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INFLUENCE OF RADIATION ON FREE CONVECTION IN MHD COUETTE FLOW BETWEEN TWO INFINITE VERTICAL POROUS PLATES IN PRESENCE OF HEAT SOURCE AND CHEMICAL REACTION

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ABSTRACT

The influence of radiation on free convection MHD couette flow between two infinite vertical porous plates in presence of heat source and chemical reaction has been investigated. The governing equations involved in the present analysis are solved by using the perturbation method. The velocity, temperature and concentration field are studied for different parameters such as Radiation parameter F, Chemical Reaction R, Heat Source parameter Q, Schmidt number Sc, Reynolds number Re, Hartmann number M etc. Also the expressions for rate of heat and mass transfer coefficients are discussed numerically. In the absence of radiation parameter (i.e. $F=0$) these results are in good agreement with the results of Ahmed et al. [1].

Keywords: *MHD, Free convection, Radiation, Chemical reaction, Heat source.*

INTRODUCTION

The study of magneto hydrodynamics (MHD) has attracted the interest of many researchers in view of important applications in many engineering problems such as MHD pumps in chemical energy technology, MHD power generators and cooling of nuclear reactors. Free convection in MHD couette flow with heat source and chemical reaction were studied by Ahmed *et al.* [1]. Bodoia *et al.* [2] investigated the development of free convection between heated vertical plates. Chamkha [3] have presented unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption. Hall current and heat transfer effects on MHD flow in a channel partially filled with a porous medium in a rotating system were examined by Chauhan *et al.* [4]. Heat transfer effects on rotating MHD couette flow in a channel partially field by a porous medium with hall current was studied by Chauchan *et al.* [5].

Radiation effects on free convection flow are important in the context of space technology and processes involving high temperatures. Radiation is the energy emitted by matter in the form of electromagnetic waves as a result of the changes in the electronic configurations of the atoms or molecules. Gbadeyan *et al.* [6] have evaluated the radiative effect on velocity, magnetic and temperature fields of a magneto hydrodynamic oscillatory flow past a limiting surface with variable suction. Hossain *et al.* [7] analyzed effect of radiation on free convection from a porous vertical plate. The transient free convection flow between two vertical parallel plates with constant heat flux at one boundary and the other maintained at a constant temperature was investigated by Narahari *et al.* [8]. Mishra *et al.* [9] studied Effects of radiation of free convection flow due to heat and mass transfer through a porous medium bounded by two vertical walls. Raptis *et al.* [10] investigated the magneto hydrodynamics free convection flow and mass transfer through a porous medium bounded by an infinite vertical porous plate with constant heat flux. Mass transfer and radiation effects of unsteady MHD free convective fluid flow embedded in porous medium with heat generation/absorption has been studied by Ramana Reddy *et al.* [11]. Rao *et al.* [12] considered radiation effects on an unsteady MHD vertical porous plate in the presence of homogeneous chemical reaction. Rajput and Sahu [13] discussed the effect of a uniform transverse magnetic field on the unsteady transient free convection flow of an incompressible viscous electrically conducting fluid between two infinite vertical parallel porous plates with constant temperature and variable mass diffusion. Singh *et al.* [14] analyzed Transient free convection flow between two vertical parallel plates.

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The main objective of the present paper is to investigate the effect of thermal radiation, chemical reaction and heat source parameter of an electrically conducting viscous incompressible fluid between two infinite vertical plates through porous medium. The behavior of the velocity, temperature, concentration has been discussed for variation in the governing parameter. Also the expressions for rate of heat and mass transfer coefficients are discussed numerically.

FORMULATION OF THE PROBLEM

We now consider a steady MHD incompressible viscous electrically conducting fluid through porous medium bounded by two infinite vertical plates at a fixed distance h in presence of transverse magnetic field and chemical reaction. The x - axis is taken along one wall of the channel and y -axis is normal to it. A transverse magnetic field B_0, of uniform strength has been applied perpendicular to the wall of the channel. The magnetic dissipation is assumed to be negligible and the Eckert number Ec is very small. Under these assumptions, the governing equations for the problem considered in this chapter are:

Equation of continuity:

$$\frac{\partial v^*}{\partial y^*}=0, \text{ which is satisfied with } v^*=-v_0 \text{ (constant suction/injection)} \tag{1}$$

Momentum equation:

$$-v_0\frac{\partial u^*}{\partial y^*}=\upsilon\frac{\partial^2 u^*}{\partial y^{*2}}+g\beta(T^*-T_s^*)+g\beta_c(C^*-C_s^*)-\frac{\upsilon u^*}{K^*}-\frac{\sigma B_0^2 u^*}{\rho} \tag{2}$$

Energy equation:

$$-v_0\frac{\partial T^*}{\partial y^*}=\frac{k}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}}+\frac{\upsilon}{C_p}\left(\frac{\partial u^*}{\partial y^*}\right)^2-Q^*(T^*-T_s^*)-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y^*} \tag{3}$$

Mass concentration equation:

$$-v_0\frac{\partial C^*}{\partial y^*}=D\frac{\partial^2 C^*}{\partial y^{*2}}-R^*(C^*-C_s^*) \tag{4}$$

