International Journal of Mathematical Archive-9(2), 2018, 152-162
Available online through www.ijma.info ISSN 2229 – 5046

RADIATION AND HALL CURRENT EFFECTS ON MHD FREE CONVECTIVE FLOW PAST AN INCLINED PARABOLIC ACCELERATED PLATE WITH VARIABLE TEMPERATURE IN A POROUS MEDIUM

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(Received On: 04-01-18; Revised & Accepted On: 30-01-18)

ABSTRACT

In this paper, we have consider the radiation and hall current effects on unsteady MHD free convection flow of a viscous incompressible electrically conducting fluid past an inclined parabolic accelerated plate in a porous medium by applying a transverse magnetic field which makes an angle (α) to the inclined plate. The fluid is assumed to be viscous, incompressible and electrically conducting with a strong magnetic field. Using the modified Ohm's law and the Bossinesq approximation the governing equations of the problem are reduced to local non-similarity boundary layer equations using suitable transformation. The dimensionless governing equations of flow field are solved numerically by a closed analytical method for various different parameters of governing flow equations. The velocity, temperature, skin-friction and Nusselt number are shown graphically and discussed qualitatively.

Keywords: *Heat Transfer, Transverse Magnetic Field, MHD Free Convection Flows, Hall Currents, Radiation, Porous Medium, Inclined Parabolic Accelerated Plate.*

1. INTRODUCTION

The MHD flow with heat and mass transfer plays an important role in different areas of science and technology like chemical engineering, mechanical engineering, biological science, petroleum engineering, biomechanics, irrigation engineering and aerospace technology. Study of radiation with heat transfer and mass diffusion is essential in describing several fluid models. A current carrying conductor in a magnetic field experiences a force that tends to move it perpendicularly to the field. In this case of an electrically conducting parabolic accelerated fluid at low pressure, there is an interaction of the magnetic field with the electric field of both the electrons and the ionized atoms of the fluid. If the magnetic field is perpendicular to the electric field a current is induced in the conductive accelerated fluid whose direction is perpendicular to both the electric field and the magnetic field.

Wilhem and Choi [1] have considered magnetohydrodynamic diffusion flow across homogeneous magnetic field. Raptis [2] has considered radiation and free convection flow through a porous medium. The effect of radiation in free convection from a vertical porous plate was studied by Hossain *et.al* [3]. Further, Raptis along with Perdikis [4] have worked on unsteady flow through a highly porous medium in the presence of radiation. The radiation effect on combined convection over a vertical flat plate embedded in a porous medium of variable porosity was presented by Pal and Mondal [5]. Vyas and Srivastava [6] have analysed radiative MHD flow over a non-isothermal stretching sheet in a porous medium. The radiation effect on MHD flow past an infinite vertical plate with variable temperature and uniform mass diffusion was analyzed by Deka and Deka [7]. Rajput and Sahu [8] have investigated the radiation effect on steady hydromagnetic flow of a viscous fluid through a vertical channel in a porous medium with heat generation or absorption. Radiation and mass transfer effects on transient free convection flow of a dissipative fluid past semi-infinite vertical plate with uniform heat and mass flux was investigated by Vasu *et.al* [9]. Influence of thermal radiation on a transient MHD Couette flow through a porous medium was considered by Baoku *et.al* [10]. Armstrong and Muthucumaraswamy [12] have worked on MHD flow past a parabolic started vertical plate with variable temperature and mass diffusion. In MHD flows, if applied magnetic field is of high strength on the flow then Hall current on MHD flow is also significant. Some papers related with combined effects of Hall current and radiation is also mentioned here.

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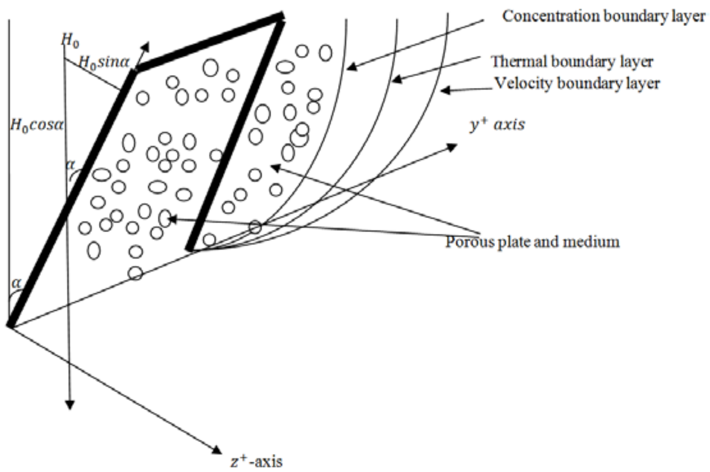
Guchhait *et.al* [11] have investigated combined effects of Hall current and radiation on MHD free convective flow in a vertical channel with an oscillatory wall temperature. Thamizhsudar and Pandurangan [13] have worked on combined effects of radiation and Hall current on MHD flow past an exponentially accelerated vertical plate in the presence of rotation. Combined effects of Hall current and magnetic field on unsteady flow past a semi-infinite vertical plate with thermal radiation and heat source was studied by Srihari [14]. Ramana Reddy *et.al* [15] has studied hall current effect on MHD free convection flow an inclined porous plate with constant heat flux. The chemical reaction effect on unsteady MHD flow past an impulsively started oscillating inclined plate with variable temperature and mass diffusion in the presence of Hall current was analyzed by Rajuput *et.al* [16].Effects of induced magnetic field and homogeneous–heterogeneous reactions on stagnation flow of a Casson fluid was investigated by Raju *et.al* [17]. Magiboi *et.al* [18] have unsteady MHD free convective flow past an inclined parabolic accelerated plate with hall current, radiation effects and variable temperature in a porous medium.

