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JOULE HEATING EFFECT ON MHD FREE CONVECTIVE HEAT ABSORBING/GENERATING VISCOUS DISSIPATIVE NEWTONIAN FLUID WITH VARIABLE TEMPERATURE

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Abstract

In the present theoretical study we have examined Joule heating effect of MHD free convective heat absorbing/generating viscous dissipative Newtonian fluid with the consideration of variable temperature. The governing equations related to the problem are solved for velocity, temperature and concentration by using numerical finite difference scheme. The variations in velocity, temperature and concentration under the effects of several physical parameters are studied and represented with the use of graphs. Also we have recorded the numerical values for local skin friction, rate of heat transfer and rate of mass transfer and discussed their characteristics.

Keywords: MHD; Heat Source/Sink; Radiation; Porous Medium; Joule Heating; Viscous Dissipation.

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1. Introduction

Many technological problems as well as natural phenomena are susceptible to MHD heat and mass transfer analysis. Geophysics concepts encounter MHD heat and mass transfer characteristics in the exchanges of conducting fluids and magnetic fields. Engineers and scientists employ many principles of MHD in the drawing of heat exchangers pumps and flow meters, in space vehicle impulsion, thermal guard, braking, power and re-entry, in creating new type of power generating systems etc. In view of technical point, MHD convection and radiation flow problems are very much considerable in the areas of planetary magnetospheres, aeronautics, chemical engineering and electronics. Several studies of the above phenomena of MHD convection have been covered by many researchers. Ashraf et al. [1] presented MHD non – Newtonian micro polar fluid flow and heat transfer in channel with stretching walls. Singh [2] obtained viscoelastic mixed convection MHD oscillatory flow through a porous medium filled in a vertical channel. Ahmed et al. [3] considered analytical model of MHD mixed convective radiating fluid with viscous dissipative heat. Sing et al. [4] studied an exact solution of an oscillatory MHD flow through a porous medium bounded by rotating porous channel in the presence of hall current. Kumar [5] discussed radiative heat transfer with MHD free convection flow over a stretching porous sheet in presence of heat source subjected to power law heat flux. Seth et al. [6] formulated the effect of rotation on unsteady hydro dynamic natural convection flow past an impulsively moving vertical plate with ramped temperature in a porous medium with thermal diffusion and heat absorption. Radiative convective flows are encountered in large number of industrial and environment processes like heating and cooling chambers, fossil fuel combustion, and evaporation from large open water reservoirs, solar power technology, astrophysical flows, and space vehicle re-entry. Radiative heat transfer plays an important role in manufacturing industries for the design of reliable equipment, nuclear power plants, gas turbines, satellite and also space vehicles. Seth et al. [7] studied effects of thermal radiation and rotation on unsteady hydro magnetic free convection flow past an impulsively moving vertical plate with ramped temperature in a porous medium. Seth et al. [8] assumed and studied unsteady hydro magnetic free convection flow past an impulsively moving vertical plate with Newtonian heating. Seth et al. [9] investigated effects of hall current and rotation on hydro magnetic natural convection flow with heat and mass transfer of a heat absorbing fluid past an impulsively moving vertical plate with ramped temperature. Singh et al. [10] employed heat and mass transfer in an unsteady MHD free convective flow through a porous medium bounded by vertical porous channel. Hayat et al. [11] established Newtonian heating and magneto hydrodynamic effects in flow of a jeffery fluid over radially stretching surface. Ali et al. [12] studied influence of thermal radiation on unsteady free convection MHD flow of brinkman type fluid in a porous medium with Newtonian heating. Khanet al. [13] analyzed natural convection flow of a nano fluid over a vertical plate with uniform surface heat flux. Rohini et al [14] examined unsteady mixed convection boundary-layer flow with suction and temperature slip effects near the stagnation point on a vertical permeable surface embedded in a porous medium. In a moving fluid, if heat and mass transfer occur simultaneously, the relations among the dynamic potentials and fluxes are of more considerable. It has been recognized that energy flux will be formed by temperature gradients as well as concentration gradients. The energy flux formed by a concentration gradient is treated as the diffusion- thermo effect. On the other hand, mass flux caused by temperature gradients is treated as thermal –diffusion effect. Soret effect is neglected in several studies which belong to heat and mass transfer phenomena because that they are of a smaller order of magnitude when compared with the effects described by Fourier’s and Fick’s laws. These become influenced when they are treated as second order phenomena and in the fields of petroleum technology, hydrology, geosciences etc. For isotope separation and in mixture between gases with very less molecular weight and of average molecular weight, the Soret effect is used. Reddy et al. [15] analyzed heat transfer in hydro magnetic rotating flow of viscous fluid through non-homogeneous porous medium with constant heat source/sink. Raju et al. [16] studied and analyzed MHD thermal diffusion natural convection flow between heated inclined plates in porous medium. Ananda reddy et al. [17] further used thermo diffusion and chemical effects with simultaneous thermal and mass diffusion in MHD mixed convection flow with Ohmic heating. Seshaiah et al. [18] also studied the effects of chemical reaction and radiation on unsteady MHD free convective fluid flow embedded in a porous medium with time-dependent suction with temperature gradient heat source. Sudheer babu et al. [19] investigated effects of the chemical reaction and radiation absorption on free convection flow through porous medium with variable suction in the presence of uniform magnetic field. Dass et al [20] analyzed mass transfer effects on MHD flow and heat transfer past a vertical porous plate through a porous medium under oscillatory suction and heat source. Mishra et al. [21] consideredmass and heat transfer effect on MHD flow of a visco-elastic fluid through porous medium with oscillatory suction and heat source. Ravikumar et al. [22] discussedcombined effects of heat absorption and MHD on convective Rivlin-Ericksen flow past a semi-infinite vertical porous plate with variable temperature and suction. Umamaheswar et al.[23]studied unsteady MHD free convective visco- elastic fluid flow bounded by an infinite inclined porous plate in the presence of heat source, viscous dissipation and ohmic heating. Uamamaheswar et al. [24] studied combined radiation and ohmic heating effects on MHD free convective visco-elastic fluid flow past a porous plate with viscous dissipation. Turan et al. [25] discussed laminar natural convection of power-law fluids in a square enclosure submitted from below to a uniform heat flux density.