The corresponding boundary conditions are:

$$u^*=0,\quad T^*=T_0^*,\quad C^*=C_0^* \quad \text{at } y^*=0$$
$$u^*=U,\quad T^*=T_1^*,\quad C^*=C_1^* \quad \text{at } y^*=h \tag{5}$$

where u^* and v^* are the velocity components in the x^* and y^* direction respectively, β and β_c are the thermal and concentration volume expansion coefficient respectively, k is the thermal conductivity, C^* is the species concentration, T^* is the fluid temperature , C_s^* and T_s^* are the concentration and temperature in static condition respectively , C_p is the specific heat at constant pressure, C_0^* and C_1^* are the species concentration at the lower wall and upper wall, D is the chemical molecular diffusivity, g is the acceleration due to gravity, h is the distance between two walls, K^* is the permeability parameter of porous medium, R^* is the rate of chemical reaction, U is the velocity of the upper wall, Q^* is the constant heat generation / absorption, ρ is the fluid density, υ is the kinematic viscosity.
Mishra et al. [9] showed local radiant for the case of an optically thin gray gas, as given below

$$\frac{\partial q_r}{\partial y^*}=-4\alpha\sigma\left(T_s^{*4}-T^{*4}\right) \tag{6}$$

where α is absorption constant, σ is the Stefan- Boltzmann constant and q_r is the heat flux. We assume that the temperature difference with in the flow are sufficiently small such that T^{*4} may be expressed as a linear function of the temperature. This is accomplished by expanding T^{*4} in a Taylor Series about T_s^* and neglecting higher-order terms, thus

$$T^{*4}=4T_s^{*4}T^*-3T_s^{*4} \tag{7}$$

We introduce the following non-dimensional quantities:

$$y=\frac{y^*}{h},\ u=\frac{u^*}{v_0},\ \theta=\frac{T^*-T_s^*}{T_0^*-T_s^*},\ \phi=\frac{C^*-C_s^*}{C_0^*-C_s^*},\ Sc=\frac{\upsilon}{D},\ \Pr=\frac{\mu C_p}{k},\ \mathrm{Re}=\frac{v_0 h}{\upsilon},$$

$$Gr = \frac{hg\beta(T_0^* - T_s^*)}{v_0^2},\ Gm = \frac{hg\beta_c(C_0^* - C_s^*)}{v_0^2},\ Ec = \frac{v_0^{\,2}}{C_p\left(T_0^* - T_s^*\right)},\ F = \frac{16\alpha\sigma T_s^{*3} h}{\rho C_p v_0},$$

$$M = \frac{\sigma B_0^2 h^2}{\rho\upsilon},\ m = \frac{T_1^* - T_s^*}{T_0^* - T_s^*},\ n = \frac{C_1^* - C_s^*}{C_0^* - C_s^*},\ R = \frac{hR^*}{v_0},\ U = \frac{U^*}{v_0},\ Q = \frac{hQ^*}{v_0},\ K = \frac{K^*}{h^2} \tag{8}$$

where Gr, Gm, R, Sc, M, Re, R, Ec, F, v_0, μ, Q, K are the thermal Grashof number, Solutal Grashof number, Prandtl number, Schmidt number, Magnetic parameter, Reynolds number, Reaction parameter, Eckert number, Thermal radiation parameter, Constant suction / injection velocity, Dynamic viscosity, Heat source parameter and Porosity parameter .

The governing equations in non-dimensional form are:

$$-\frac{\partial u}{\partial y} = \frac{1}{\mathrm{Re}}\frac{\partial^2 u}{\partial y^2} + Gr\theta + Gm\phi - \frac{u}{\mathrm{Re}\,K} - \frac{Mu}{\mathrm{Re}} \tag{9}$$

$$-\frac{\partial \theta}{\partial y} = \frac{1}{\mathrm{Pr}\,\mathrm{Re}}\frac{\partial^2 \theta}{\partial y^2} + \frac{Ec}{\mathrm{Re}}\left(\frac{\partial u}{\partial y}\right)^2 - \left(Q + F\right)\theta \tag{10}$$

$$-\frac{\partial \phi}{\partial y} = \frac{1}{Sc\,\mathrm{Re}}\frac{\partial^2 \phi}{\partial y^2} - R\phi \tag{11}$$

The corresponding boundary condition in non-dimensional form are reduced to

$$u = 0,\ \ \theta = 1,\ \ \phi = 1 \quad \text{at } y = 0$$
$$u = U,\ \ \theta = m,\ \ \phi = n \ \text{ at } y = 1 \tag{12}$$

SOLUTION OF THE PROBLEM:

The solution of equation (11) subject to the conditions (12) is

$$\phi = A_4 e^{A_1 y} + A_3 e^{A_2 y}$$

In order to solve the dimensionless governing equation (9) and (10), we assume the solution of the following form because Ec ($<<1$ for all the incompressible fluids), therefore solutions of the equations to be of the form:

$$\left.\begin{aligned} u &= u_0(y) + Ecu_1(y) + Ec^2 u_2(y) + \dots\dots\dots \\ \theta &= \theta_0(y) + Ec\theta_1(y) + Ec^2\theta_2(y) + \dots\dots\dots \end{aligned}\right\} \tag{13}$$

Substituting equation (13) into Equation (9- 10), equating coefficients of the terms with the same powers of Ec and neglecting terms of higher order, the following equations were obtained.