In this paper an analysis of radiation and hall current effects on MHD free convective flow past an inclined parabolic accelerated plate with variable temperature in a porous medium has done. The problem is solved by using a closed analytically method. A selected set of graphical results illustrating the effects of various parameters involved in the problem are presented and discussed effectively.

2. MATHEMATICAL MODEL OF THE PROBLEM

Flow is unsteady and laminar of an electrically non conducting plate inclined at an angle (α) from vertical is considered here. The coordinates system is chosen in such a way that $x^* -$axis is considered along the porous plate, $y^* -$axis is taken along the width of the plate and $z^* -$axis normal to the plane of the plate. The fluid under consideration is Newtonian, viscous, incompressible and electrically conducting with constant physical properties. The magnetic Reynolds number is assumed to be small enough so that the induced magnetic field is negligible. The effect of viscous dissipation is neglected in the energy equation. It is assumed that there is no applied voltage, which implies the absence of an electric field. Soret and Dufour effects are neglected. We employ a Darcian viscous model for porous medium. The velocity vector is of the form $\vec{q} = \left(u^*, v^*, 0\right)$. A strong transverse magnetic field which makes an angle of α with the inclined plate and the vertical. There is no chemical reaction between the diffusing species and the fluid. Liquid metals and ionized gases have permeability μ_e so that we write $B = \mu_e H$ in the frame of references. All the physical properties so of the fluid are considered to be constant .All velocities are small compared with that of light $\frac{q^2}{C^2} << 1$. Thermal conductivity k is assumed to be constant. Under all this assumption the physical configuration and coordinate system of this study is presented in the figure below



Taking into consideration the assumptions made above, the governing equations for natural convection flow with heat transfer of an electrically conducting, viscous, incompressible, optically thin radiating fluid through a porous medium taking Hall current into account, Boussinesq approximations are given by:

Continuity Equation

$$\frac{\partial w^*}{\partial z^*} = 0 \qquad (1)$$

Momentum Equation

$$\left(\frac{\partial u^*}{\partial t^*} - w_0^* \frac{\partial u^*}{\partial z^*}\right) = \nu \frac{\partial^2 u}{\partial z^{*2}} + g\beta_T\left(T^* - T_\alpha^*\right)\cos\alpha + \frac{\sigma\mu_e^2 H_0^2 \sin^2\alpha}{\rho}\frac{\left(mv^*\sin\alpha - u^*\right)}{\left(1+m^2\sin^2\alpha\right)} - u^*\frac{\nu}{k^*} \quad (2)$$

$$\left(\frac{\partial v^*}{\partial t^*} - w_0^* \frac{\partial v^*}{\partial z^*}\right) = \nu \frac{\partial^2 v^*}{\partial z^{*2}} - \frac{\sigma\mu_e^2 H_0^2 \sin^2\alpha}{\rho}\frac{\left(mu^*\sin\alpha + v^*\right)}{\left(1+m^2\sin^2\alpha\right)} - \frac{\nu}{k^*}v^* \quad (3)$$

Energy Equation

$$\frac{\partial T^*}{\partial t^*} - w_0^* \frac{\partial T^*}{\partial z^*} = \frac{k}{\rho c_p}\frac{\partial^2 T^*}{\partial z^{*2}} - \frac{1}{\rho c_p}\frac{\partial q_r^*}{\partial z^*} \quad (4)$$

where $u^*, v^*, \nu, \rho, \sigma, m = \omega_e\tau_e, \omega_e, \tau_e, g, \beta_T T^*, T_\alpha^*, k, C_p\mu_e, e, \eta_e p_e$ fluid velocity in x -direction, fluid velocity in y-direction, kinematic coefficient of viscosity, fluid density, electrical conductivity, Hall current parameter, cyclotron frequency, electron collision time, acceleration due to gravity, volumetric coefficient to thermal expansion, fluid temperature, temperature of the ambient fluid, Thermal conductivity of the fluid, specific heat at constant pressure, the magnetic permeability, the electric charge, the number density of electron, the electron pressure respectively.

Equations (2), (3), and (4) are subject to the following initial and boundary conditions.

$$\begin{aligned} &t^* \le 0 : u^* = 0, v^* = 0, T^* = T_\infty^* && \forall \quad z^* \\ &t^* > 0 : u^* = U_0 t^{*2}, v^* = 0, T_\infty^* + \left(T_W^* + T_\infty^*\right)At^*, && \text{at} \quad z^* = 0 \\ &t^* > 0 : u^* \to 0, v^* \to 0 : T^* \to T_\infty^* && \text{as} \quad z^* \to \infty \end{aligned} \quad (5)$$

We now use Rosseland approximation which leads to the value of radiative heat flux as q_r^*

$$q_r^* = -\frac{4\sigma^*\partial T^{*2}}{3k^*\partial z^*} \quad (6)$$

where k^* is mean absorption coefficient and σ^* is Stefan- Boltzmann constant. It may be noted that by using Rosseland approximation we limit our analysis to optically thick fluids. Assuming small temperature differences between fluid temperature T^* and free stream temperature T_α^* the Eq.(4) is linearized by expanding T^{*4} in Taylors series about free stream temperature T_α^*, after neglecting second and higher order terms in $\left(T^* - T_\alpha^*\right)$ it takes the for

$$T^{*4} \cong 4T_\alpha^{*3}T^* - 3T_\alpha^{*4} \quad (7)$$

By using equations (6)and (7), equation (4) reduces to

$$\frac{\partial T^*}{\partial t^*} - w_0^* \frac{\partial T^*}{\partial z^*} = \frac{k}{\rho c_p}\frac{\partial^2 T^*}{\partial z^{*2}} + \frac{16\sigma^* T_\alpha^{*3}}{\rho c_p 3k^*}\frac{\partial^2 T^*}{\partial z^{*2}} \quad (8)$$

