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CHEMICAL REACTION EFFECTS ON MHD FREE CONVECTION HEAT AND MASS TRANSFER FLOW THROUGH A POROUS MEDIUM BOUNDED BY TWO VERTICAL WALLS IN THE PRESENCE OF RADIATION

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Abstract: *The present paper analyzes the effect of chemical reaction on free convective magneto hydrodynamic (MHD) flow of steady, laminar, incompressible fluid between two vertical walls filled with porous materials. The flow passes through an exponential radiative stretching sheet in the presence of magnetic field. The governing PDE of the fluid flow are solved using perturbation technique. Approximate solutions are derived for velocity, temperature and concentration field. The influences of various physical parameters on velocity, temperature, and solutal concentration profiles are presented through graphs and the numerical computation of physical quantities such as skin friction coefficient, Sherwood number, Nusselt number are presented and discussed.*

1.1 Introduction

Problems involving Magneto Hydrodynamics (MHD) are very important in many fields such as geophysical and astrophysical problems, plasma studies, nuclear reactors, geothermal energy extractions and the boundary layer control in the field of aerodynamics. The possible usage of MHD is effect a flow stream of an electrically conducting fluid for the purpose of thermal production, braking, propulsion and control. The effects of Magnetic field on free convection flow problems have been attracted by many investigators [6-8]. Chemical reactions can be codified as either heterogeneous or homogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction. In well-mixed systems, the reaction is heterogeneous, if it takes place at an interface and homogeneous, if it takes place in solution. In most cases of chemical reactions, the reaction rate depends on the concentration of the species itself.

Chemical reaction have plentiful industrial applications such as several engineering, industrial, astrophysical and geophysical application, such as polymer production, manufacturing of ceramic, packed-bed catalytic reactors, enhanced oil recovery, food processing, underground energy transport, cooling of nuclear reactors, high-speed plasma wind, magnetized plasma flow, cosmic jets and stellar systems. A clear understanding of the nature of interaction between thermal and concentration buoyancies is necessary to control these processes. Anjali Devi and Kandasamy2000 investigated the effects of chemical reaction heat and mass transfer on MHD flow past a semi-infinite plate. Chamkha. J Ali, (2004)studied "heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption Kandaswamy.R , Periasamy K, SivagnanaPrabhu KK (2005), studied Chemical reaction, heat and mass transfer on MHD flow over a vertical stretching surface with heat source and thermal stratification effects. Murti et al 2005, studied the Radiation, chemical reaction, Double dispersion effects on Heat and mass transfer in non-Newtonian fluids. Muthukumaraswamy 2010 studied Chemical Reaction Effects on Vertical Oscillating Plate with Variable Temperature.

Radiation heat transfer is ubiquitous, because all matter emits and absorbs electromagnetic radiation. Theelectromagnetic radiation spectrum is huge, but heat transfer is mostly concerned with a small part of it,called thermal radiation. Thermal radiation effect plays a significant role in controlling heat transfer procession polymer processing industry. The quality of the final product depends to a certain extent on heat controllingfactors. Also, the effects of thermal radiation on flow and heat transfer processes are important in thedesign of many advanced energy convection systems which operate at high temperature. Thermal radiationoccurring within these systems is usually the result of emission by the hot walls and the working fluid.Thermal radiation effects become more important when the difference between the surface and the ambienttemperature is large. Thus thermal radiation is one of the vital factors controlling the heat and mass transfer.The knowledge of radiation heat transfer in the system can perhaps lead to a desired product with soughtcharacteristics. Pal 2009, analyzed heat and mass transfer in two - dimensional stagnation-point flow of anincompressible viscous fluid over a stretching vertical sheet in the presence of buoyancy force and thermalradiation. Pal and Mondal 2009, studied the influence of temperature - dependent viscosity and thermal radiation on MHD forced convection over a non-isothermal wedge.