Zeroth order terms:

$$u_0'' + \mathrm{Re}\,u_0' - k_1 u_0 = -Gr\,\mathrm{Re}\,\theta_0 - Gm\,\mathrm{Re}\,\phi \tag{14}$$
$$\theta_0'' + \mathrm{Pr}\,\mathrm{Re}\,\theta_0' - \mathrm{Pr}\,\mathrm{Re}(Q+F)\theta_0 = 0 \tag{15}$$

The boundary conditions are:

$$u_0 = 0,\ \ \theta_0 = 1 \quad \text{at } y = 0$$
$$u_0 = 0,\ \ \theta_0 = m \ \text{ at } y = 1 \tag{16}$$

First order terms:

$$u_1'' + \mathrm{Re}\,u_1' - k_1 u_1 = -Gr\,\mathrm{Re}\,\theta_1, \quad \text{where } k_1 = \left(\frac{1}{k} + M\right) \tag{17}$$

$$\theta_1'' + \mathrm{Pr}\,\mathrm{Re}\,\theta_1' - \mathrm{Pr}\,\mathrm{Re}(Q+F)\theta_1 = -\mathrm{Pr}\,u_0'^{\,2} \tag{18}$$

The boundary conditions are:

$$u_1 = 0,\ \ \theta_1 = 0 \quad \text{at } y = 0$$
$$u_1 = 0,\ \ \theta_1 = 0 \quad \text{at } y = 1 \tag{19}$$

By solving equation (14)-(15) and (17)-(18) under the boundary conditions (16) and (19), we get the solution of u_0 , θ_0 u_1 , θ_1 and the solution of the velocity profile and temperature distribution as follows:

$$\begin{aligned} u = {} & D_3e^{D_1y} + D_4e^{D_2y} - k_2e^{B_1y} - k_3e^{B_2y} - k_4e^{A_1y} - k_5e^{A_2y} + Ec(F_3e^{F_1y} + F_4e^{F_2y} - Gr\,\mathrm{Re}\{k_{27}e^{E_1y} \\ & + k_{28}e^{E_2y} - k_{29}e^{2D_1y} - k_{30}e^{2D_2y} - k_{31}e^{2B_1y} - k_{32}e^{2B_2y} - k_{33}e^{2A_1y} - k_{34}e^{2A_2y} - k_{35}e^{(D_1+D_2)y} + k_{36}e^{(D_1+B_1)y} \\ & + k_{37}e^{(D_1+B_2)y} + k_{38}e^{(D_1+A_1)y} + k_{39}e^{(D_1+A_2)y} + k_{40}e^{(D_2+B_1)y} + k_{41}e^{(D_2+B_2)y} + k_{42}e^{(D_2+A_1)y} + k_{43}e^{(D_2+A_2)y} \\ & - k_{44}e^{(B_1+B_2)y} - k_{45}e^{(A_1+B_1)y} - k_{46}e^{(B_1+A_2)y} - k_{47}e^{(A_1+B_2)y} - k_{48}e^{(B_1+A_2)y} - k_{49}e^{(A_1+A_2)y}\}) \end{aligned}$$

$$\begin{aligned} \theta = {} & B_3e^{B_1y} + B_4e^{B_2y} + Ec(E_3e^{E_1y} + E_4e^{E_2y} - k_6e^{2D_1y} - k_7e^{2D_2y} - k_8e^{2B_1y} - k_9e^{2B_2y} - k_{10}e^{2A_1y} - k_{11}e^{2A_2y} \\ & - k_{12}e^{(D_1+D_2)y} + k_{13}e^{(D_1+B_1)y} + k_{14}e^{(D_1+B_2)y} + k_{15}e^{(D_1+A_1)y} + k_{16}e^{(D_1+A_2)y} + k_{17}e^{(D_2+B_1)y} + k_{18}e^{(D_2+B_2)y} + k_{19}e^{(D_2+A_1)y} \\ & + k_{20}e^{(D_2+A_2)y} - k_{21}e^{(B_1+B_2)y} - k_{22}e^{(A_1+B_1)y} - k_{23}e^{(B_1+A_2)y} - k_{24}e^{(A_1+B_2)y} - k_{25}e^{(B_2+A_2)y} - k_{26}e^{(A_1+A_2)y}) \end{aligned}$$

