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MHD HEAT ABSORBING AND ROTATING FLUID FLOW THROUGH A POROUS PLATE

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Abstract

In this paper we have studied MHD rotating and chemically reactive porous plate with heat absorption. The governing equations involved in the present analysis are solved by the finite difference technique. The expressions for the distribution of velocity, the temperature and the concentration are computed and with the aid of these the expressions for skin friction, Nusselt number and Sherwood number in non-dimensional from are derived. The effects of various physical parameters on the above flow quantities are studied through the graphs and tables.

Keywords: MHD, Heat transfer, Mass transfer, Porous plate, Heat absorption.

1. INTRODUCTION

The study of heat generation or absorption effects in moving fluids is significant in perspective of several physical problems, such as fluids undergoing exothermic or endothermic chemical reactions. Combined heat and mass transfer problems with chemical reaction are of importance in many processes and have, therefore received a respectable amount of tending in recent years. For example in the power industry among the methods of generation electric power is one in which electrical energy is extracted directly form a moving conducting fluids. Many practical diffusive operations involve the molecular diffusion of a species in the presence of chemical reaction within or at the boundary. The problems of hydromagnetic convective flow in a porous medium have drawn respectable tending of various researchers outstanding to its importance in various scientific and technological applications viz. problems of boundary layer flow control, geothermal energy extraction, metallurgy, chemical, mineral and petroleum engineering, etc. and on the performance of so many engineering devices victimisation electrically conducting fluids, namely, MHD generators, MHD pumps, MHD accelerators, MHD flow-meters, nuclear reactors, plasma jet engines, etc. Chamkha [1] analysed the effect of heat generation or absorption on hydromagnetic three dimensional free convection flows over a vertical stretching surface. The flow through porous media is a subject of almost usual interest and egresses as a separate intensive research area because heat and mass transfer in porous medium is very much dominant in nature and can also be brushed in many technological processes. In this context the effect of temperature-dependent heat sources has been studied by Moalem [2] taking into account the steady state heat transfer within porous medium. A comprehensive review of the studies of convective heat transfer mechanism through porous media has been made by Nield and Bejan [3]. Hiremath and Patil [4] calculated the effect on free convection currents on the oscillatory flow through a porous medium, which is delimited by vertical plane surface of constant temperature. Hydromagnetic unsteady mixed convection and mass transfer flow past a vertical porous plate absorbed in a porous medium in front of hall current was enquired by Sharma and Chaudhary [5]. El-Amin [6] determined the MHD free convection and mass transfer flow in a micropolar fluid over a stationary vertical plate with constant suction. Kim [7] analysed unsteady MHD free convection flow past a moving semi-infinite vertical porous plate inserted in a porous medium with variable suction. Theoretical/experimental enquiries of convective boundary layer flow with heat and mass transfer induce due to a moving surface with a uniform or non-uniform velocity play an important role in various manufacturing processes in industry which include the boundary layer flow along material handling conveyers, extrusion of plastic sheets, cooling of an infinite metallic plate in cooling bath, glass blowing, continuous casting and levitation, design of chemical processing equipment, establishment and distributionof fog, dispersion of temperature and moisture over agricultural fields and groves of trees, damage of crops due to freezing, common industrial sight especially in power plants, etc. Holding in view the importance of such study, Jha [8] determined hydromagnetic free convection and mass transfer flow past a uniformly expressed moving vertical plate through a porous medium. Ibrahim et al. [9] enquired unsteady hydromagnetic free convection flow of micro-polar fluid and heattransfer past a vertical porous plate through a porous medium in the presence of thermal and mass diffusions with a constant heat source. Makinde and Sibanda [10] studied MHD mixed convective flow with heat and mass transfer past a vertical plate inserted in a porous medium with constant wall suction. Tien and Vafai [11].Bejan and Khair [12] determined heat and mass transfer by natural convection in a porous medium. Nakayama and Koyama [13] engaged an integral method for free convection from a vertical heated surface in a thermally ranked porous medium. In view of above applications Cheng and Minkowycz [14] studied the problem of natural convection through a vertical plate. At first, Tien [15] analysed free convective heat transfer from a rotating cone. Hering and Grosh [16] calculated in mixed convection and reported the results by parting the regimes of flow as purely free, forced and combined convection flows. Chamkha [17] studied thermophoretic effect on hydromagnetic convective flow over a flat surface, vertical cylinder, in a fluid concentrated porous medium. Partha [18] analysed thermophoresis particle deposit on natural convective in a non-Darcy porous medium with Soret and Dufour effects under permeable and impermeable conditions. Ghosh [19] investigated the hydrodynamic fluctuating flow of a viscoelastic fluid in a porous channel, where the channels oscillate with a given velocity in their own planes. Das [20] studied viscoelastic effects on unsteady two-dimensional and mass transfer of a viscoelastic fluid in a porous channel with radiative heat transfer. From the previous literature survey about unsteady fluid flow, we enquire that little papers were done in porous medium. Al-Odat and Ghamd [21] carried out numerical investigation of Dufour and Soret effects on unsteady MHD natural convection flow past a vertical plate inserted in non-Darcy porous medium and used implicit finite difference scheme of the Crank-Nicolson type with tri diagonal matrix manipulation method to solve governing non linear dimensionless equations. Mustafa et al.[22] concentrated on heat and mass transfer in the unsteady squeezing flow between parallel plates and victimised Homotopy Analysis Method(HAM) to construct the series solution of the problem. Shvets and Vishevskiy [23] reported on the effect of dissipation on convective heat transfer in the flow of non-Newtonian fluids. Recently, Rahman et al. [24], studied many thermal boundary layer fluid flow problems with variable viscosity and thermal conductivity. Few other studies are reported recently on the topics in the literature [25-37] related to this the work of this manuscript are also referred. Motivated by the above studies in this manuscript we attempted to investigate MHD heat absorbing and rotating fluid flow through a porous plate.