1.2 Mathematical formulation

We have considered a two dimensional steady flow of a laminar free convective incompressible electrically conducting fluid past an infinite vertical porous plate, embedded in a porous medium in the presence of thermal radiation and a homogeneous chemicalreaction. A uniform magnetic field of strength B_0 is applied perpendicular to the plate. Let h be the distance between the plates. It is assumed that there is applied voltage which results the absence of electric field. The transversely applied magnetic field and magnetic Reynolds number are assumed to be very small so that the induced magnetic field and Hall currents are negligible [6]. The suction velocity is assumed in the form $v = -v_0$, where v_0 is the constant suction /injection.

$$\frac{\partial v}{\partial y} = 0 \tag{1.1}$$

$$v\frac{\partial u}{\partial y} = v\frac{\partial^2 u}{\partial y^2} + g\beta(T - T_\infty) + g\beta^*(\mathrm{C} - C_\infty) - \left(\frac{\sigma B_0^2}{\rho}\right)u + \left(\frac{v}{k}\right)u \tag{1.2}$$

$$v\frac{\partial T}{\partial y} = \frac{\lambda}{\rho C_P}\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho C_P}\frac{\partial q_r}{\partial y} - \frac{Q_0}{\rho C_P}(T - T_\infty) + \mathrm{Q}_l'(C - C_\infty) \tag{1.3}$$

$$v\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} - Kr'(C - C_\infty) \tag{1.4}$$

Where u and v are the velocity components along and perpendicular to the surface, g is the acceleration due to gravity, T the temperature of the fluid near the plate, T_∞ the free stream temperature, C concentration, β the coefficient of thermal expansions , $\beta^*$the volumetric coefficient of expansion of the spices concentration, k the thermal conductivity, $C_p$the specific heat of constantpressure, $B_0$the magnetic field coefficient, μ viscosity of the fluid, the density, σ the magnetic permeability of fluid , V_0 constant suction velocity, v the kinematic viscosity and D chemical molecular diffusivity.

The relevant boundary conditions are

$$u = 0, \quad \theta = 1, C = 1 \quad \text{at} \quad y = 0$$

$$u = 0, \quad \theta = 0, C = 0 \quad \text{at} \quad y = 1 \tag{1.5}$$

$$v = -v_0 \text{ constant}.$$

Where $v_0 > 0$ corresponds to steady suction velocity normal.

The local radiant for the case of an optically thin gray gas is expressed by

$$\frac{\partial q_r}{\partial y} = -4\alpha^* \sigma (T_\infty^4 - T^4) \tag{1.6}$$

It is assume that the temperature differences within the flow are sufficiently small such that T^4may be expressed as a linear function of the temperature. This is accomplished by expanding T^4in a Taylor series about T_∞ and neglecting higher-order terms, thus

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \tag{1.7}$$

By using equations (1.6) and (1.7), equation (1.3) reduces to

$$-v_0 \frac{\partial T}{\partial y} = \frac{\lambda}{\rho C_P} \frac{\partial^2 T}{\partial y^2} + 16a^* \sigma T_\infty^3 (T - T_\infty) - \frac{Q_0}{\rho C_P} (T - T_\infty) + Q_l'(C - C_\infty) \tag{1.8}$$

We introduce the following non-dimensional quantities

$$u = \frac{u^*}{v_0},\ y = \frac{v_0 y^*}{v},\ M = \frac{\sigma B_0^2 v}{v_0^2 \rho},\ \theta = \frac{(T - T_\infty) v_0 \lambda}{qv},\ \Pr = \frac{\mu C_P}{\lambda}$$

$$\alpha = \frac{V_0^2 K}{v^2},\ C = \frac{(C - C_\infty) v_0 D}{mv},\ Gr = \frac{\rho \beta g v^2 (T_W - T_\infty)}{v_0^3 \mu}, \quad Gc = \frac{\rho \beta g (C - C_\infty)}{v_0^3}$$

$$Sc = \frac{v}{D}, \quad Kr = \frac{Kr' mv}{DV_0^2},\ Q_0 = \frac{\phi V_0^2 \rho C_P}{v}, \quad Q_l' = \frac{QqV_0^2 D}{mv\lambda},\ R = \frac{16\alpha v^2 \sigma T_\infty^3}{kv_0^2} \tag{1.9}$$

WhereGr is Grashof number, Pr is Prandtl number, M is Magnetic number, $Sc$is Schmidt number, Kr is Chemical reaction parameter, Q_l s heat absorption parameter, ϕ is heat source parameter, and R Radiation parameter where q is the heat flux term per unit area and m is the mass flux per unit area.