The Physical quantities of interest are the heat transfer rate i.e. the Nusselt number Nu_1 (Moving wall) and Nu_2 (Stationary wall) and mass transfer rate i.e. the Sherwood number Sh_1 (Moving wall) and Sh_2 (Stationary wall) across the channels at the moving wall and the stationary wall are given as

$$Nu_1 = -\frac{x}{(T_0^* - T_s^*)}\left(\frac{\partial T^*}{\partial y^*}\right)_{y=1} \Rightarrow Nu_1 = -\left(\frac{\partial \theta}{\partial y}\right)_{y=1} \text{ and } Nu_2 = -\frac{x}{(T_0^* - T_s^*)}\left(\frac{\partial T^*}{\partial y^*}\right)_{y=0} \Rightarrow Nu_2 = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0}$$

$$Sh_1 = -\frac{x}{(C_0^* - C_s^*)}\left(\frac{\partial C^*}{\partial y^*}\right)_{y=1} \Rightarrow Sh_1 = -\left(\frac{\partial \phi}{\partial y}\right)_{y=1} \text{ and } Sh_2 = -\frac{x}{(C_0^* - C_s^*)}\left(\frac{\partial C^*}{\partial y^*}\right)_{y=0} \Rightarrow Sh_2 = -\left(\frac{\partial \phi}{\partial y}\right)_{y=0}$$

RESULT AND DISCUSSION

In order to get physical insight into the problem, numerical computations for the representative velocity field, temperature field, concentration field and coefficient of the mass transfer in term of Sherwood number respectively at the plate have been carried out for different value of parameter. Figure 1-3 exhibits the velocity profiles against y for different value of radiation parameter F, heat source parameter Q and reaction parameter R. From these figure it is seen that the velocity decreases with increases radiation parameter F, heat source parameter Q and reaction parameter R. It is observed that there is a fall in velocity in presence of high thermal radiation. Figure 4-5 shows that the velocity distribution against y for different value of Schmidt number Sc and Solutal Grashof number Gm. We noticed that the velocity increases with increases Sc and Gm. It is observed in figure 6 that the velocity decreases with an increases Prandtl number $\Pr$. Figure 7-8 demonstrates the effect of Reynolds number Re and Grashof number Gr against y on the velocity field. It is inferred that the velocity increases with an increasing the Reynolds number Re and Grashof number Gr. In figure 9-11 and 13, velocity and temperature profile plotted for different value of M, F, Q, $\Pr$. In these figure it is seen that velocity and temperature decrease with increases M, F, Q, $\Pr$. Figure 12 shows that the velocity increases with increasing Porosity parameter K. The temperature profile for different value of the radiation parameter F are illustrated in figure 10. It is noticed that as the radiation parameter increases, the temperature decreases. This is due to the fact that the divergence of the radiative heat flux increases as ρC_p decreases, which in turn increases the rate of radiative heat, transferred to the fluid. Therefore heat is able to diffuse away from the two infinite vertical porous plates causing the fluid temperature to decrease. Figure 14 display the effect of Gr on the temperature. As the Grashof number increases the temperature increases. In Figure 15-16, the temperature profiles are shown for different values of Porosity parameter K and Reynolds number Re. It is observed that an increase in K leads to a fall in the temperature. Also, the temperature decreases with increases Re. Figure 17-18, depicts dimensionless temperature for various values of Solutal Grashof number Gm and magnetic parameter M when all other parameters that appear in the temperature field are kept constant. We observe that temperature profile increases with increasing Solutal Grashof number Gm and magnetic parameter M. The variation of the concentration distribution C versus y under the influence of chemical reaction parameter R, Reynolds number Re and Schmidt number Sc is presented in the figures 19-21. Physically this show that an increase in Sc causes a decrease in the molecular diffusion D. These figures indicate that the thickness of the concentration boundary layer rises up under the effect of chemical molecular diffusion whereas it drops due to chemical reaction.

Table 1 show the variation of Sherwood number Sh_1 (Moving wall) and Sh_2 (Stationary wall) with different value of Sc, Re and R at $n=1$. Table 1 exhibit how the coefficient of the rate of mass transfer from the plate to the fluid in terms of the Sherwood number Sh is affected by the Schmidt number, Reynolds number and chemical reaction. It is noticed from this table that the variation of Sherwood number Sh_1 and Sh_2 respectively increases and decreases with decrease in Sc and increase in Re, R. Table 2 show the variation of Nusselt number Nu_1 (Moving wall) and Nu_2 (Stationary wall) with different value of Sc, Pr, F Re, R, Gr, Gm and Q at $M=1$, $m=1$, $n=2$, $Ec=0.001$, $K=1$. It is observed from this table that variation of Nusselt number Nu_1 and Nu_2 respectively increases and decreases with an decrease Sc. From this table 2 moving wall Nu_1 decreases with increase in Pr, F, Re, R, Q and decease in Gr, Gm. Similarly stationary wall Nu_2 increases with increase in Pr, F, Q and decease in Gr, Gm. Table 2 show that Nu_2 decreases with increase in Re, R. In the absence of radiation parameter these results are in good agreement with the results of Ahmed *et al.* [1].

CONCLUSION

We summarize below the following results of physical interest on the velocity, temperature and concentration distributions of the flow field and also rate of heat and mass transfer coefficient at the walls:

- The velocity distribution decreased with increased values of radiation parameter, heat source parameter, reaction parameter, magnetic parameter and Prandtl number.
- The velocity distribution increases as parameters of Schmidt number, Solutal Grashof number, Reynolds number, Grashof number, Porosity parameter increases.
- The temperature increases with increasing of Grashof number, Solutal Grashof number and magnetic parameters and decreases with increasing of thermal radiation parameter, heat source parameter, Prandtl number, Reynolds number and porosity parameter.
- The concentration decreased with increasing reaction parameter, Reynolds number and Schmidt number.
- The rate of mass transfer from the plate to the fluid in terms of the Sherwood number increase with the influence of Schmidt number, Reynolds number and chemical reaction.
- The rate of heat transfer from the plate to the fluid in term of Nusselt number increases and decrease with increases and decreses some parameters respectively.
- Our results of present study (in the absence of radiation parameter i.e. $F=0$) agree very well with the results of Ahmed *et al.* [1].