2. Mathematical Formulation

We have considered MHD free convective heat absorbing/generating viscous dissipative Newtonian fluid with variable temperature and concentration under the influence of thermal diffusion and Joule heating effects. A magnetic field of consistent strength is applied vertical to the plate. Let x^*-axis is taken along the plate in the vertically upward direction and the y^*-axis is taken perpendicular to the plate. At time $t \le 0$, the plate is maintained at the temperature higher than ambient temperature T_∞ and the fluid is at rest. At time $t > 0$, the plate is linearly accelerated with increasing time in its own plane and the temperature decreases with temperature $T = 1/(1+at)$. Similarly the species concentration decreases with time t. It is assumed that the effect of viscous dissipation is negligible and by usual Boussineq's and boundary layer approximation. Based on the above considerations the flow is governed by the following equations;

$$\frac{\partial u^*}{\partial t^*} = \nu \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta_T\left(T^* - T_\infty\right) - \frac{\sigma B_0^2 u^*}{\rho} - \frac{\nu}{k}u^* \tag{1}$$

$$\rho C_p \frac{\partial T^*}{\partial t^*} = k_T \frac{\partial^2 T^*}{\partial y^{*2}} - Q^*\left(T^* - T_\infty\right) - \frac{\partial q_r^*}{\partial y^*} + \sigma {B_0}^2 u^{*^2} + \mu(\frac{\partial u^*}{\partial y^*})^2 \tag{2}$$

The corresponding initial and boundary conditions governed are

$$\left.\begin{array}{l} u^* = 0, T^* = T_\infty, \qquad for\, all \quad y^*, t^* \le 0 \\ t^* > 0:\ u^* = U_0 a^* t^*, \mathrm{T}^* = T_\infty + \left(\dfrac{T_s^* - T_\infty}{1 + At^*}\right) \quad at\, y^* = 0 \\ \qquad u^* = 0,\ T^* = T_\infty, \qquad as\ y^* \to \infty \end{array}\right\} \tag{3}$$

Where $A = \frac{U_0^2}{\nu}$.The non-dimensional quantities are as follows:

$$u = \frac{u^*}{U_0},\ t = \frac{t^* U_0^2}{\nu},\ y = \frac{y^* U_0}{\nu},\ \theta = \frac{T^* - T_\infty}{T_s^* - T_\infty},\ a = \frac{a^*\nu}{U_0^2},\ \frac{\partial q_r^*}{\partial y^*} = 4(T^* - T_\infty)I^*,$$

$$M = \frac{\sigma B_0^2 \nu}{\rho U_0^2},\ Gr = \frac{\nu g \beta_T\left(T_s^* - T_\infty\right)}{U_0^3},\ K = \frac{kU_0^2}{\nu^2},\ \Pr = \frac{\rho\nu C_p}{k_T},\ Q = \frac{Q^*\nu^2}{k_T U_0^2}, \tag{4}$$

$$F=\frac{4\nu I^*}{\rho C_p U_0^2},\ ,\mathrm{E}_C=\frac{U_0{}^2}{\rho C_p(T_s^*-T_\infty)}.$$