We get

$$-\frac{\partial u}{\partial y}=\frac{\partial^2 u}{\partial y^2}+Gr\theta+GcC-(\alpha^{-1}+M)u \tag{1.10}$$

$$-\frac{\partial \theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2}-R\theta-\theta\phi-Q_l C \tag{1.11}$$

$$-\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2 c}{\partial y^2}-KrC \tag{1.12}$$

Subject to the boundary conditions

$$u=0,\quad \theta=1,\ C=1 \quad \text{at} \quad y=0$$

$$u=0,\quad \theta=0,\ C=0 \quad \text{at} \quad y=1 \tag{1.13}$$

1.3 Solution of the problem

In order to solve the set partial differential equations (1.10) to (1.12) in non-dimensional form subject to boundary conditions, we assumed the velocity, temperature and concentration in a series expansion in powers of E where E<<1 as given below.

$$u(y)=u_0(y)+Eu_1(y)+O(\varepsilon^2) \tag{1.14}$$

$$\theta(y)=\theta_0(y)+E\theta_1(y)+O(\varepsilon^2)$$

$$C(y)=C_0(y)+EC_1(y)+O(\varepsilon^2)$$

Substituting equations (1.14) into equations (1.10) to (1.12) and equating the coefficient of similar powers of E and neglecting the higher powers of E, we obtain the following ordinary differential equations for (u_0, θ_0,C_0) and

(u_1 ,θ_1 , C_1).

$$u_0''+u_0'-(\alpha^{-1}+M)u_0=-Gr\theta_0-GcC_0 \tag{1.15}$$

$$\theta_0''+\Pr\theta_0'-\Pr(R+\phi)\theta_0=\Pr Q_l C_0 \tag{1.16}$$

$$C_0''+ScC_0'-KrScC_0=0 \tag{1.17}$$

$$u_1''+u_1'-(\alpha^{-1}+M)u_1=-Gr\theta_1-GcC_1 \tag{1.18}$$

$$\theta_1'' + \Pr\theta_1' - \Pr(R+\phi)\theta_1 = \Pr Q_l C_1 \tag{1.19}$$

$$C_1'' + ScC_1' - KrScC_1 = 0 \tag{1.20}$$

and the corresponding boundary conditions are

$$u_0 = 0, \quad u_1 = 0 \quad , \quad \theta_0 = 1 \, , \quad \theta_1 = 0 \, , C_0 = 1 \, , C_1 = 0 \quad \text{at} \quad y = 0$$

$$u_0 = 0, \quad u_1 = 0 \, , \quad \theta_0 = 0 \, , \quad \theta_1 = 0 \, , C_0 = 0 \, , C_1 = 0 \quad \text{at} \quad y = 1 \tag{1.21}$$

Solving equations (1.15) to (20).with the help of (1.21)., we get

$$u_0 = P_6 e^{m_5 y} + P_5 e^{-m_6 y} + P_1 e^{m_3 y} + P_2 e^{-m_4 y} + P_3 e^{m_1 y} + P_4 e^{-m_2 y}$$

$$u_1 = 0$$

$$\theta_0 = B_4 e^{m_3 y} + B_3 e^{-m_4 y} + A_1 e^{m_1 y} + A_2 e^{-m_2 y}$$

$$\theta_1 = 0$$

$$C_0 = B_1 e^{m_1 y} + B_2 e^{-m_2 y}$$

$$C_1 = 0$$

$$u(\mathrm{y}) = P_6 e^{m_5 y} + P_5 e^{-m_6 y} + P_1 e^{m_3 y} + P_2 e^{-m_4 y} + P_3 e^{m_1 y} + P_4 e^{-m_2 y}$$

$$\theta(y) = B_4 e^{m_3 y} + B_3 e^{-m_4 y} + A_1 e^{m_1 y} + A_2 e^{-m_2 y}$$

$$C(y) = B_1 e^{m_1 y} + B_2 e^{-m_2 y}$$

The skin-friction coefficient, the Nusselt number and the Sherwood number near the plate, are important physical parameters for this type of boundary-layer flow. These parameters can be defined and determined as follows:
The skin-friction coefficient at the plate is given by

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = m_5 P_6 - m_6 P_5 + m_3 P_1 - m_4 P_2 + m_1 P_3 - m_2 P_4$$