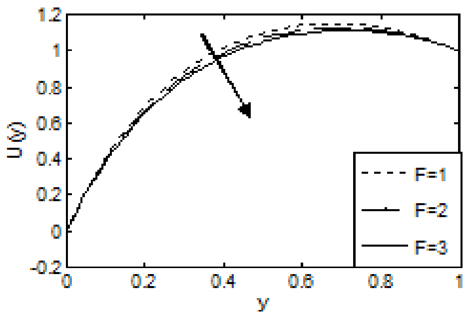

Figure 1: Velocity versus y under F for
$Sc=0.6$, $\mathrm{Re}=2$, $R=2$, $M=2$, $K=1$, $\mathrm{Pr}=.71$, $m=1$, $n=1$,
$Gr=2$, $Gm=2$, $U=1$, $Ec=0.001$, $Q=1$

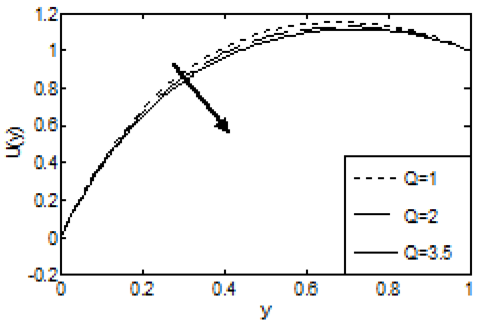

Figure 2: Velocity versus y under Q for
$Sc=0.6$, $\mathrm{Re}=2$, $R=2$, $M=2$, $K=1$, $\mathrm{Pr}=.71$, $m=1$, $n=1$,
$Gr=2$, $Gm=2$, $U=1$, $Ec=0.001$, $F=1$.

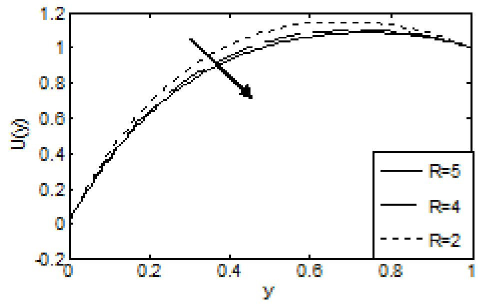

Figure 3: Velocity versus y under R for
$Sc=0.6$, $\mathrm{Re}=2$, $M=2$, $K=1$, $\mathrm{Pr}=.71$, $m=1$, $n=1$, $Q=1$
$Gr=2$, $Gm=2$, $U=1$, $Ec=0.001$, $F=1$.

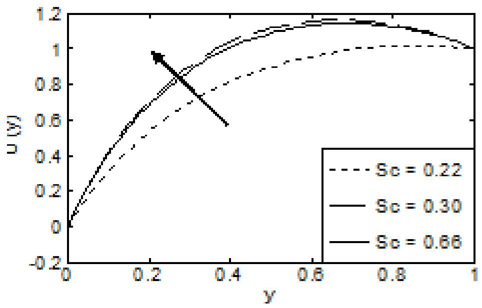

Figure 4: Velocity versus y under Sc for
$F=1$, $\mathrm{Re}=2$, $R=2$, $M=2$, $K=1$, $\mathrm{Pr}=.71$, $m=1$, $n=1$,
$Gr=2$, $Gm=2$, $U=1$, $Ec=0.001$, $Q=1$.

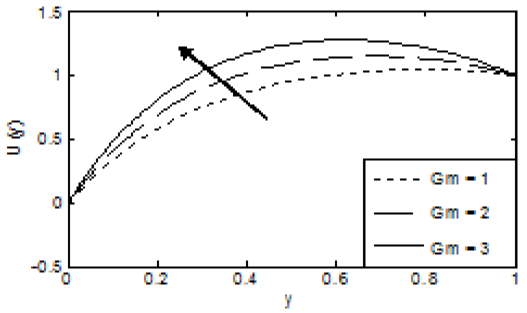

Figure 5: Velocity versus y under Gm for
$Sc = 0.6$, $\mathrm{Re} = 2$, $R = 2$, $M = 2$, $K = 1$, $\mathrm{Pr} = .71$, $m = 1$, $n = 1$,
$Gr = 2, U = 1, Ec = 0.001, Q = 1, F = 1$.

