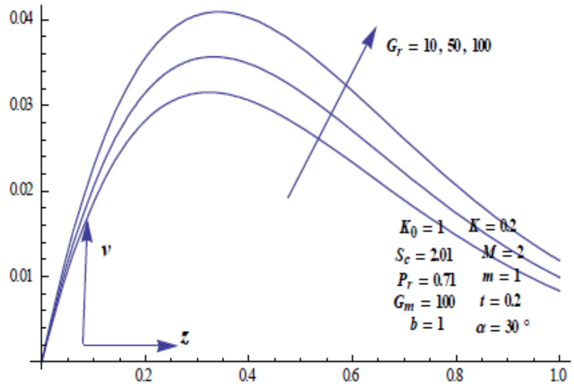


**Figure-2.3:** Velocity v for different values of *Gr*

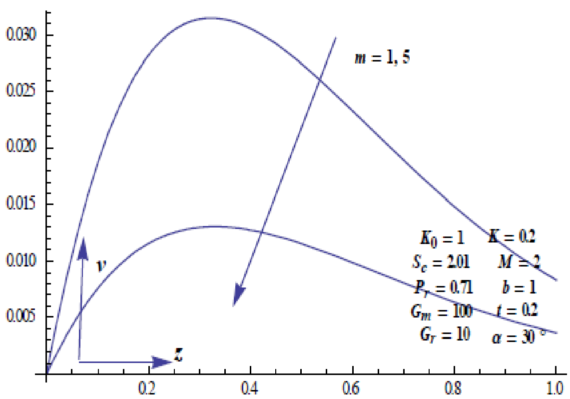


**Figure-2.4:** Velocity v for different values of *m*

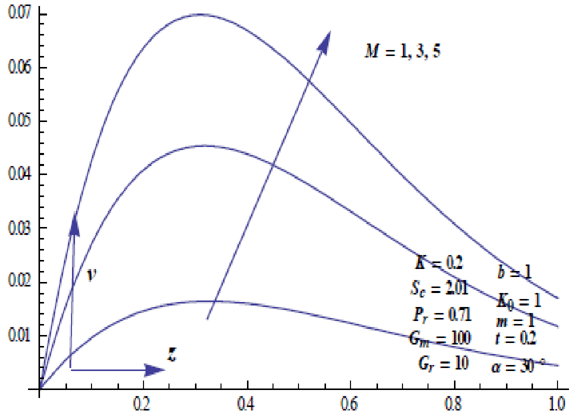


**Figure-2.5:** Velocity v for different values of *M*

 