The rate of heat transfer in terms of Nusselt number at the plate is given by

$$Nu = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = m_3 B_4 - m_4 B_3 + m_1 A_1 - m_2 A_2$$

The Sherwood number at the plate is given by

$$Sh = \left(\frac{\partial C}{\partial y}\right)_{y=0} = m_1 B_1 - m_2 B_2$$

1.4 Results and Discussions

The numerical values of the velocity, temperature, concentration, Skin friction, Nusselt number and Sherwood number are computed for different values of physical parameters like magnetic parameter (M), radiation parameter (R) ,chemical reaction (Kr) the effects of these parameters on flow quantities are studied through graphs 1.1-1.16.

Figure 1.1plotsthevelocity profiles againstthespan- wise coordinate*y* for different magnetic field parameter *M*. this illustrates that velocity decreases astheexistence of magnetic field becomes stronger. Thisconclusion agreeswith thefactthatmagneticfieldexerts retarding forceonthefree- convectionflow.

From figure 1.2 it isseen, that the velocity decreases with increasing the Chemical reaction parameter Kr.

Figure 1.3 illustrates the dimensionless velocity*u*for different values of the Pran dtl number *Pr*. The analytical results show that the effect of increasing values of Prandtl number results in a decreasingvelocity.It is observed from Figure 1.4 that an increase in Grashof number for heat transfer Gr leads to a rise in the values of velocity u due to enhancement in buoyancy force. The plot of velocity profile for different values of Grashof number for mass transfer GC is given in Figure 1.5. It is observed that velocity increase for the increasing values of Grashof number for mass transfer Gc.

The effect of the Radiation parameter *R* on the dimensionless velocity *u* is shown in Figure.6. Figure1.6shows that velocity component decreases with an increase in the radiation parameter*R*. The influence of the Schmidt number *Sc*on velocity profiles are plotted in Figure 1.7.TheSchmidt number *Sc*embodiesthe ratio of the momentum to the mass diffusivity. It is noticed that as the Schmidt number *Sc* increases the velocity decreases. This causes theconcentration buoyancyeffects to decrease yielding a reduction in the fluid velocity.

Figure 1.8 depictsthedimensionless velocity component *u*profilesfordifferentvaluesofheatsink parameter*Ql*.Itisnoticed thatanincrease intheheat sink parameter*Ql*resultsindecreaseinthedimensionless velocity component u within the boundary layer.

The concentration profiles for different values of Schmidt number *Sc* are plotted in Figure 1.11.ForSchmidt number Sc, the value0.6 correspondstowatervaporand represents a diffusing chemicalspecies of most common interest in air. The analytical results show that the effect of increasing Schmidt number in air and water results in a decreasing concentration distribution across the boundary layer. Theresults alsoindicate thattheeffect onSchmidt numberonthevelocityandconcentration ismoreinwateras comparedtothatinair

Figure 1.12displays thattheconcentration decreases with increasing the Chemical reaction parameter Kr.