We introduce the following non-dimensional quantities:

$$u = \frac{u^*}{\left(\nu^2 U_0\right)^{\frac{1}{5}}}, v = \frac{v^*}{\left(\nu^2 U_0\right)^{\frac{1}{5}}}, w_0 = \frac{w_0^*}{\left(\nu^2 U_0\right)^{\frac{1}{5}}}, k = k^*\left(\frac{U_0^2}{\nu^6}\right)^{\frac{1}{5}}, z = z^*\left(\frac{U_0}{\nu^3}\right)^{\frac{1}{5}}$$

$$t = t^*\left(\frac{U_0^2}{\upsilon}\right)^{\frac{1}{5}}, \Pr = \frac{\nu\rho c_p}{k}, Gr = \frac{\beta T\rho\left(T_w^* - T_\infty^*\right)}{\left(vU_0^3\right)^{\frac{1}{5}}}, \theta = \frac{T^* - T_\alpha^*}{T_w^* - T_\infty^*},$$

$$M = \frac{\sigma}{\rho}\frac{\mu_e^2 H_0^2 \psi^2}{\left(m_*^2 + 1\right)}\left(\nu^2 U_0\right)^{\frac{1}{5}}, F = \frac{4T_\alpha^{*3}}{kk^*}$$

where Gr, M, Pr, R, and yare thermal Grashof number, the magnetic parameter, Prandtl number, radiation parameter and permeability of porous medium, respectively.

Equations (2), (3), and (8) reduce to the following dimensionless form:

$$\left(\frac{\partial u}{\partial t}-w_0\frac{\partial u}{\partial z}\right)=\frac{\partial^2 u}{\partial z^2}+Gr\theta\cos\alpha-\left(\frac{M^2\sin^2\alpha}{1+m^2\sin^2\alpha}+\frac{1}{k}\right)u+\frac{mM^2}{1+m^2\sin^2\alpha}\upsilon \tag{9}$$

$$\left(\frac{\partial v}{\partial t}-w_0\frac{\partial v}{\partial z}\right)=\frac{\partial^2 v}{\partial z^2}-\left(\frac{M^2\sin^2\alpha}{1+m^2\sin^2\alpha}+\frac{1}{k}\right)v-\frac{mM^2}{1+m^2\sin^2\alpha}u \tag{10}$$

$$\left(\frac{\partial \theta}{\partial t}-w_0\frac{\partial \theta}{\partial z}\right)=\frac{1}{\Pr}\left(1+\frac{4R}{3}\right)\frac{\partial^2\theta}{\partial z^2} \tag{11}$$

Also the boundary conditions become

$$\begin{aligned}&t\le 0: u=0v=0,\theta=0,\forall z\\&t>0: u=t^2, v=0,\theta=t,\quad at\ z=0\\&t>0: u\to 0, v\to 0,\theta\to 0\ as\ z\to\infty\end{aligned} \tag{12}$$

Equations (9)-(10) in non-dimensional form, reduce to

$$\left(\frac{\partial F}{\partial t}-\frac{\partial F}{\partial z}\right)=\frac{\partial^2 F}{\partial z^2}+Gr\theta\cos\alpha-\left(k_1+ik_2\right)F \tag{13}$$

$$\left(\frac{\partial \theta}{\partial t}-\frac{\partial \theta}{\partial z}\right)=\frac{1}{\Pr}\left(1+\frac{4R}{3}\right)\frac{\partial^2\theta}{\partial z^2} \tag{14}$$

The corresponding boundary conditions are

$$\begin{aligned}&t\le 0: F=0,\theta=0,\forall z\\&t>0: F=t^2,\ \theta=t,\quad \text{at}\quad z=0\\&t>0: F\to 0,\theta\to 0\quad \text{as}\quad z\to\infty\end{aligned} \tag{15}$$

where $F=u+iv,\ k_1=\left(\frac{M^2\sin^2\alpha}{1+m^2\sin^2\alpha}+\frac{1}{k}\right), k_2=\frac{mM^2}{1+m^2\sin^2\alpha}$

3. SOLUTION OF THE PROBLEM

Equations (13) and (14) are coupled, non – linear partial differential equations and these cannot be solved in closed form. However, these Equations can be reduced to a set of ordinary differential equations, which can be solved closed analytically. This can be done by representing the velocity, temperature and concentration of the fluid in the neighbourhood of the plate as

$$\begin{aligned}F(z,t)&=F_0(z)e^{i\omega t}\\\theta(z,t)&=\theta_0(y)e^{i\omega t}\end{aligned} \tag{16}$$

Substituting (16) in Equations (13) and (14), we obtain

$$F_0''+F_0'-A_2F_0=-Gr\cos\alpha\theta_0 \tag{17}$$

$$A_3\theta_0''+\theta_0'-i\omega\theta_0=0 \tag{18}$$

The corresponding boundary conditions can be written as

$$\begin{aligned}&F_0=t^2e^{-i\omega t},\ \theta_0=te^{-i\omega t}\ \text{at}\ z=0\\&F_0\to 0,\ \theta_0\to 0\qquad \text{as}\ z\to\infty\end{aligned} \tag{19}$$