The non-dimensional parameters applied to the equations (1)-(3) and they reduces to following form

$$\frac{\partial u}{\partial t}=\frac{\partial^2 u}{\partial y^2}+Gr\,\theta-M\,u-\frac{1}{K}u \tag{5}$$

$$\frac{\partial\theta}{\partial t}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial y^2}-\frac{1}{\Pr}Q\theta-F\theta+M\ E\ u^2+(\frac{\partial u}{\partial y})^2 \tag{6}$$

(7)

The corresponding initial and boundary conditions are

$$\left.\begin{array}{ll} u=0,\quad \theta=0, & \text{for all}\quad y,t\le 0\\ t>0:\ u=at,\ \theta=\dfrac{1}{1+t}, & at\ \ y=0\\ u=0,\quad \theta=0, & as\ y\to\infty \end{array}\right\} \tag{8}$$

3. Method of Solution

The linear partial differential equations (5)-(7) with the initial and boundary conditions (8) are to be solved. In general the exact solution is impossible for this type of set of equations and so we have solved the above equations by introducing finite-difference method. The comparable finite difference schemes pertaining the equations (5)-(7) are as follows:

$$\frac{u_{i,j+1}-u_{i,j}}{\Delta t}=Gr\,\theta_{i,j}+\frac{u_{i-1,j}-2u_{i,j}+u_{i+1,j}}{(\Delta y)^2}-M\,u_{i,j}-\frac{1}{K}u_{i,j} \tag{9}$$

$$\frac{\theta_{i,j+1}-\theta_{i,j}}{\Delta t}=\frac{1}{\Pr}\frac{\theta_{i-1,j}-2\theta_{i,j}+\theta_{i+1,j}}{(\Delta y)^2}-\frac{Q}{\Pr}\theta_{i,j}-F\theta_{i,j}+M\ \mathrm{E}\ (\mathrm{u}_{i,j})^2+\mathrm{E}\ (\frac{u_{i+1,j}-u_{i,j}}{(\Delta y)})^2 \tag{10}$$

Here, the suffix i corresponds to y and j to time. The mesh system is divided by taking Δy = 0.1. From the initial condition in (8), we have the following equivalent:

$u(i,0)=0,\ \theta(i,0)=0\quad for\ all\ i$

The boundary conditions from (8) are expressed in finite-difference form as follows

$$u(0,j)=at,\theta(0,j)=\frac{1}{1+t}\ for\ all\ j$$

$$u(i_{\max},j)=0,\theta(i_{\max},j)=0,C(i_{\max},j)=0\ \ for\ all\ j$$

(Here $i_{\max}$ was taken as 200)The velocity at the end of time step viz, u(i, j+1)(i=1,200) is computed from (9) in terms of velocity, temperature and concentration at points on the earlier time-step. After that θ (i, j +1) is computed from (10). The procedure is repeated until t = 0.5 (i.e. j = 500). During computation Δt was chosen as 0.001.

4. Results and Discussion

To gain the details of physics of the flow field, we have examined the influence of Hartmann number (M), Grashof number (Gr), Prandtl number (Pr), porous permeability (K), heat absorption parameter (Q), radiation parameter (F), Joul heating parameter on the velocity, temperature, concentration, shear stress and Nusselt number. The effect of magnetic parameter on velocity can be seen in figure 1 and noticed that the velocity falls down with increasing values of Hartmann number. The transverse magnetic field normal to the flow acts in the opposite direction of the flow which has the effect to slow the motion of the fluid. The effect of permeability parameter on velocity is displayed in figure 2 which shows that for rising values of permeability parameter the velocity also increases. Figure 3 displays the effect of Prandtl number on velocity distribution. It is noticed that the velocity decreases with increasing values of Prandtl number. This is because the fluid of low Prandtl number has high thermal diffusivity hence attains higher temperature in constant state, which in turn means more buoyancy force i.e. more fluid velocity with respect to comparatively high Prandtl fluid. Figure 4 displays the effect of radiation parameter on velocity distribution. It is noticed that the velocity decreases with increasing values of radiation parameter. Figure 5 shows the effect of heat absorption on velocity distribution. It is noticed that the velocity decreases with increasing values of heat absorption.