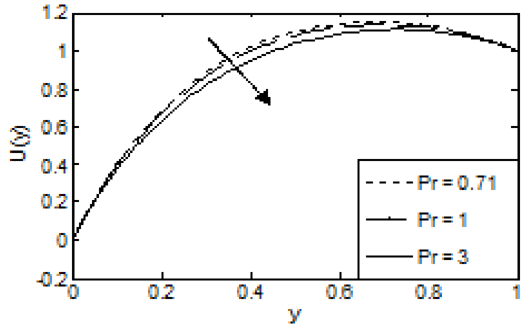

Figure 6: Velocity versus y under Pr for
$Sc = 0.6$, $\mathrm{Re} = 2$, $R = 2$, $M = 2$, $K = 1$, $m = 1$, $n = 1$, $F = 1$
$Gr = 2$, $Gm = 2, U = 1, Ec = 0.001, Q = 1$.

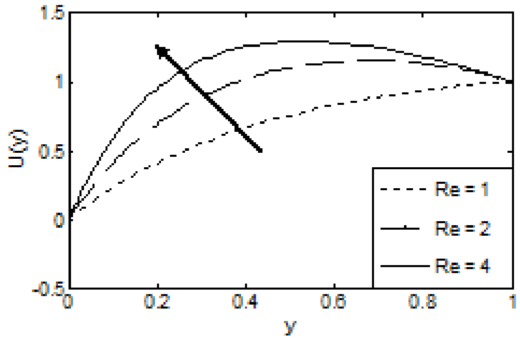

Figure 7: Velocity versus y under Re for
$Sc = 0.6$, $R = 2$, $M = 2$, $K = 1$, $\mathrm{Pr} = .71$, $m = 1$, $n = 1$, $F = 1$
$Gr = 2$, $Gm = 2, U = 1, Ec = 0.001, Q = 1$.

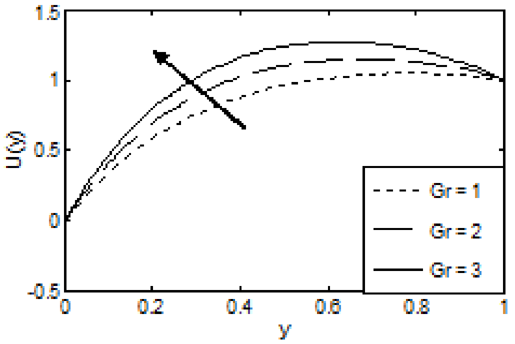

Figure 8: Velocity versus y under Gr for
$Sc = 0.6$, $\mathrm{Re} = 2$, $R = 2$, $M = 2$, $K = 1$, $\mathrm{Pr} = .71$, $m = 1$, $n = 1$,
$Gm = 2, U = 1, Ec = 0.001, Q = 1, F = 1$.

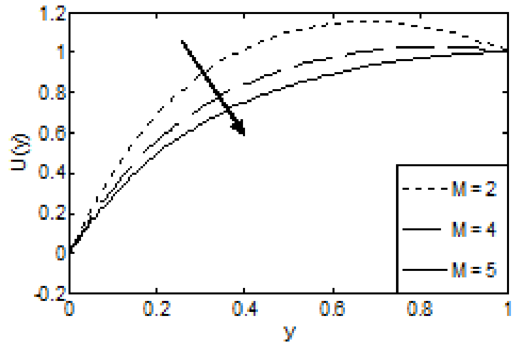

Figure 9: Velocity versus y under M for
$Sc = 0.6$, $\mathrm{Re} = 2$, $R = 2$, $K = 1$, $\mathrm{Pr} = .71$, $m = 1$, $n = 1$, $F = 1$
$Gr = 2$, $Gm = 2, U = 1, Ec = 0.001, Q = 1$.

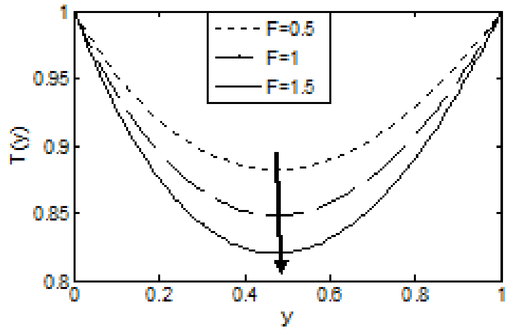

Figure 10: Temperature y under F
$Sc = 0.6$, $\mathrm{Re} = 1$, $R = 1$, $M = 1$, $K = 1$, $\mathrm{Pr} = .71$, $m = 1$, $n = 2$,
$Gr = 1, Gm = 1, U = 1, Ec = 0.001, Q = 1$.

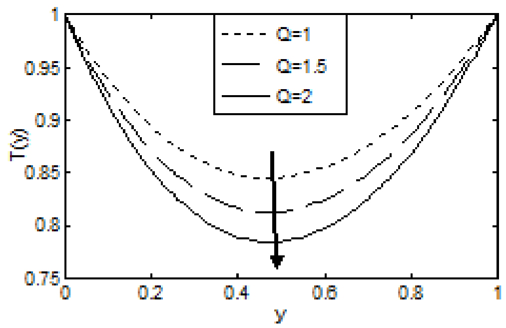

Figure 11: Temperature versus y under Q for
$Sc = 0.6$, $\mathrm{Re} = 1$, $R = 1$, $M = 1$, $K = 1$, $\mathrm{Pr} = .71$, $m = 1$, $n = 2$,
$Gr = 1, Gm = 1, U = 1, Ec = 0.001, F = 1$.