Solving Equations (17) and (18) under the boundary conditions (19), we obtain the velocity and temperature distribution in the boundary layer as

$$F\left(z,t\right)=e^{-B_1z}B_4+B_3e^{-B_2z} \tag{20}$$

$$\theta(z,t)=t\ e^{-B_2z} \tag{21}$$

It is now important to calculate the physical quantities of primary interest, which are the local wall shear stress and the local surface heat. Given the velocity field in the boundary layer, we can now calculate the local wall shear stress (i.e., skin- friction) is given by

$$\tau_f = -\left(\frac{\partial F}{\partial z}\right)_{z=0} = B_1 B_4 + B_2 B_3$$

Knowing the temperature field, it is interesting to study the effect of the free convection and radiation on the rate of heat transfer q_w^*. This is given by

$$q_w^* = -k\left(\frac{\partial T'}{\partial y'}\right)_{y'=0} - \frac{4\sigma^*}{3k_1^*}\left(\frac{\partial T'^4}{\partial y'}\right)_{y'=0}$$

The dimensionless local surface heat flux (i.e., Nusselt number) is obtained as

$$Nu = -\left(\frac{\partial \theta}{\partial z}\right)_{z=0} = tB_2$$

RESULTS AND DISCUSSION

In order to bring out the salient features of the flow of velocity and temperature profiles have been computed by using a closed analytical method. We have presented the non-dimensional velocity components and temperature distribution for different values of angle of inclination (α), magnetic parameter (M), radiation parameter (R), Hall parameter (m), Prandtl number (Pr), Grashof number (Gr), permeability parameter (K), time (t) and frequency of excitation (ω) in Figures (2)-(14).

Figure (2) illustrated that the effect of angle of inclination on velocity profiles. It is observed that an angle of inclination parameter increases, the velocity profiles decreases. The effect of magnetic field on velocity profiles in the boundary layer is depicted in Figure (3). From this figure it is seen that the velocity starts from minimum value at the surface and increase till it attains the peak value and then starts decreasing until it reaches to the minimum value at the end of the boundary layer for all the values of magnetic field parameter. It is interesting to note that the effect of magnetic field is to decrease the value of the velocity profiles throughout the boundary layer. The effect of magnetic field is more prominent at the point of peak value i.e. the peak value drastically decreases with increases in the value of magnetic field, because the presence of magnetic field in an electrically conducting fluid introduce a force called the Lorentz force, which acts against the flow if the magnetic field is applied in the normal direction, as in the present problem. This type of resisting force slows down the fluid velocity as shown in this figure.

Figures (4) and (5) shows the velocity and temperature profiles for different values of the radiation parameter (***R)***. It is noticed that the radiation parameter increases, the velocity and temperature both decreases. From figure (6), it is observed that the Hall current parameter increase the velocity is also increases. Figures (7) and (8) illustrates the effect of velocity and temperature profiles for different values of Prandtl number ***Pr***. The numerical results show that the effect of increasing values of Prandtl number result in an increasing the velocity field and reverse trend is observed in the temperature profiles. This leads to thermal boundary layer thickness.

For the case of different values of thermal Grashof number ***Gr***, the velocity profiles in the boundary layer are shown in Figure (9). As expected, it is observed that an increase in ***Gr*** leads to increase in the values of velocity due to enhancement in buoyancy force. Here the positive values of ***Gr*** correspond to cooling of the surface. Figure (10) shows the velocity profiles for different values of the permeability parameter ***K***, clearly as ***K*** increases the peak values of the velocity tends to increase. Figure (11) presents typical velocity profiles in the boundary layer for various values of the time. It is observed that the velocity increases with an increasing the time. Figures (12) and (13) are display the effects of frequency of frequency of excitation on the velocity and temperature profiles respectively. As the frequency of excitation increases the velocity increase but reverse trend is observed in the temperature profiles.

CONCLUSIONS

The problem of two-dimensional fluid flow in the presence of radiation and Hall current effects under the influence of uniform magnetic field applied normal to the flow is formulated and solved numerically. A closed analytical method with the help of MATLAB program is adopted to solve the equations governing the flow.

- It is observed that decreasing the velocity for increasing the values of inclined angle (α), magnetic parameter (M), radiation parameter (R) and Hall parameter (m) and increasing the Prandtl number (Pr) the velocity increases.
- It is found that increasing the Prandtl number results in a decrease in the temperature profile.
- An increase in Radiation parameter leads to a decrease in the temperature distribution in the thermal boundary layer.