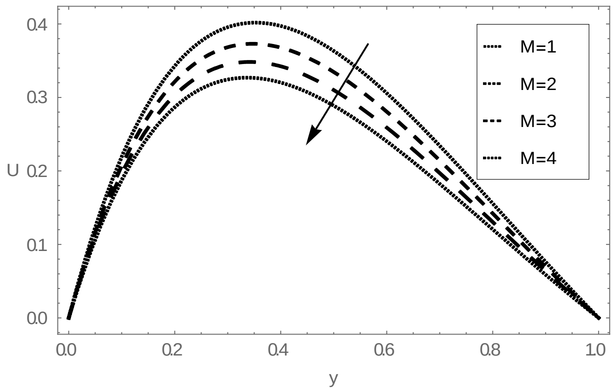

Fig.1.1 Velocity profiles for various values of M

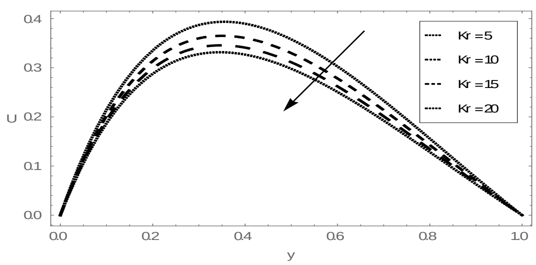

Fig.1.2Velocity profiles for various values of Kr

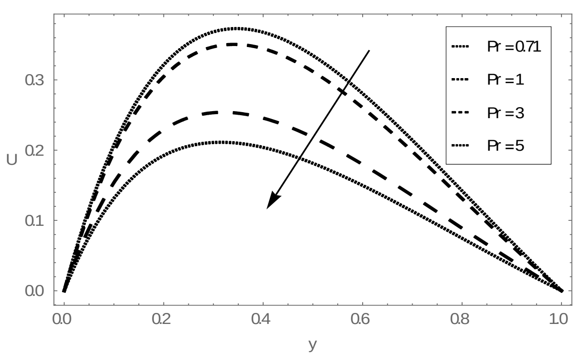

Fig.1.3Velocity profiles for various values of Pr

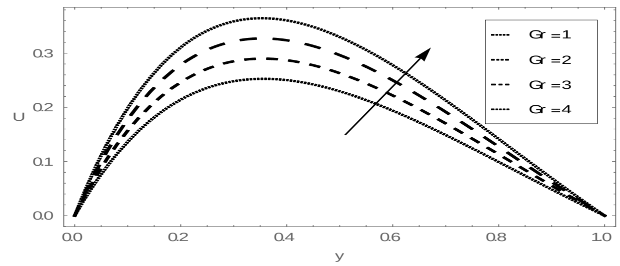

Fig.1.4Velocity profiles for various values of Gr

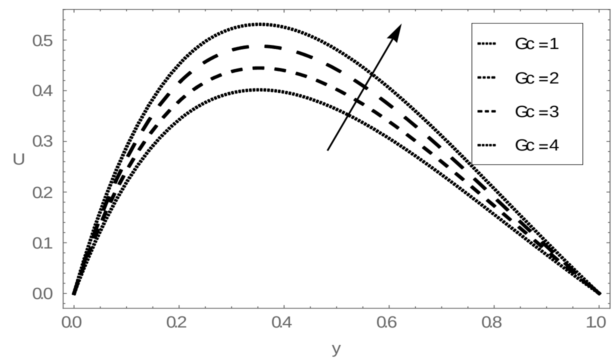

Fig.1.5Velocity profiles for various values of Gc

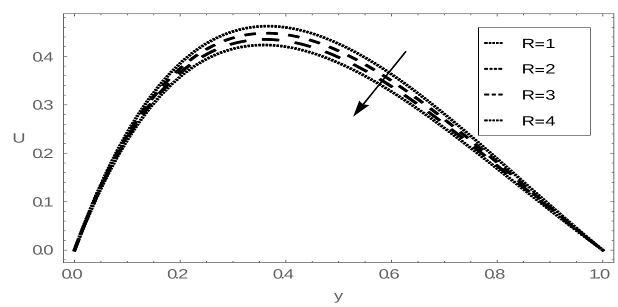

Fig.1.6Velocity profiles for various values of R

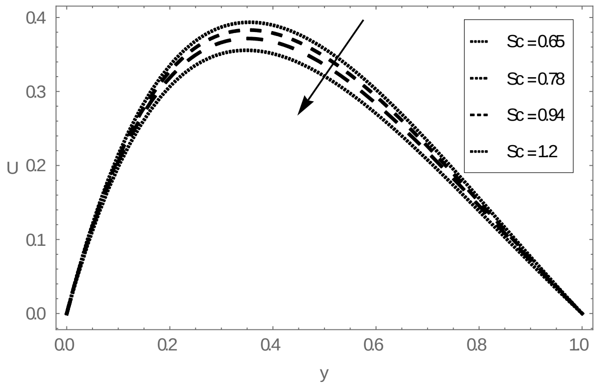

Fig.1.7Velocity profiles for various values of Sc

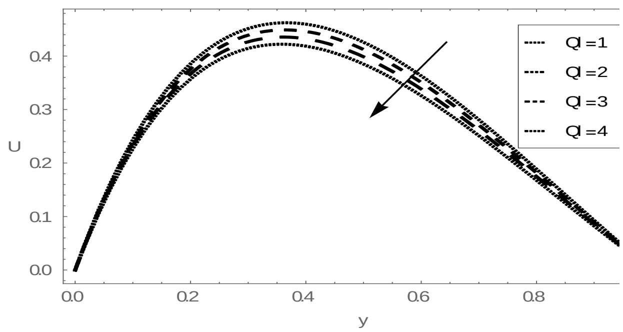

Fig.1.8Velocity profiles for various values of Q_l

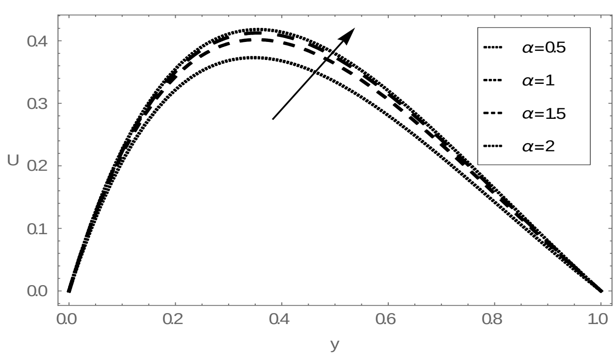

Fig.1.9Velocity profiles for various values of α

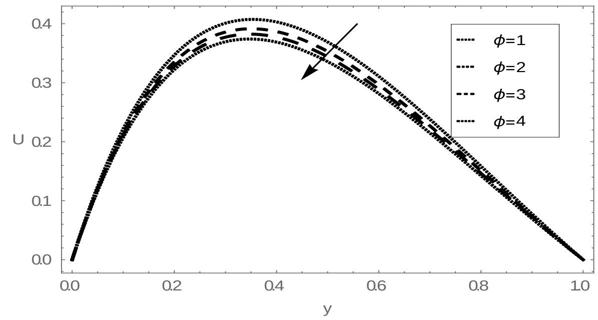

Fig.1.10Velocity profiles for various values of ϕ

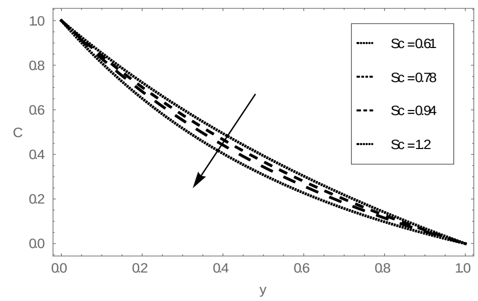

Fig1.11concentration profiles for various values of Sc

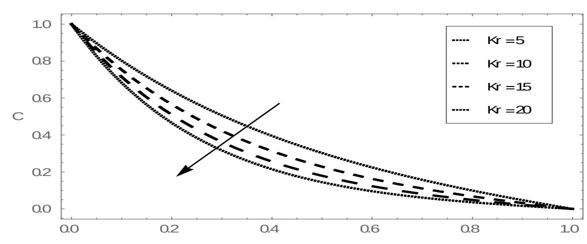

Fig.1.12concentration profiles for various values of Kr

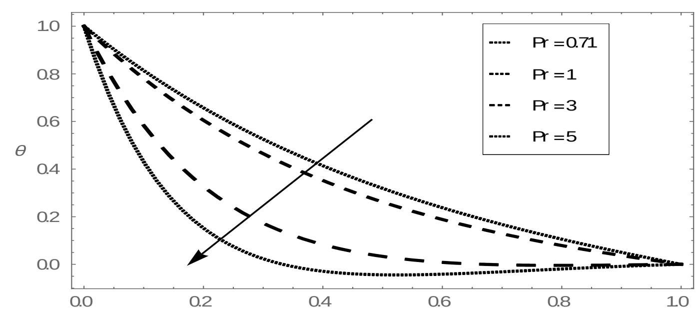

Fig 1.13 Temperature profiles for various values of Pr

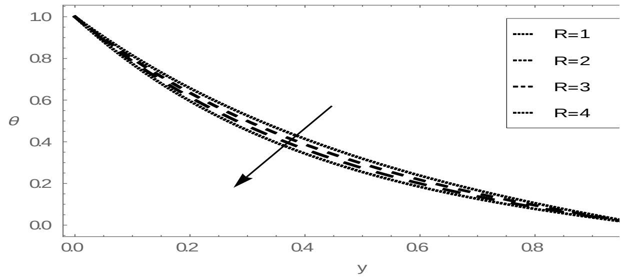

Fig.1.14 Temperature profiles for various values of R