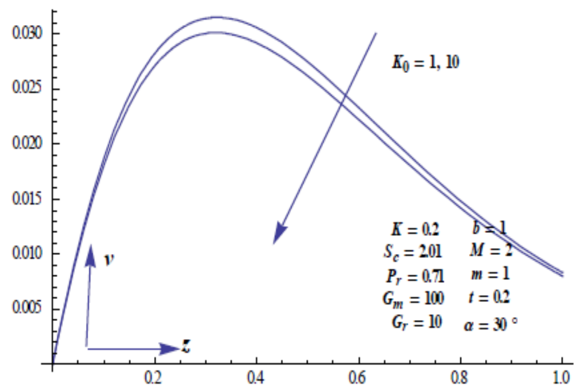


**Figure-2.6:** Velocity v for different values of $K_0$

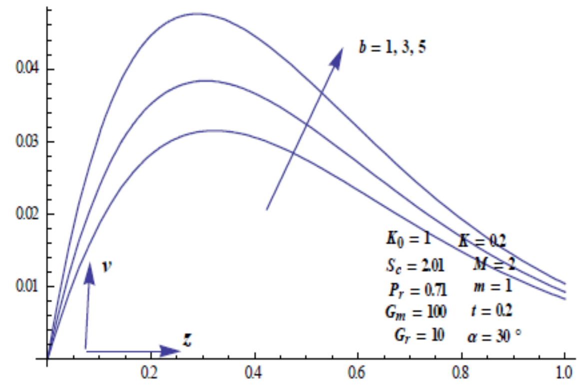


**Figure-2.7:** Velocity v different values of *b*

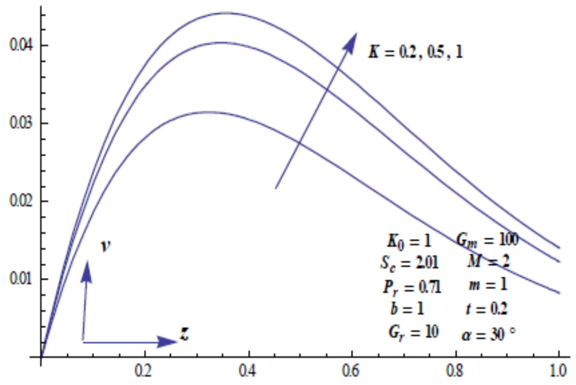


**Figure-2.8:** Velocity v different values of *K*

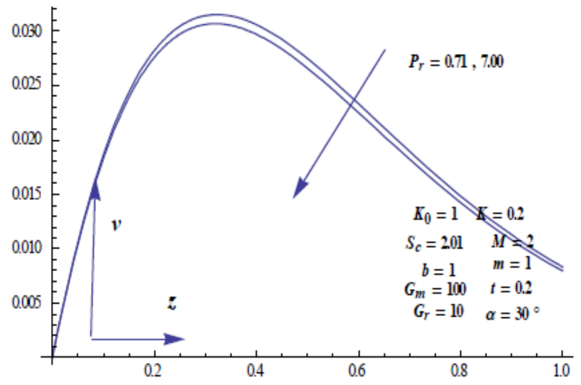


**Figure-2.9:** Velocity v different values of *Pr*

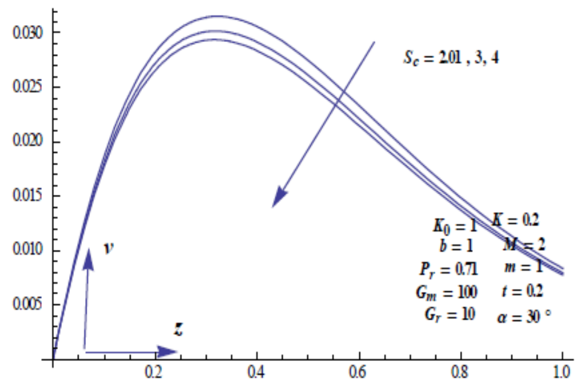


**Figure-2.10:** Velocity v for different values of *Sc*

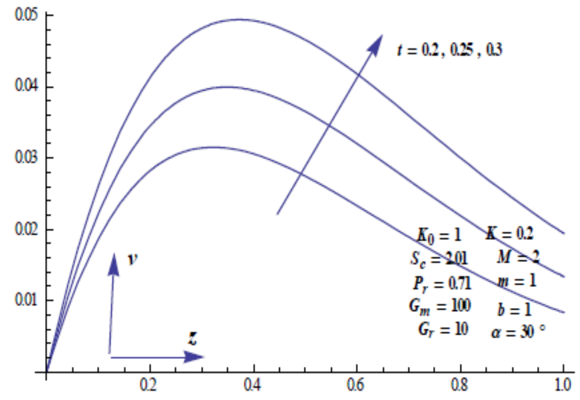


**Figure-2.11:** Velocity v for different values of *t*

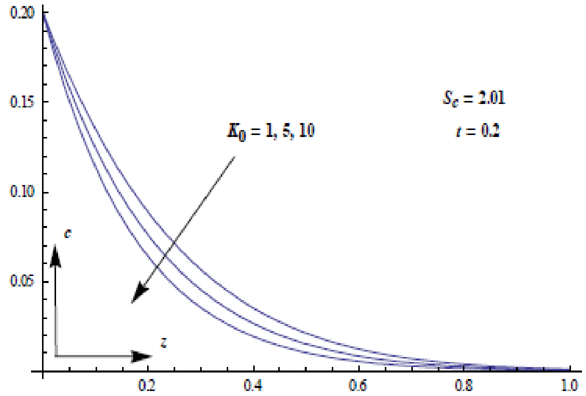


**Figure-3.1:** Concentration c for different values of *Ko*

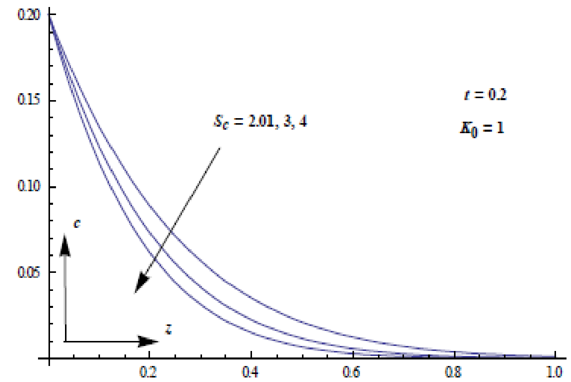


**Figure-3.2:** Concentration c for different values of *Sc*

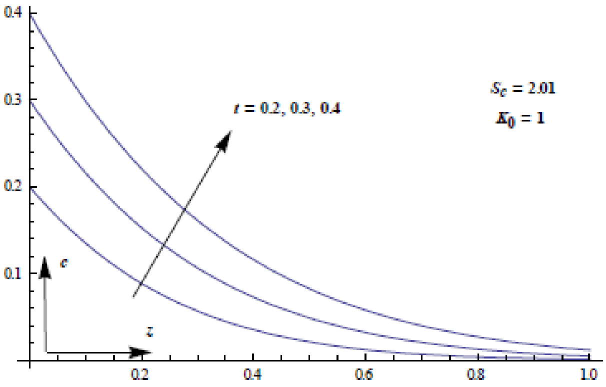


**Figure-3.3:** Concentration c for different values of *t*

**Table-1:** Skin friction for different Parameters.

| α (in degree) | $M$ | $m$ | $Pr$ | $Sc$ | $Gm$ | $Gr$ | $K_0$ | $K$ | $t$ | $b$ | $\tau_x$ | $\tau_y$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 2 | 1 | 0.71 | 2.01 | 100 | 10 | 1 | 0.2 | 0.2 | 1 | 8.52178 | 3.23741 |
| 30 | 2 | 1 | 0.71 | 2.01 | 100 | 10 | 1 | 0.2 | 0.2 | 1 | 7.29792 | 2.92419 |
| 60 | 2 | 1 | 0.71 | 2.01 | 100 | 10 | 1 | 0.2 | 0.2 | 1 | 2.81379 | 1.77658 |
| 30 | 3 | 1 | 0.71 | 2.01 | 100 | 10 | 1 | 0.2 | 0.2 | 1 | 5.57206 | 3.19740 |
| 30 | 5 | 1 | 0.71 | 2.01 | 100 | 10 | 1 | 0.2 | 0.2 | 1 | 3.30955 | 3.19760 |
| 30 | 2 | 3 | 0.71 | 2.01 | 100 | 10 | 1 | 0.2 | 0.2 | 1 | 10.7310 | 3.04336 |
| 30 | 2 | 5 | 0.71 | 2.01 | 100 | 10 | 1 | 0.2 | 0.2 | 1 | 11.7683 | 2.20051 |
| 30 | 2 | 1 | 7.00 | 2.01 | 100 | 10 | 1 | 0.2 | 0.2 | 1 | 7.16722 | 2.92064 |
| 30 | 2 | 1 | 0.71 | 3.00 | 100 | 10 | 1 | 0.2 | 0.2 | 1 | 14.7514 | 8.27996 |