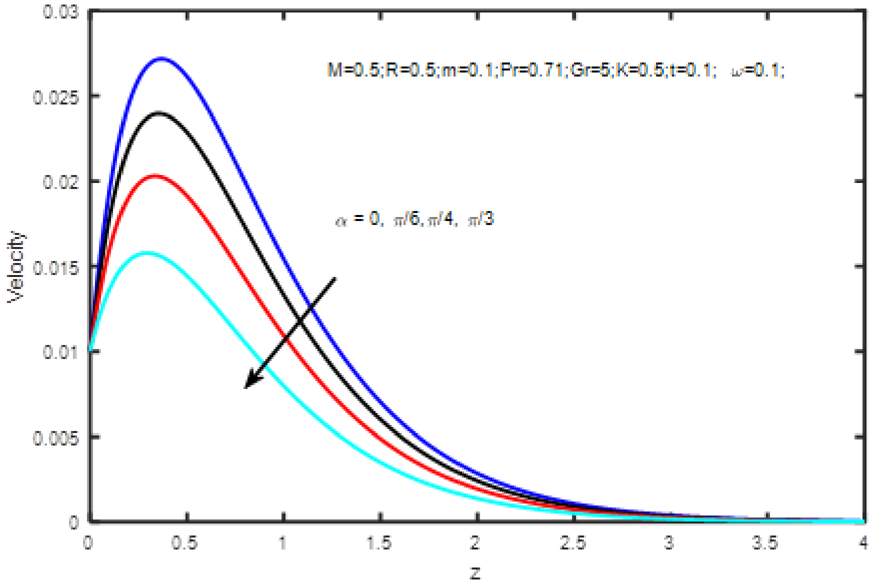


Figure-2: Velocity Profiles for different values of α

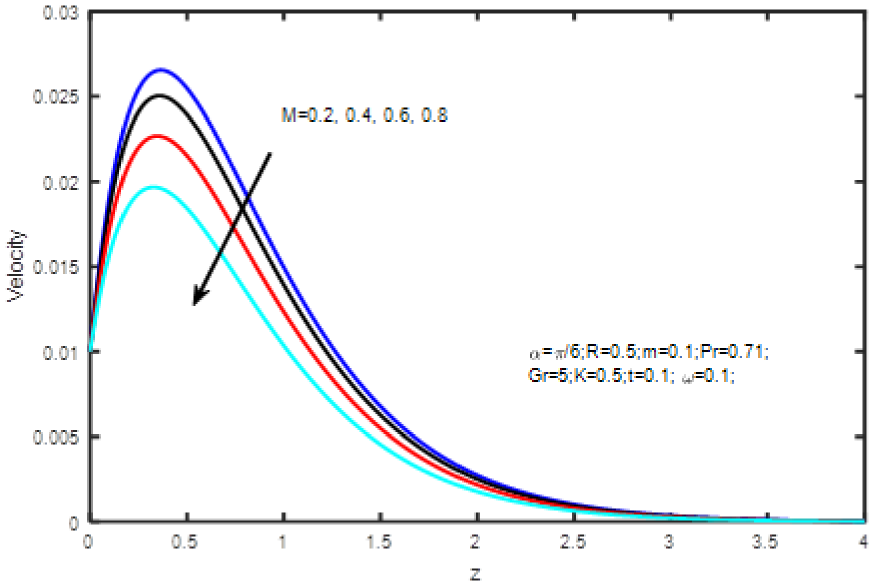


Figure-3: Velocity Profiles for different values of M

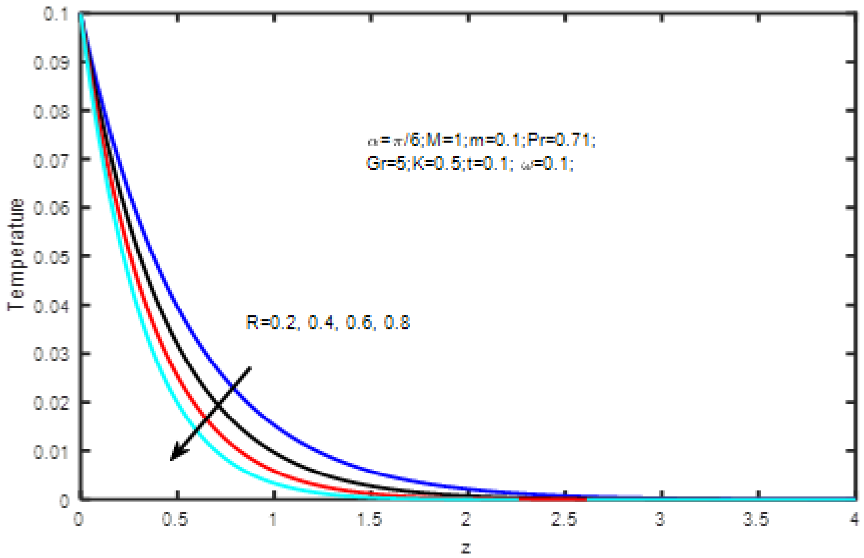


Figure-4: Temperature Profiles for different values of R

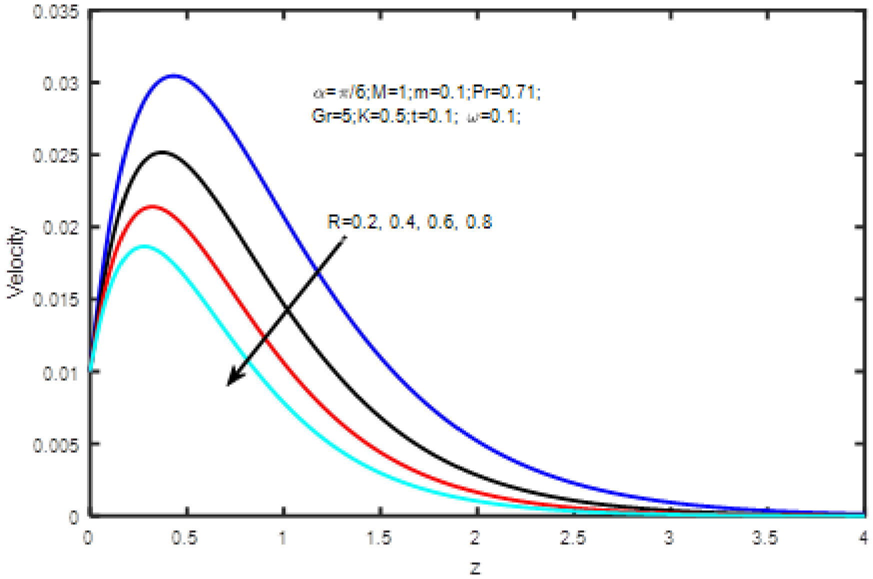