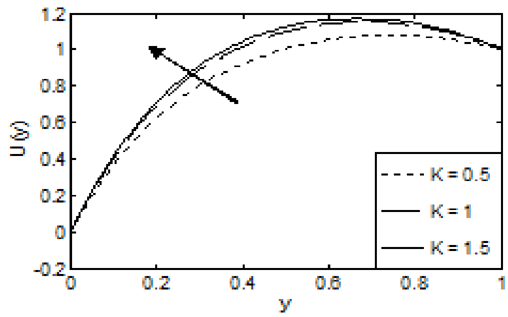

Figure 12: Velocity versus y under K for
$Sc = 0.6$, $\mathrm{Re} = 2$, $R = 2$, $M = 2$, $\mathrm{Pr} = .71$, $m = 1$, $n = 1$, $F = 1$
$Gr = 2$, $Gm = 2, U = 1, Ec = 0.001, Q = 1$.

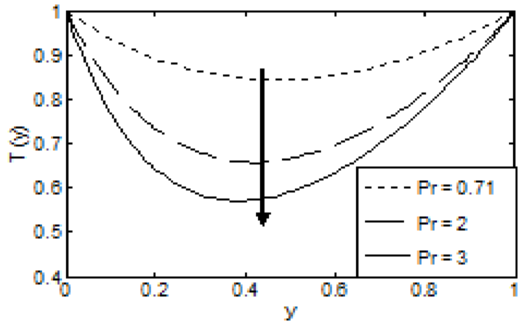

Figure 13: Temperature versus y under Pr for
$Sc = 0.6$, $\mathrm{Re} = 1, R = 1, M = 1, K = 1, m = 1, n = 2, F = 1$
$Gr = 1, Gm = 1, U = 1, Ec = 0.001, Q = 1.$

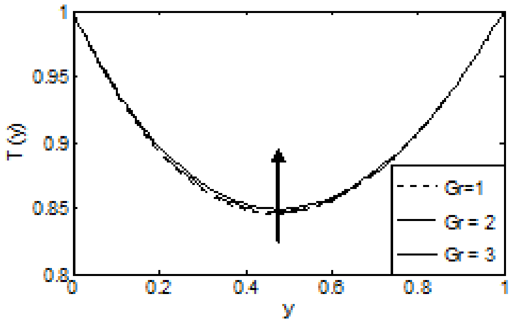

Figure 14: Temperature versus y under Gr for
$Sc = 0.6$, $\mathrm{Re} = 1, R = 1, M = 1, K = 1, m = 1, n = 2, F = 1$
$\mathrm{Pr} = 0.71, Gm = 1, U = 1, Ec = 0.001, Q = 1.$

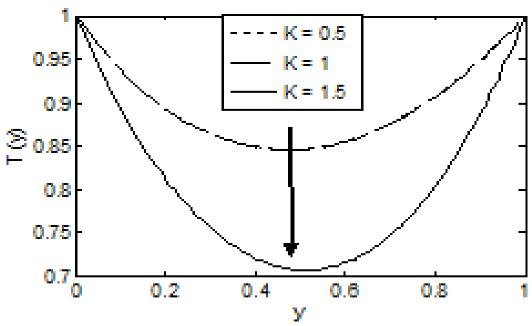

Figure 15: Temperature versus y under K for
$Sc = 0.6$, $\mathrm{Pr} = 0.71$, $\mathrm{Re} = 1, R = 1, M = 1, m = 1, n = 2, F = 1$
$Gr = 2, Gm = 2, U = 1, Ec = 0.001, Q = 1.$

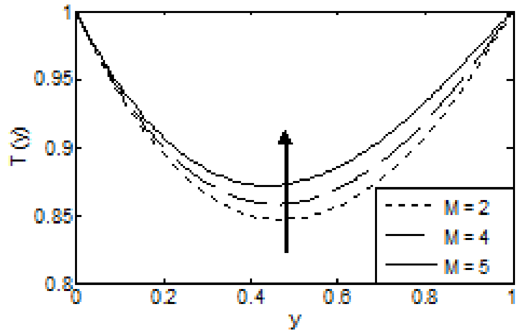

Figure 18: Temperature versus y under M for
$Sc = 0.6$, $\mathrm{Pr} = 0.71$, $\mathrm{Re} = 1, R = 1, K = 1, m = 1, n = 2, F = 1$
$Gr = 1, Gm = 1, U = 1, Ec = 0.001, Q = 1.$

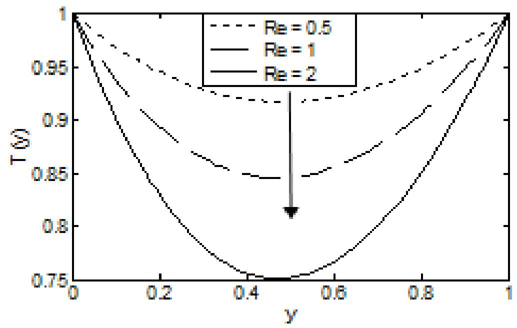

Figure 16: Temperature versus y under Re for
$Sc = 0.6$, $\mathrm{Pr} = 0.71$, $R = 1, M = 1, K = 1, m = 1, n = 2, F = 1$
$Gr = 1, Gm = 1, U = 1, Ec = 0.001, Q = 1.$