2. MATHEMATICAL FORMULATION

We consider a viscous incompressible, electrically conducting, heat absorbing/generating and chemically reacting Newtonian fluid flow past an infinite vertical porous. A magnetic field of uniform strength is applied perpendicular 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 also At time $t^*>0$ the temperature and Concentration of the plate $y^*= 0$ is raised to with time t and thereafter remains constant and that of $y^*\to\infty$is lowered to end. It is assumed that the effect of viscous dissipation is negligible. Based on the above assumptions and followed by the results of Umamaheswar et al. [33-37], the equations governing the flow along with the relevant boundary conditions are given below:

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

$$\frac{\partial v^*}{\partial t^*}-2\Omega u^*=\nu\frac{\partial^2 v^*}{\partial y^{*2}}-\frac{\sigma B_0^2 u^*}{\rho}-\frac{\nu}{k}u^* \tag{2}$$

$$\rho C_p\frac{\partial T^*}{\partial t^*}=k_T\frac{\partial^2 T^*}{\partial y^{*2}}-Q^*\left(T^*-T_\infty\right) \tag{3}$$

$$\frac{\partial C^*}{\partial t^*}=D\frac{\partial^2 C^*}{\partial y^{*2}}-K_r^*(C^*-C_\infty) \tag{4}$$

The corresponding initial and boundary conditions are

$$\left.\begin{array}{ll} u^*=0,\ v^*=0, T^*=T_\infty,\ C^*=C_\infty & for\ all\quad y^*,t^*\le 0\\ t^*>0:\ u^*=U_0a^*t^*, v^*=v_0a^*t^*, T^*=T_\infty+(T_w^*-T_\infty^*)e^{a^*t^*}, & \\ C^*=C_\infty+(C_s^*-C_\infty^*)e^{a^*t^*}\ \ at\ y^*=0 & \\ \quad u^*\to 0,\ T^*\to T_\infty^*,\ C^*\to C_\infty^* & as\ y^*\to\infty \end{array}\right\} \tag{5}$$