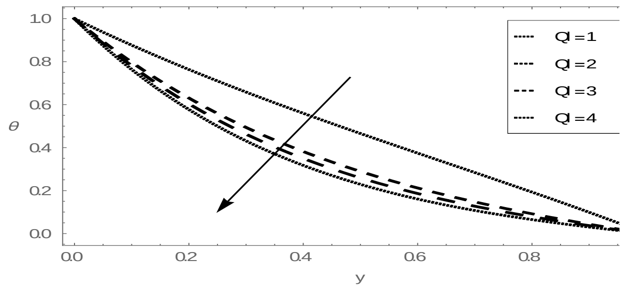

Fig.1.15 Temperature profiles for various values of Q1

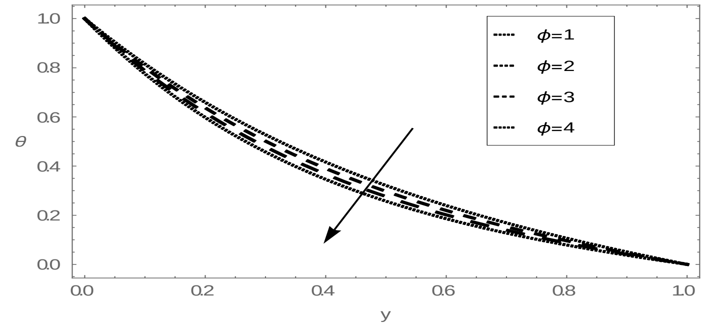

Fig1.16 Temperature profiles for various values of ϕ

Fromfigure1.13.itisobservedthatanincreaseinthe Prandtl number resultsadecrease ofthethermal boundary layerthickness andingeneralloweraveragetemperature withinthe boundarylayer.The reasonisthat smaller values of *Pr*areequivalentto increasing the thermal conductivities, and therefore heat is able to diffuse away from the heated plate morerapidly than for higher values of *Pr*. Hence in the case of smaller Prandtlnumbers as the boundary layer is thicker andtherate of heat transfer is reduced.

Figure 1.14showsthevariationoftemperatureprofiles with respect to the radiation parameter*R*. From this figure, it is observed that as temperature decreases for the increasing values of radiation parameter *R*. This resultqualitatively agreeswithexpectations, sincetheeffectofradiationisto decreasethe rate ofenergytransportto thefluid,thereby decreasingthetemperatureofthefluid. The influence of the parameter heats in kon dimensionless temperature profiles θ isplottedinFigure1.15. Itisnoticedthatdimensionlesstemperaturedecreaseswithan increaseinheat sinkparameter*Ql*.