| 30 | 2 | 1 | 0.71 | 4.00 | 100 | 10 | 1 | 0.2 | 0.2 | 1 | 28.6901 | 28.3203 |
| 30 | 2 | 1 | 0.71 | 2.01 | 10 | 10 | 1 | 0.2 | 0.2 | 1 | -1.99761 | 0.48486 |
| 30 | 2 | 1 | 0.71 | 2.01 | 50 | 10 | 1 | 0.2 | 0.2 | 1 | 2.03374 | 1.56901 |
| 30 | 2 | 1 | 0.71 | 2.01 | 100 | 50 | 1 | 0.2 | 0.2 | 1 | 8.42268 | 2.94390 |
| 30 | 2 | 1 | 0.71 | 2.01 | 100 | 100 | 1 | 0.2 | 0.2 | 1 | 9.82864 | 2.96853 |
| 30 | 2 | 1 | 0.71 | 2.01 | 100 | 10 | 5 | 0.2 | 0.2 | 1 | 13.7523 | -11.2023 |
| 30 | 2 | 1 | 0.71 | 2.01 | 100 | 10 | 10 | 0.2 | 0.2 | 1 | 0.98453 | -0.47930 |
| 30 | 2 | 1 | 0.71 | 2.01 | 100 | 10 | 10 | 0.5 | 0.2 | 1 | 13.2100 | 33.9004 |
| 30 | 2 | 1 | 0.71 | 2.01 | 100 | 10 | 10 | 1.0 | 0.2 | 1 | -39.6732 | 28.9697 |
| 30 | 2 | 1 | 0.71 | 2.01 | 100 | 10 | 1 | 0.2 | 0.3 | 1 | 12.9159 | 4.34719 |
| 30 | 2 | 1 | 0.71 | 2.01 | 100 | 10 | 1 | 0.2 | 0.4 | 1 | 18.6483 | 5.78354 |
| 30 | 2 | 1 | 0.71 | 2.01 | 100 | 10 | 1 | 0.2 | 0.2 | 3 | 5.07323 | 3.00124 |
| 30 | 2 | 1 | 0.71 | 2.01 | 100 | 10 | 1 | 0.2 | 0.2 | 5 | 1.53083 | 3.11014 |

**Table-2:** Sherwood number for different Parameters.

| $K_0$ | Sc | t | $S_h$ |
|---|---|---|---|
| 1 | 2.01 | 0.2 | -0.762200 |
| 5 | 2.01 | 0.2 | -0.933049 |
| 10 | 2.01 | 0.2 | -1.118240 |
| 1 | 3.00 | 0.2 | -0.931175 |
| 1 | 4.00 | 0.2 | -1.075230 |
| 1 | 2.01 | 0.3 | -0.961323 |
| 1 | 2.01 | 0.4 | -1.141570 |

## CONCLUSION

The conclusions of the study are as follows:

- Primary velocity increases with the increase in thermal Grashof number, mass Grashof number, Hall current parameter, permeability parameter, acceleration parameter and time.
- Primary velocity decreases with angle of inclination of plate, the magnetic field, chemical reaction parameter, Prandtl number and Schmidt number.