Figure-5: Velocity Profiles for different values of R

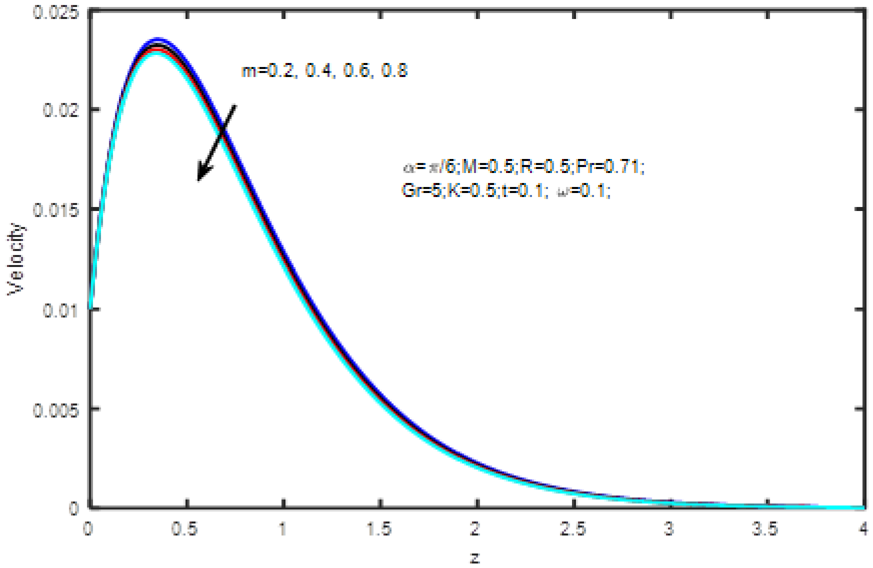


Figure-6: Velocity Profiles for different values of m

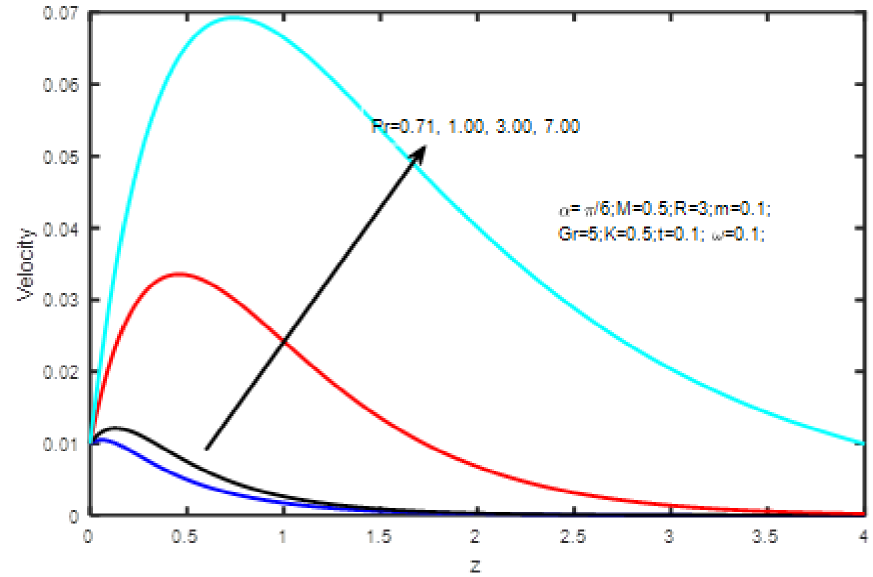


Figure-7: Velocity Profiles for different values of Pr

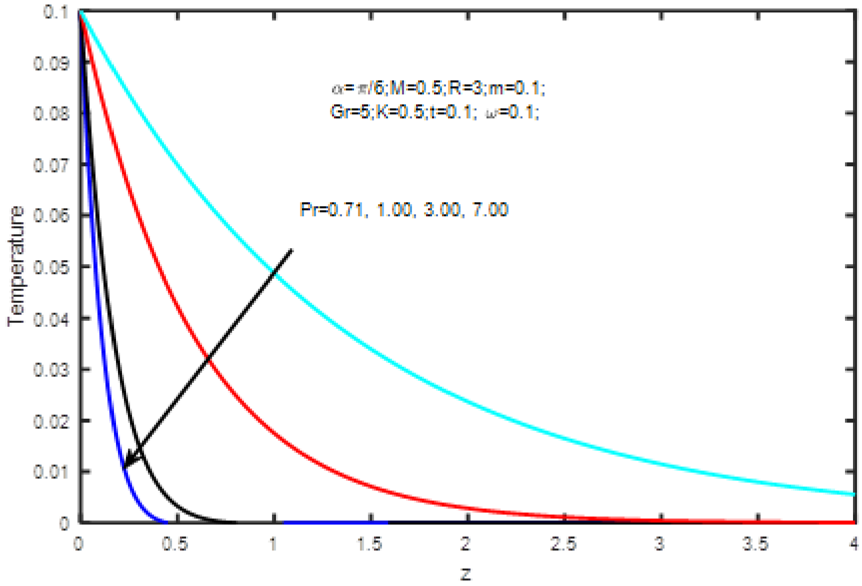