Now the following non-dimensional quantities are introduced:

$$u=\frac{u^*}{U_0},\ t=\frac{t^*U_0^2}{\nu},\ y=\frac{y^*U_0}{\nu},\ \theta=\frac{T^*-T_\infty}{T_s^*-T_\infty},$$

$$C=\frac{C^*-C_\infty}{C_s^*-C_\infty},\ a=\frac{a^*\nu}{U_0^2},$$

$$Gr=\frac{\nu g\beta_T\left(T_s^*-T_\infty\right)}{U_0^3}, \text{(Grashof number)}$$

$$Gm=\frac{\nu g\beta_C\left(C_s^*-C_\infty\right)}{U_0^3}, \text{(Modified Grashof number)}$$

$$M=\frac{\sigma B_0^2\nu}{\rho U_0^2}, \text{(Magnetic parameter)}$$

$$k_1^2=\frac{\Omega\nu}{U_0^2}, \text{(Rotation parameter)}$$

$K = \frac{kU_0^2}{\nu^2}$, (Permeability of the porous medium)

$\Pr = \frac{\rho \nu C_p}{k_T}$, (Prandtl number)

$Q = \frac{Q^* \nu^2}{k_T U_0^2}$, (Heat absorption)

$Sc = \frac{\nu}{D}$, (Schmidt number)

Introducing the above mentioned non-dimensional quantities in set of equations (1)-(4), we get the following set of dimensionless equations:

$$\frac{\partial u}{\partial t} + 2k_1^2 v = \frac{\partial^2 u}{\partial y^2} + Gr\,\theta + Gm\,C - M\,u - \frac{1}{K}u \quad 6)$$

$$\frac{\partial v}{\partial t} - 2k_1^2 u = \frac{\partial^2 v}{\partial y^2} - M\,v - \frac{1}{K}v \quad (7)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} + Q\theta \quad (8)$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - KrC \quad (9)$$

The corresponding initial and boundary conditions are

$$\left.\begin{array}{lll} u = 0,\ v = 0,\ \theta = 0, \quad \mathrm{C} = 0 & \text{for all} & \mathrm{y,t} \le 0 \\ t > 0:\ u = at, v = at,\ \theta = e^{at},\ \mathrm{C} = e^{at} & at & y = 0 \\ u \to 0,\ \ v \to 0,\ \theta \to 0, \quad \mathrm{C} \to 0 & as & y \to \infty \end{array}\right\} \quad (10)$$

3. METHOD OF SOLUTION

Equations (6)-(9) are linear partial differential equations and are to be solved with the initial and boundary conditions (10). In fact the exact solution is not possible for this set of equations and hence we solve these equations by finite-difference method. The equivalent finite difference schemes of equations for (6)-(9) are as follows:

$$\frac{u_{i,j+1} - u_{i,j}}{\Delta t} + k_1^2 v_{i,j} = Gr\,\theta_{i,j} + Gm\,C_{i,j} + \frac{u_{i-1,j} - 2u_{i,j} + u_{i+1,j}}{(\Delta y)^2} - M\,u_{i,j} - \frac{1}{K}u_{i,j} \quad (11)$$

$$\frac{v_{i,j+1} - v_{i,j}}{\Delta t} - 2k_1^2 u_{i,j} = \frac{v_{i-1,j} - 2v_{i,j} + v_{i+1,j}}{(\Delta y)^2} - M\,v_{i,j} - \frac{1}{K}v_{i,j} \quad (12)$$

$$\frac{\theta_{i,j+1} - \theta_{i,j}}{\Delta t} = \frac{1}{\Pr}\frac{\theta_{i-1,j} - 2\theta_{i,j} + \theta_{i+1,j}}{(\Delta y)^2} + Q\theta_{i,j} \quad (13)$$

$$\frac{C_{i,j+1}-C_{i,j}}{\Delta t}=\frac{1}{Sc}\frac{C_{i-1,j}-2C_{i,j}+C_{i+1,j}}{(\Delta y)^2}-KrC_{i,j} \qquad (14)$$