 

- Secondary velocity increases with the increase in thermal Grashof number, mass Grashof number, the magnetic field, permeability parameter, acceleration parameter and time.
- Secondary velocity decreases with the angle of inclination of plate, Hall current parameter, chemical reaction parameter, Prandtl number and Schmidt number.
- $\tau_x$ increases with the increase in *Gm, Gr, m, Sc* and *t*, and it decreases with *α, b*, $K_0$, *M, K* and *Pr*.
- $\tau_y$ increases with the increase in *Gm, Gr*, $K_0$, *M, b, Sc* and *t*, and it decreases with *α, K, m* and *Pr*
- $S_h$ decreases with $K_0$, *Sc* and *t*.

## APPENDIX

$$A_1 = 1 + A_{16} + e^{2\sqrt{az}}(1 - A_{17}),\ A_2 = -A_1,\ A_3 = A_{16} - A_1,\ A_4 = -1 + A_{22} + A_{18}(A_{23} - 1),$$

$$A_5 = -1 + A_{24} + A_{19}(A_{25} - 1),\ A_6 = -1 - A_{26} + A_{18}(A_{27} - 1),\ A_7 = -A_6,\ A_8 = -1 - A_{20} + A_{30}(A_{21} - 1),$$

$$A_9 = A_8 + 2(A_{20} + 1),\ A_{10} = -1 - A_{28} + A_{19}(A_{29} - 1),\ A_{11} = \frac{e^{-\sqrt{az}}}{z}(2A_1 + 2atA_2 + \sqrt{a}A_3),$$

$$A_{12} = -1 + erf\left[\frac{z\sqrt{P_r}}{2\sqrt{t}}\right],\ A_{13} = e^{\frac{at}{-1+S_c} - z\sqrt{\frac{(a-K_0)S_c}{-1+S_c}} - \frac{tK_0S_c}{-1+S_c}},\ A_{14} = e^{\frac{at}{-1+P_r} - z\sqrt{\frac{(a)P_r}{-1+P_r}}},\ A_{15} = 1 + A_{31} + e^{2\sqrt{a+bz}}A_{32},$$

$$A_{16} = erf[\frac{2\sqrt{at} - z}{2\sqrt{t}}],\ A_{17} = erf[\frac{2\sqrt{at} + z}{2\sqrt{t}}],\ A_{18} = e^{-2z\sqrt{\frac{aP_r}{-1+P_r}}},\ A_{19} = e^{-2z\sqrt{\frac{(a-K_0)S_c}{-1+S_c}}},\ A_{20} = erf\left[\sqrt{tK_0} - \frac{z\sqrt{S_c}}{2\sqrt{t}}\right],$$

$$A_{21} = erf\left[\sqrt{tK_0} + \frac{z\sqrt{S_c}}{2\sqrt{t}}\right],\ A_{22} = erf[\frac{z - 2t\sqrt{\frac{aP_r}{-1+P_r}}}{2t}],\ A_{23} = erf[\frac{z + 2t\sqrt{\frac{aP_r}{-1+P_r}}}{2t}],$$

$$A_{24} = erf[\frac{z - 2t\sqrt{\frac{(a-K_0)S_c}{-1+S_c}}}{2t}],\ A_{25} = erf[\frac{z + 2t\sqrt{\frac{(a-K_0)S_c}{-1+S_c}}}{2t}],\ A_{26} = erf[\frac{2t\sqrt{\frac{a}{-1+P_r}} - z\sqrt{P_r}}{2\sqrt{t}}],$$

$$A_{27} = erf[\frac{2t\sqrt{\frac{a}{-1+P_r}} + z\sqrt{P_r}}{2\sqrt{t}}],\ A_{28} = erf[\sqrt{t}\sqrt{\frac{(a-K_0)}{-1+S_c}} - \frac{zS_c}{2\sqrt{t}}],\ A_{29} = erf[\sqrt{t}\sqrt{\frac{(a-K_0)}{-1+S_c}} + \frac{zS_c}{2\sqrt{t}}],$$

$$A_{30} = erf[e^{2z\sqrt{K_0\sqrt{S_c}}}],\ A_{31} = erf[\frac{2\sqrt{a+bt} - z}{2\sqrt{t}}],\ A_{32} = erfc[\frac{2\sqrt{a+bt} + z}{2\sqrt{t}}],$$

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