Figure-8: Temperature Profiles for different values of Pr

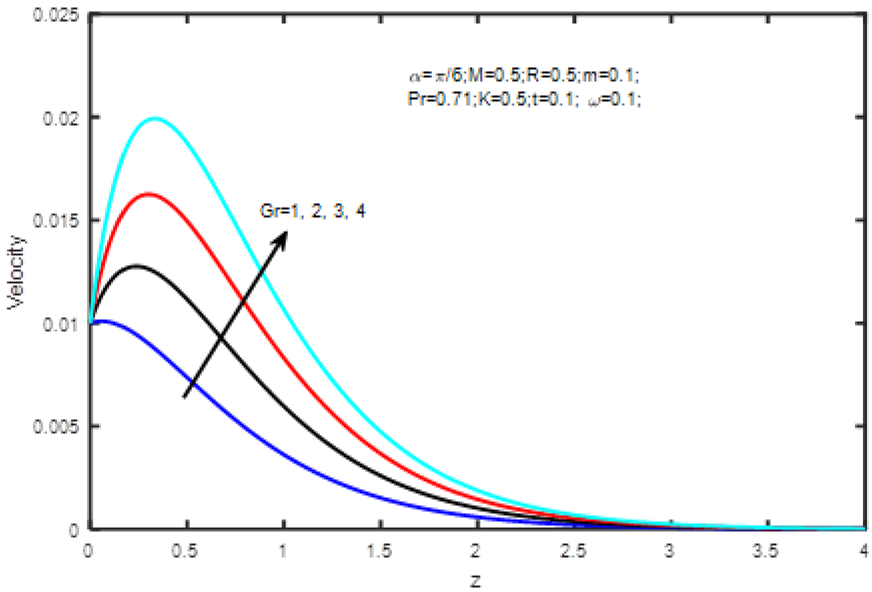


Figure-9: Velocity Profiles for different values of Gr

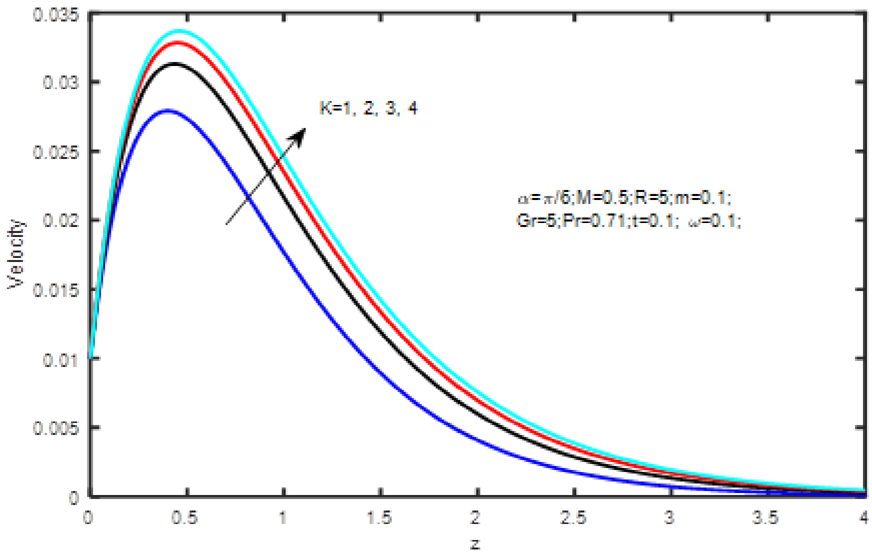


Figure-10: Velocity Profiles for different values of K

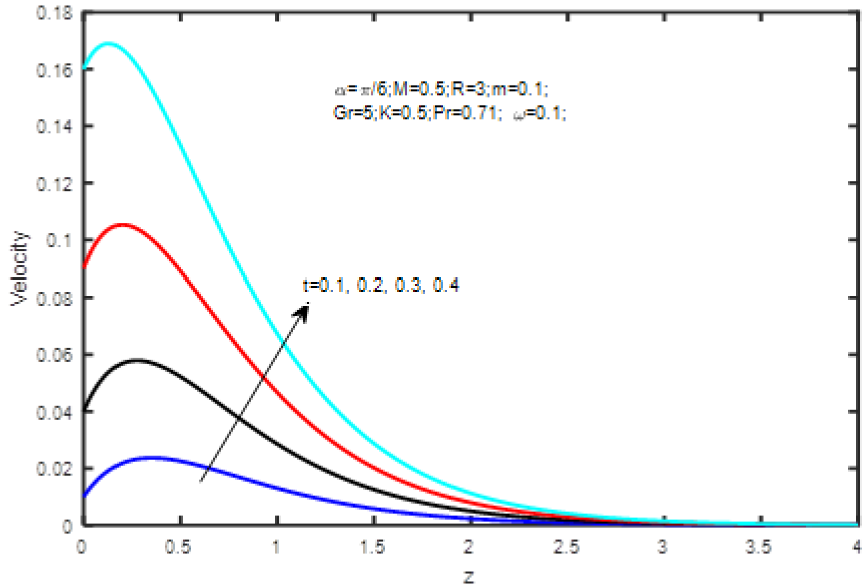


Figure-11: Velocity Profiles for different values of t.