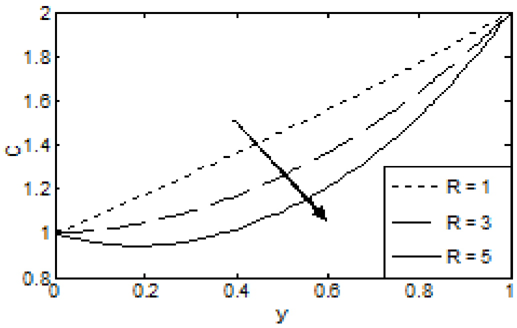

Figure 19: Concentration versus y under R for
$Sc = 0.66, \mathrm{Re} = 1, n = 2.$

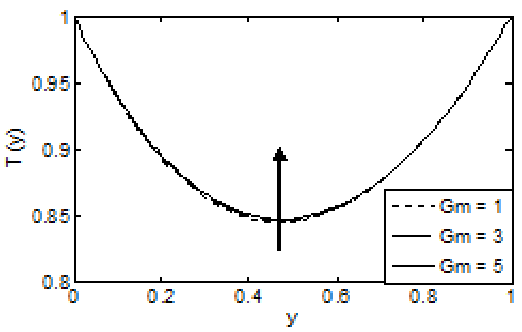

Figure 17: Temperature versus y under Gm for
$Sc = 0.6$, $\mathrm{Pr} = 0.71$, $R = 1, M = 1, K = 1, m = 1, n = 2, F = 1$
$Gr = 1, \mathrm{Re} = 1, U = 1, Ec = 0.001, Q = 1.$

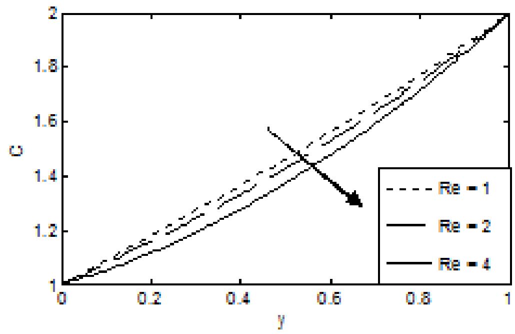

Figure 20: Concentration versus y under Re for
$Sc = 0.66, \mathrm{R} = 1, n = 2.$

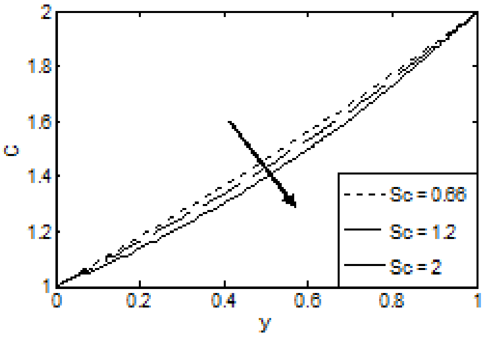

Figure 21: Concentration versus y under Sc for $R = 1, \mathrm{Re} = 1, n = 2.$

Table-1: Variation of Sherwood number Sh_1 (Moving wall) and Sh_2 (Stationary wall) with different value of Sc, Re and R at $n = 1$

Sc	Re	R	Sh_1	Sh_2
0.66	**1**	**1**	**-0.2796**	**0.3466**
0.30	**1**	**1**	**-0.1391**	**0.1536**
0.66	**2**	**1**	**-0.4747**	**0.7200**
0.66	**1**	**2**	**-0.5338**	**0.6587**

Table-2: Variation of Nusselt number Nu_1 (Moving wall) and Nu_2 (Stationary wall) with different value of Sc, Pr, F Re, R, Gr, Gm and Q at $M = 1$, $m = 1$, $n = 2$, $Ec = 0.001$, $K = 1$.

Sc	Pr	F	Re	R	Gr	Gm	Q	Nu_1	Nu_2
0.66	**0.71**	**1**	**1**	**1**	**2**	**2**	**1**	**-0.5654**	**0.6910**
0.30	**0.71**	**1**	**1**	**1**	**2**	**2**	**1**	**-0.5637**	**0.6875**
0.66	**2**	**1**	**1**	**1**	**2**	**2**	**1**	**-1.0929**	**1.9978**
0.66	**0.71**	**2**	**1**	**1**	**2**	**2**	**1**	**-0.7918**	**0.8818**
0.66	**0.71**	**1**	**2**	**1**	**2**	**2**	**1**	**-0.9373**	**0.1638**
0.66	**0.71**	**1**	**1**	**2**	**2**	**2**	**1**	**-0.5707**	**0.6899**
0.66	**0.71**	**1**	**1**	**1**	**1**	**2**	**1**	**-0.5681**	**0.7088**
0.66	**0.71**	**1**	**1**	**1**	**2**	**1**	**1**	**-0.5665**	**0.6985**
0.66	**0.71**	**1**	**1**	**1**	**2**	**2**	**2**	**-0.7918**	**0.8818**

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