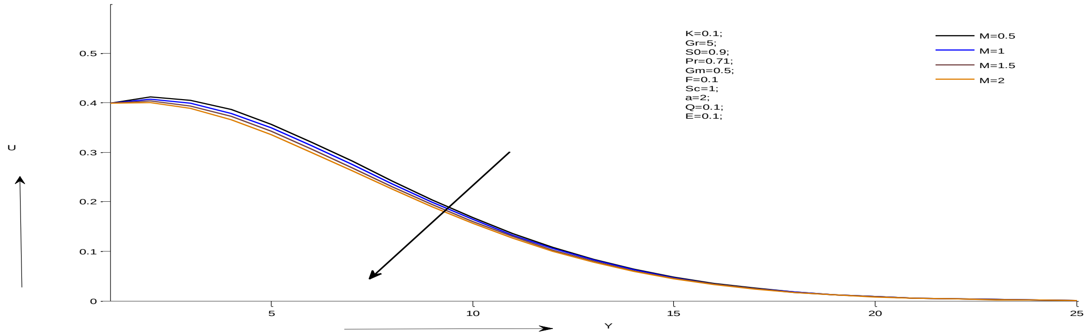

Figure 1: Effect of M on Velocity

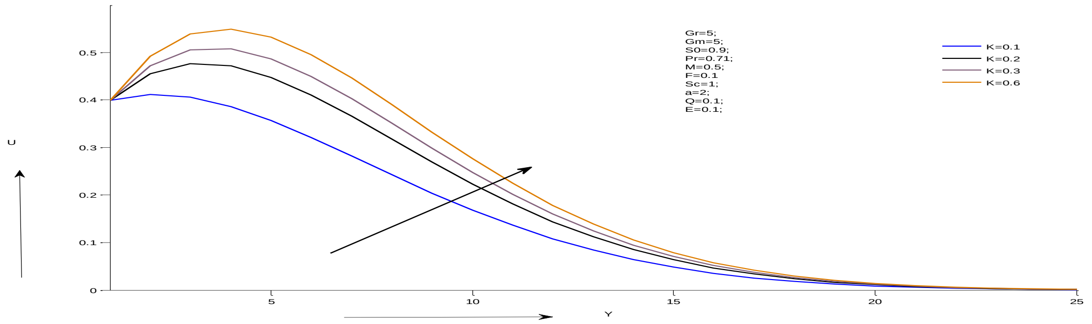

Figure 2: Effect of porosity parameter K onVelocity

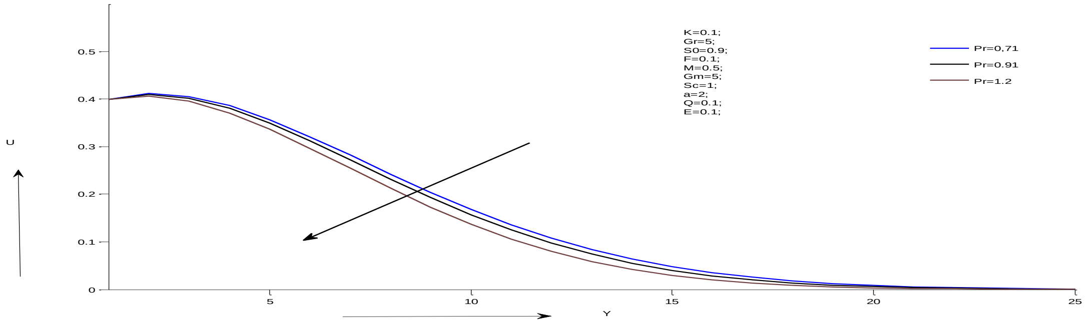

Figure 3: Effect of Pr on Velocity

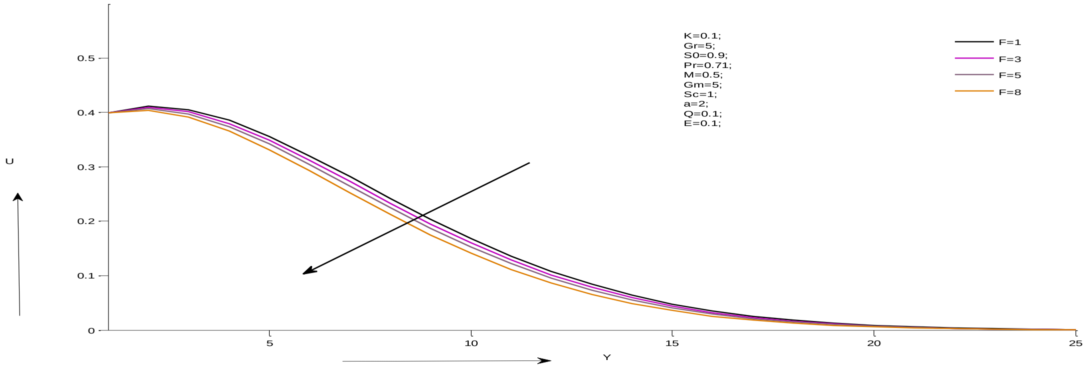

Figure 4: Effect of F on Velocity

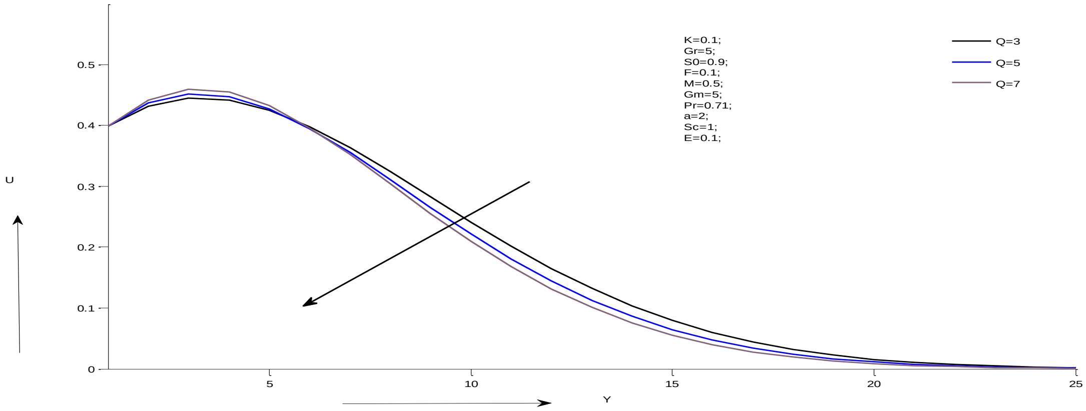

Figure 5: Effect of Q on Velocity.

As per the considered boundary conditions of the flow field, the temperature of the fluid attains its maximum value at the plate surface and decreases exponentially to the free stream zero value away from the plate. The effect of Prandtl number on temperature is presented in figure 6. It is seen that the surface temperature decreases with the increase in Prandtl number. This happens because reduced fluid velocity would mean heat is not convected readily and hence surface temperature decreases. The effect of heat absorption parameter on temperature is exhibited in figure 7. It reveals that the temperature falls down under the influence of heat absorption parameter. The central reason behind this effect is that the heat absorption causes a decrease in the kinetic energy as well as thermal energy of the fluid. Hence the momentum and thermal boundary layers get thinner in case of heat absorbing fluids. Figure 8 demonstrates the effect of radiation parameter on temperature distribution. It shows that the temperature decreases with increasing values of radiation parameter. The effect of Eckert number on temperature is displayed in figure 9. The temperature increases with increasing values of Eckert number. The effect of magnetic parameter number on temperature is shown in figure 10. The temperature decreases with increasing values of magnetic parameter.