Here, the suffix i refer to y and j to time. The mesh system is divided by taking Δy = 0.1. From the initial condition in (10), we have the following equivalent:

$$u(i,0)=0,\ \theta(i,0)=0, C(i,0)=0 \ \ for\, all\, i \qquad (15)$$

The boundary conditions from (10) are expressed in finite-difference form as follows

$$\begin{aligned} &u(0,j)=at, v(0,j)=at, \theta(0,j)=e^{at},\\ &C(0,j)=e^{at} \ \ for\, all\, j\\ &u(i_{\max},j)=0, v(i_{\max},j)=0, \theta(i_{\max},j)=0,\\ &C(i_{\max},j)=0 \ \ for\, all\, j \end{aligned} \qquad (16)$$

(Here i_{max} was taken as 200)

The primary velocity at the end of time step viz, u (i, j+1) (i=1,200) is computed from (11) and the secondary velocity at the end of time step viz, v (i, j+1) (i=1,200) is computed from (12) in terms of velocity, temperature and concentration at points on the earlier time-step. After that θ (i, j +1) is computed from (13) and then C (i, j +1) is computed from (14). The procedure is repeated until t = 0.5 (i.e. j = 500). During computation Δt was chosen as 0.001.

Skin-friction:

The skin-friction in non-dimensional form is given by

$$\tau=\left(\frac{du}{dy}\right)_{y=0}, where\ \tau=\frac{\tau^1}{\rho U_0^2} \qquad (17)$$

Rate of heat transfer:

The dimensionless rate of heat transfer in terms of Nusselt number is given by

$$Nu=-\left(\frac{d\theta}{dy}\right)_{y=0} \qquad (18)$$

Rate of mass transfer:

The dimensionless rate of mass transfer in terms of Sherwood number is given by

$$Sh=-\left(\frac{dC}{dy}\right)_{y=0} \qquad (19)$$

4. RESULTS AND DISCUSSION

In order to validate the equations reported in the previous section, a numerical analysis of the results is carried out in this section with the help of graphs and tables. The influences of various physical parameters involved in the problem are discussed on the flow quantities with the help of graphs and tables. The variations in velocity boundary layer are studied from the figures 1-8. Figures 1 and 2 depict the effects of thermal Grash of number and solutal Grash of number on primary velocity profiles respectively. As expected velocity increases with the increasing values of both the buoyancy parameters. This due to the fact that the buoyancy force has significance influence on the velocity as we have considered the vertical plate, therefore it is true physically and these results are in good agreement with the similar results of several authors [25-37].