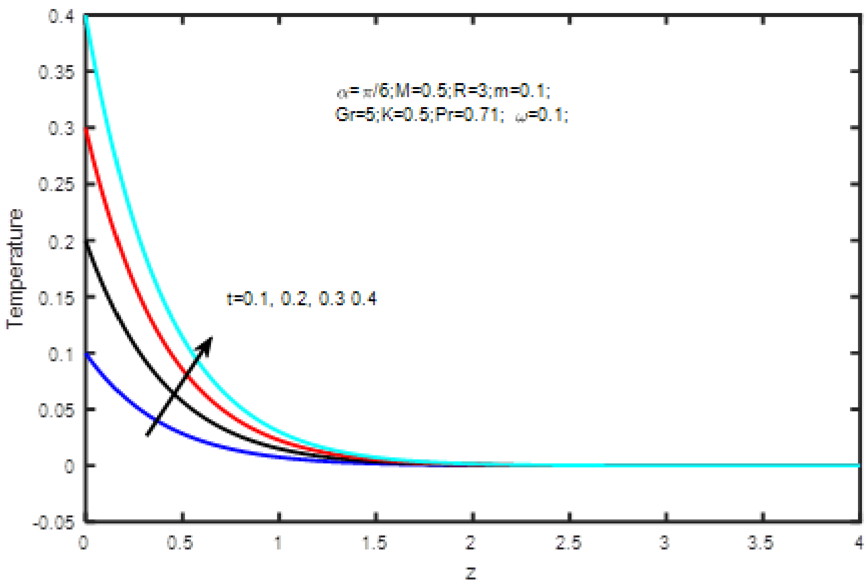


Figure-12: Temperature Profiles for different values of t

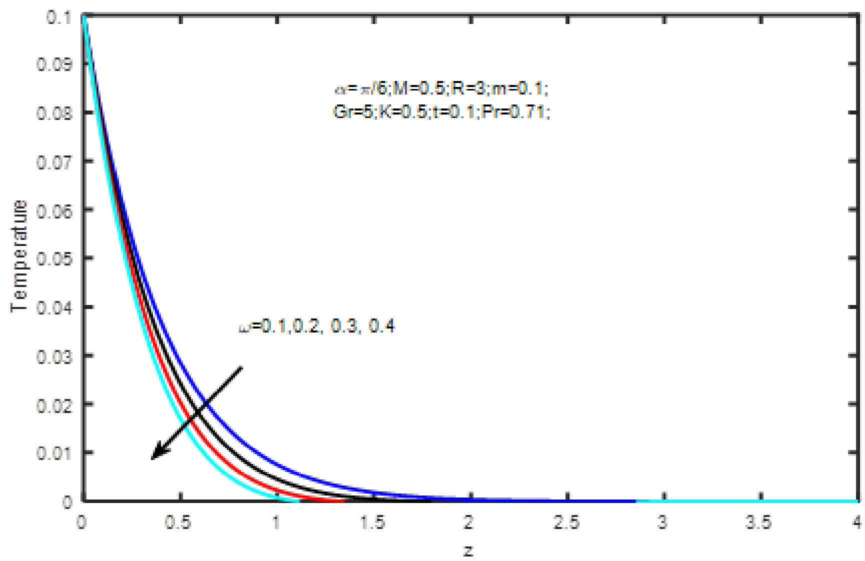


Figure-13: Temperature Profiles for different values of ω

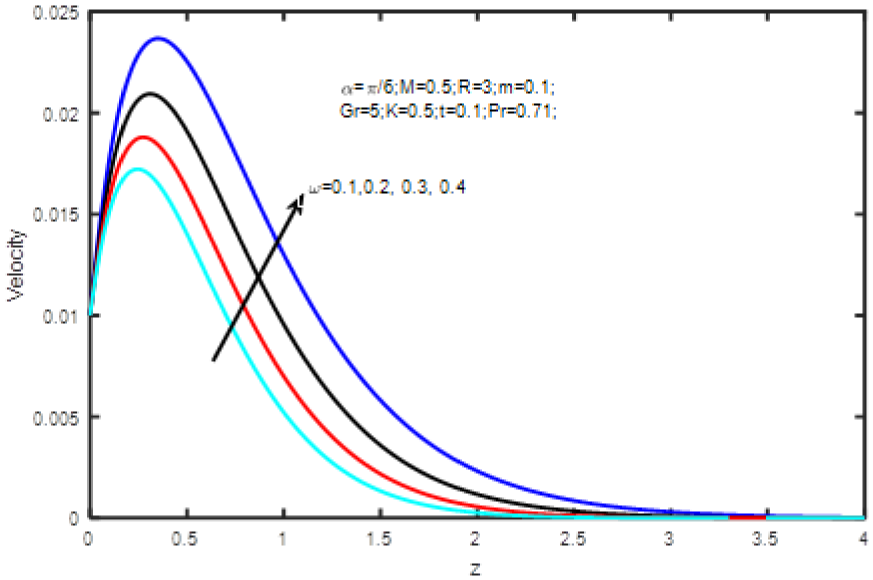


Figure-14: Velocity Profiles for different values of ω

APPENDIX:

$$F = u + i\upsilon,$$

$$A_1 = \frac{M^2 \sin^2 \alpha}{1 + m^2 \sin^2 \alpha} + \frac{1}{k} + \frac{mM^2}{1 + m^2 \sin^2 \alpha}$$

$$A_2 = A_1 + i\omega$$

$$A_3 = \frac{1}{\Pr}\left(1 + \frac{4R}{3}\right)$$

$$B_1 = \frac{1 + \sqrt{1 + 4A_2}}{2}$$

$$B_2 = \frac{1 + \sqrt{1 + 4A_3 i\omega}}{2A_3}$$

$$B_3 = -\frac{Gr \cos\alpha \, t}{B_2^2 - B_2 - A_2}$$

$$B_4 = t^2 - B_3$$

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Source of support: Nil, Conflict of interest: None Declared.