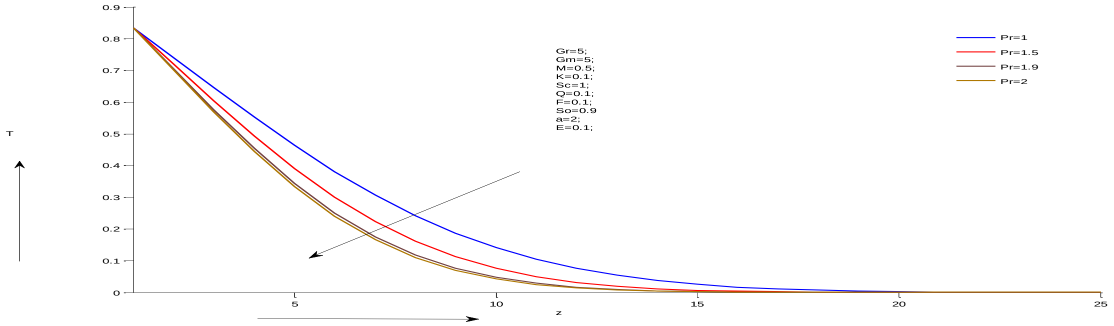

Figure 6: Effect of Pr on Temperature

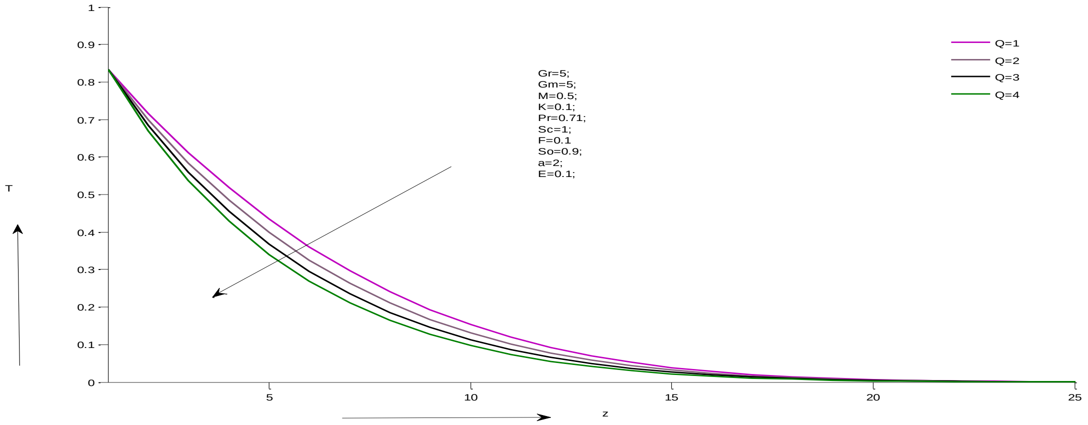

Figure 7: Effect of Q on Temperature

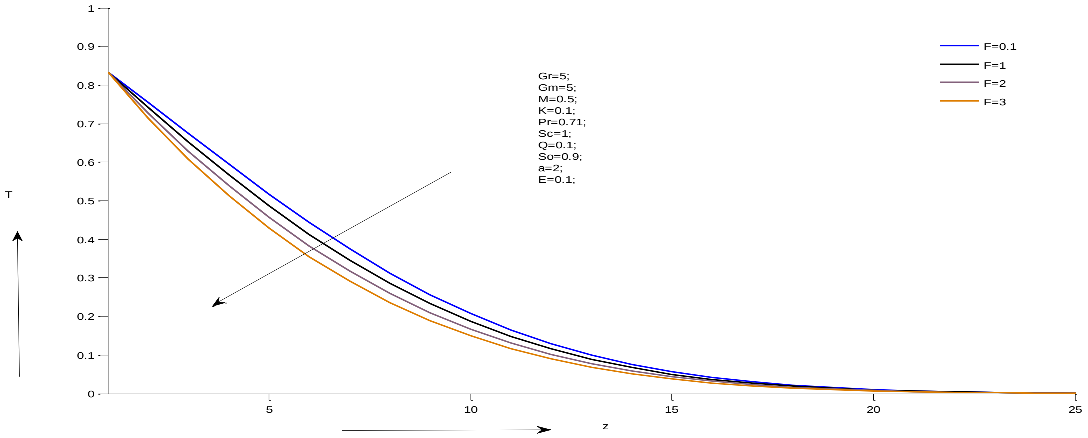

Figure 8: Effect of F on Temperature

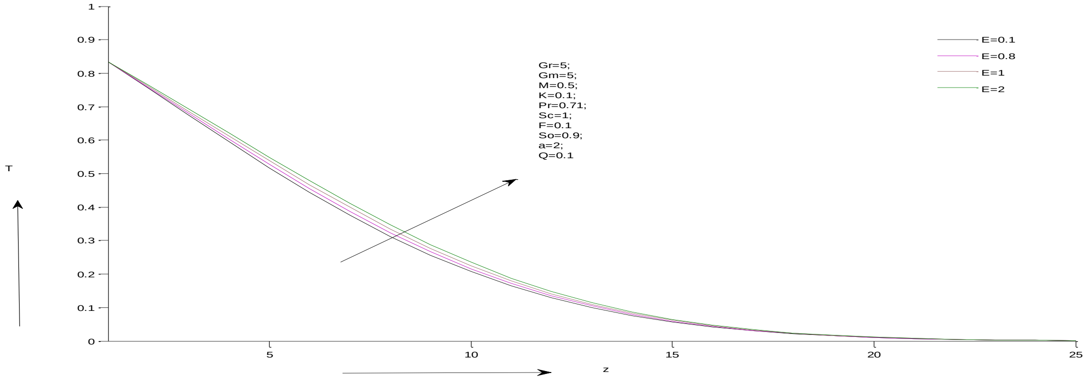

Figure 9: Effect of Eckert number on Temperature

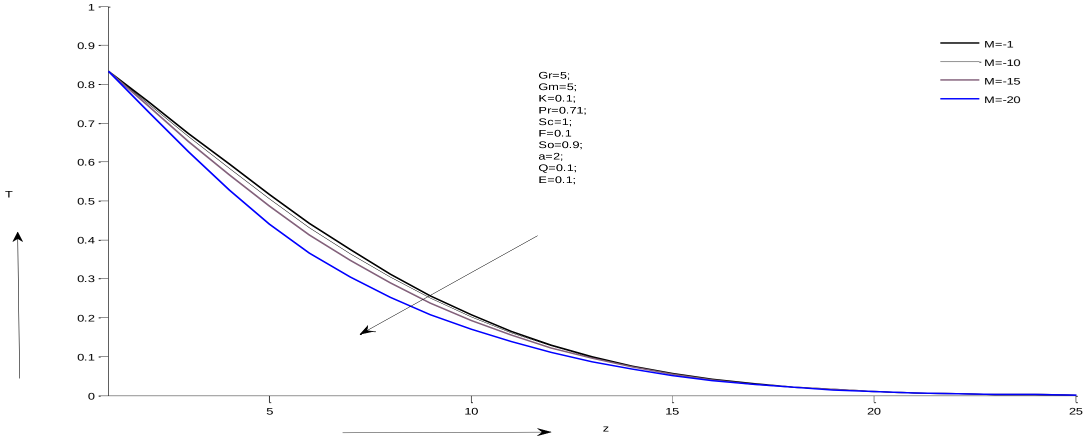

Figure 10: Effect of M on Temperature

Figure 11 demonstrates the effect of porosity parameter on skin friction. It shows that the skin friction reduces with raising values of porosity parameter. Figure 12 shows the variations in skin friction. The skin friction increases with an increase in magnetic parameter. Figure 13 shows that the effect of radiation parameter on Nusselt number. It is examined that the Nusselt number increases with the increase in radiation parameter. Figure 14 shows that the effect of heat absorption parameter on Nusselt number. It is clear that the Nusselt number increases with the increasing values of heat absorption parameter.