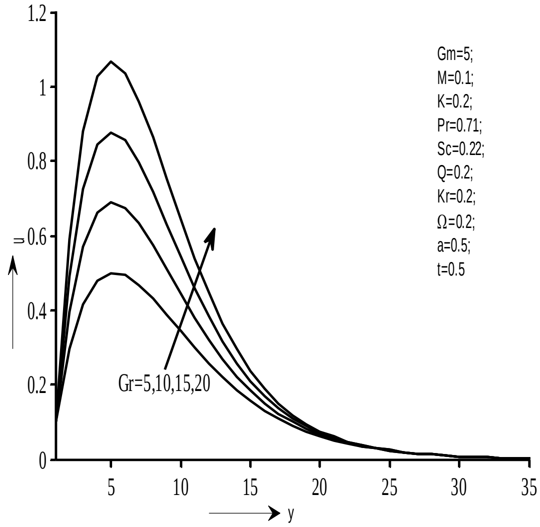

Figure 1: Effect of Gr on Primary velocity

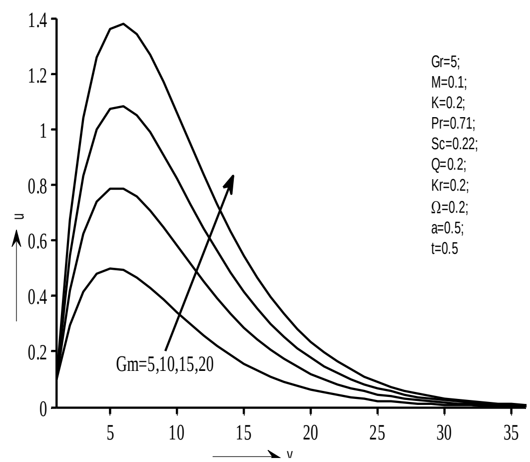

Figure 2: Effect of Gm on Primary velocity

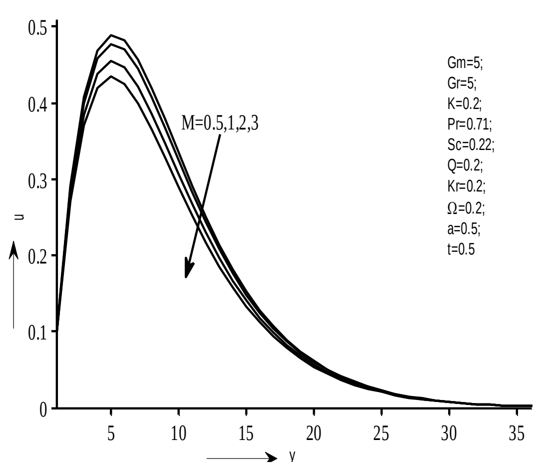

Figure 3: Effect of M on Primary velocity

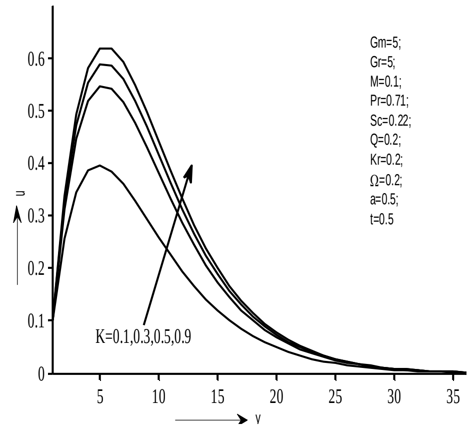

Figure 4: Effect of K on Primary velocity

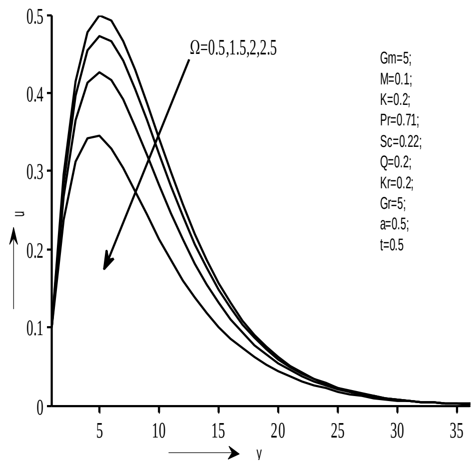

Figure 5: Effect of Ω on Primary velocity

The influences of magnetic parameter, permeability parameter and rotation parameter are presented through figures 3-5 on primary velocity respectively. From these figures it is noticed that velocity decreases when the values of magnetic parameter as well as rotation parameter are increased. Of course it has reverse tendency in the case of permeability parameter. These results are also true physically, because magnetic force acts as a retarding force which is known as the Lorentz force that slow down the velocity across the momentum boundary layer. Secondary velocity profiles also show the similar tendency in the presence of these three parameters which is noticed from the figures 6-8.

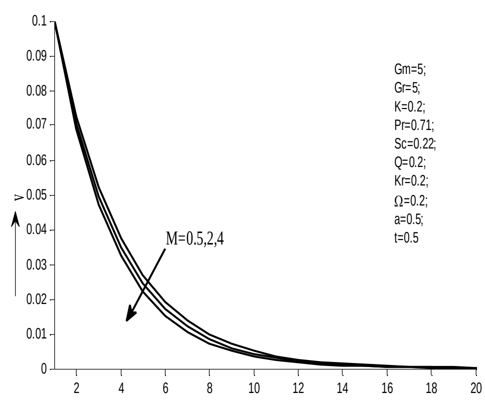

Figure 6: Effect of M on Secondary velocity

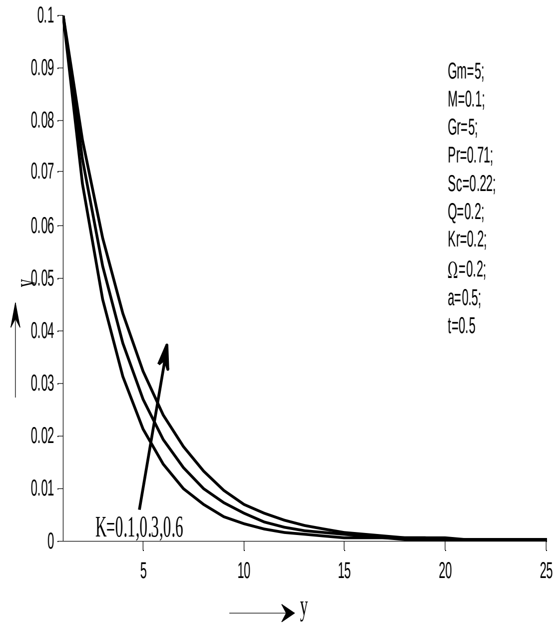

Figure 7: Effect of K on Secondary velocity

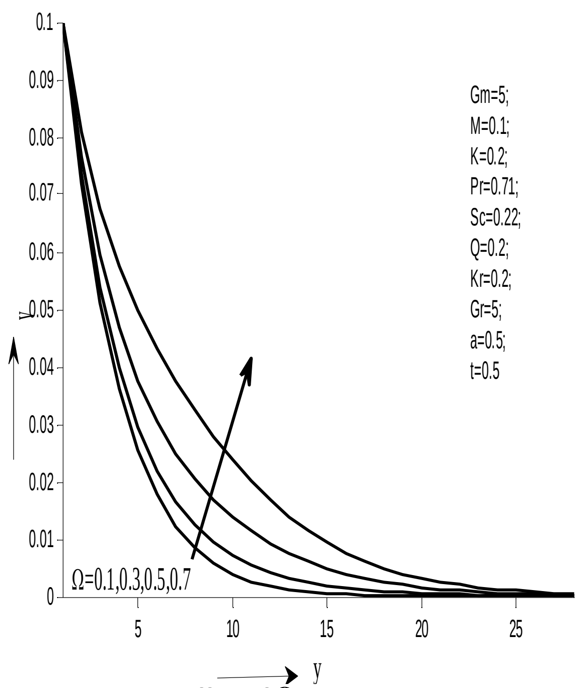

Figure 8: Effect of Ω on Secondary velocity

Variations in temperature distribution are studied through figures 9-10. Figure 9 explains the influence of Prandtl number on temperature. From this figure it is observed that increasing values of Prandtl number condenses the temperature boundary layer. Similarly the effect of heat absorption parameter on temperature is presented in figure 10, from which it is noticed that temperature increases with an increase in heat generation parameter. Effects of Schmidt number, chemical reaction parameter and Soret number are presented through figures 11-12. From these figures it is observed that concentration decreases with the increasing values of Schmidt number as well as chemical reaction parameter. Variations in skin friction coefficient with thermal Grash of number, Solutal Grash of number, magnetic parameter, permeability parameter and rotation parameter are presented in table1, from this table it is observed that both the components of skin friction coefficients decrease when the values of thermal Grash of number and Solutal Grash of number are increased. Whereas it shows reverse tendency in the cases of magnetic parameter, permeability parameter and rotation parameter (except the secondary component for the case of rotation parameter). In table 2, effects of Prandtl number and heat absorption parameter are presented on skin friction and Nusselt number. When the values of Prandtl number and heat absorption parameter are increasing skin friction coefficient along the main flow stream decreases but has opposite action on the secondary flow direction. Of course Nusselt number increases for the increasing values of both Prandtl number and absorption parameter. Effects of chemical reaction parameter and Schmidt number on skin friction and Sherwood number are presented through table 3. Sherwood number increases when the values of both parameters increase but skin friction coefficient components have mixed results in this case.