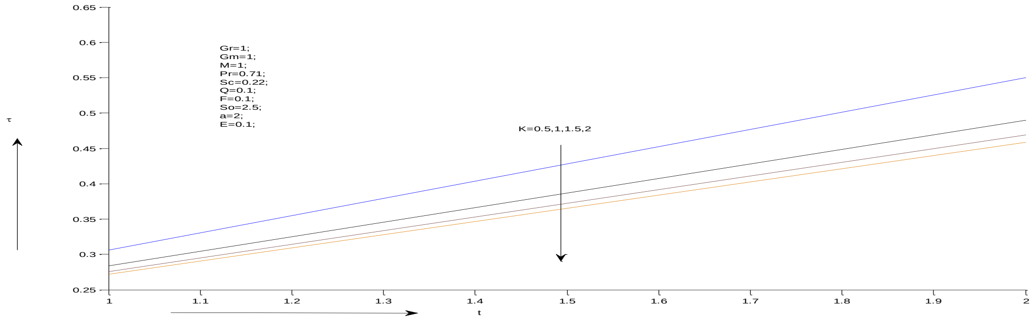

Figure 11: Effect of K on Skin friction

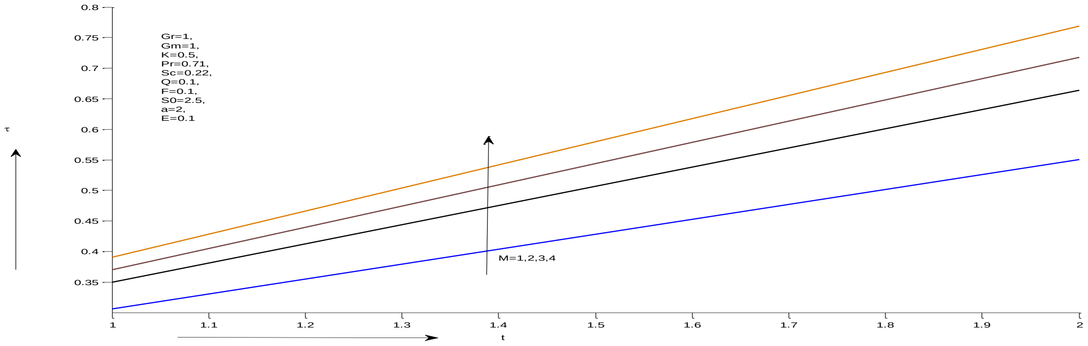

Figure 12: Effect of M on Skin friction

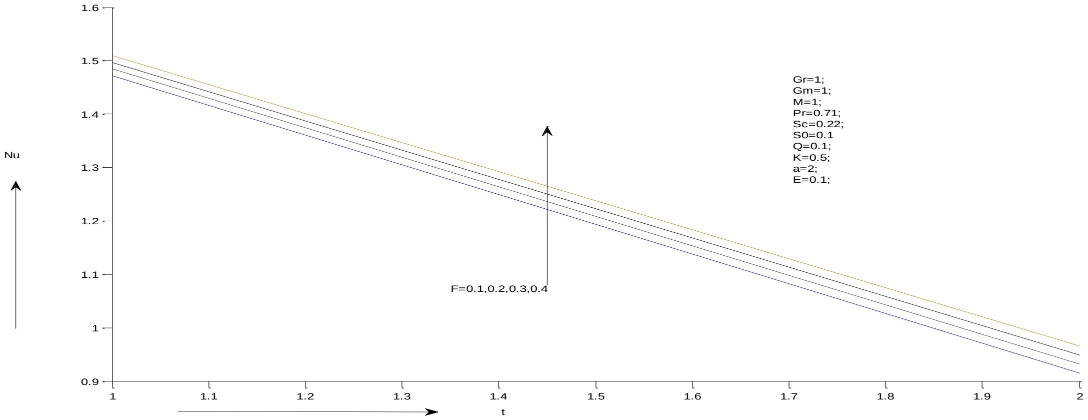

Figure 13: Effect of F on Nusselt number

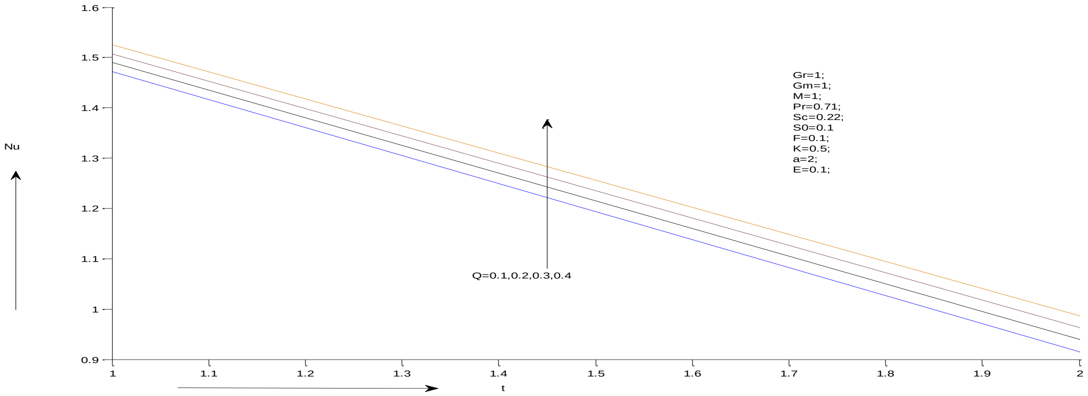

Figure 14: Effect of Q on Nusselt number.

5. Conclusion

The variations in the velocity and temperature with the effects of various parameters examined in the problem are studied through graphs. Some of the above parameters on Skin friction and Nusselt number are observed.

- With the increasing values of Grashof number, porosity parameter, Soret number, the fluid velocity increases, but in case of magnetic parameter, Prandtl number, radiation parameter, a reverse trend is found.

- For increasing values of Prandtl number, heat absorption parameter and radiation parameter, the temperature of the fluid reduces.

With the increasing values of heat absorption parameter and radiation parameter, Nusselt number increases.

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