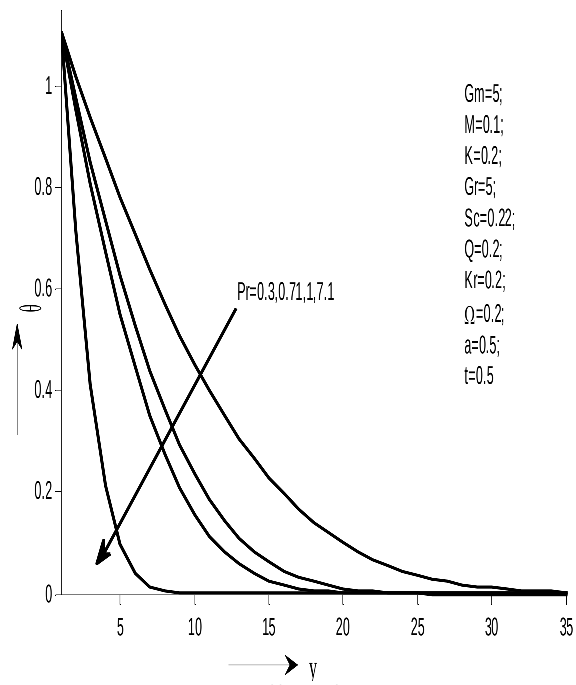

Figure 9: Effect of Pr on temperature

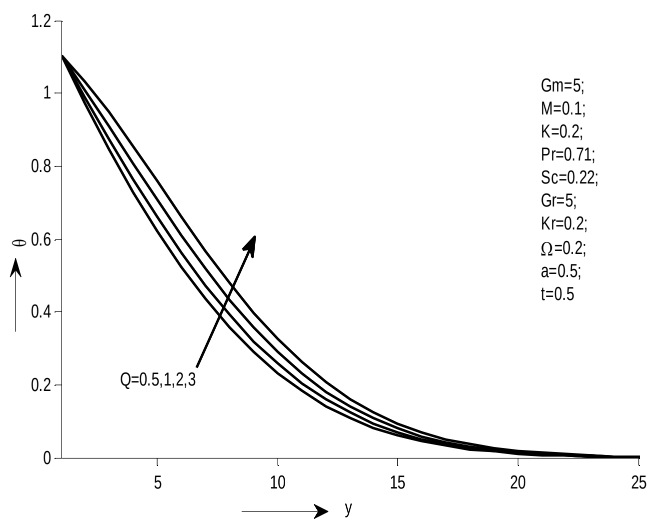

Figure 10: Effect of Q on temperature

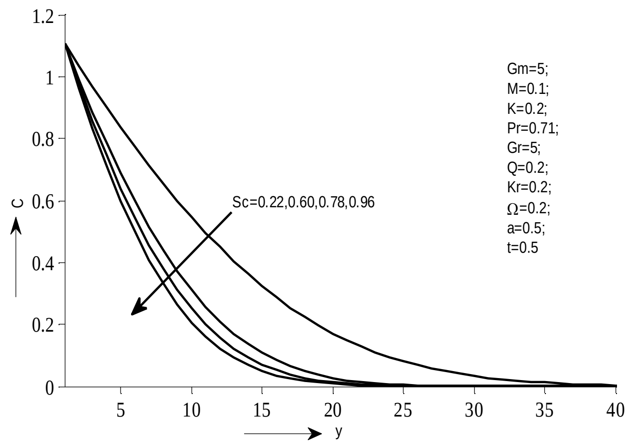

Figure 11: Effect of Sc on Concentration

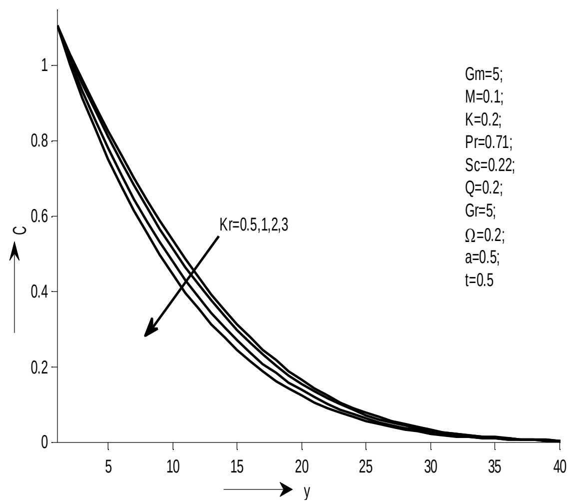

Figure 12: Effect of Kr on Concentration

Table 1: Variation in skin friction under the influence of Grashofnumber modified Grashof number, magnetic parameter, porosity parameter and rotation parameter:

Gr	Gm	M	K	Ω	τ_x	τ_y
5	5	3	1.2	2.2	5.8445	0.0089
10	5	3	1.2	2.2	5.5072	0.0067
15	5	3	1.2	2.2	5.2635	0.0054
20	5	3	1.2	2.2	5.0324	0.0024
5	10	3	1.2	2.2	5.6356	0.2337
5	15	3	1.2	2.2	5.4309	0.1868
5	20	3	1.2	2.2	5.3235	0.0536
5	5	0.5	1.2	2.2	2.2790	0.0232
5	5	1	1.2	2.2	3.9619	0.0258
5	5	2	1.2	2.2	4.7387	0.0325
5	5	3	2.2	2.2	3.0392	0.0018
5	5	3	3.2	2.2	3.1400	0.0021
5	5	3	4.2	2.2	3.2403	0.0032
5	5	3	1.2	3.2	3.1142	0.0019
5	5	3	1.2	4.2	3.1254	0.0017
5	5	3	1.2	8.2	3.1365	0.0014

Table 2: Variations in skin friction and Nusselt number under the influence of Prandtl number, heat source parameter and radiation parameter.

Pr	Q	τ_x	τ_y	Nu
0.71	1	2.2324	0.0121	2.4282
1	1	1.6543	0.0326	4.4974
3	1	1.5464	0.0462	5.4583
7.1	1	1.3542	0.0571	6.5026
2	3	2.5832	0.0028	1.9562
2	4	2.3826	0.0045	2.1823

Table 3: Effect of chemical reaction parameter and Schmidt number on skin friction and Sherwood number

Kr	Sc	τ_x	τ_y	Sh
3	1	2.9356	0.0010	0.8081
5	1	2.8762	0.0207	1.2738
6	1	2.8560	0.0960	1.3198
3	1	3.0213	0.1330	0.1903
3	2	3.0649	0.0026	0.4004
3	3	3.1086	0.0022	0.9918

5. CONCLUSIONS

In the analysis of the flow the following conclusions are made:

- The primary velocity of the fluid increases when the values of rotation parameter increase and the secondary velocity decreases in the same case.
- The temperature of the fluid enhances for increasing values of heat absorption parameter.
- The existence of chemical reaction leads to a decrease in the concentration of the fluid.

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