Table 1.1-1.5 show the effects of the thermal Grashof number , radiation parameter, chemical reaction parameter, the Schmidt number and magnetic parameter on skin friction Cf,theNusselt number Nu, and Sherwood number Sh. From table 1.1 it is observed that as Gr increased skin friction increased. From table 1,2 it can be easily seen that as radiation parameter increases radiation parameter increases, the skin friction decreases and nusselt number decreases from table 1,3 it is noticed that as Kr increases the skin friction decreases and the Sherwood number decreases.From table 1.4 it is observed that as Schmidt number increases the skin friction and Sherwood number decreases. Finally table 1.5 shows that as M increases the skin friction decreases.

Table 1.1 Effects of Gr on skin friction

Gr	**Cf**
1	**1.71797**
2	**1.9828**

3	**2.24764**
4	**2.51247**

Table 1.2 Effects of radiation on skin friction and Nusselt number

R	**Cf**	**Nu**
1	**2.77465**	**-2.03112**
2	**2.72817**	**-2.21323**
3	**2.6864**	**-2.38345**
4	**2.64861**	**-2.54346**

Table 1.3 Effects of Kr on skin friction and Sherwood number

Kr	**Cf**	**Sh**
5	**2.60269**	**-2.18318**
10	**2.45868**	**-2.82813**
15	**2.35769**	**-3.35917**
20	**2.28196**	**-3.81746S**

Table 1.4 Effects of Sc on skin friction and Sherwood number

Sc	**Cf**	**Sh**
0.66	**2.77465**	**-2.27064**
0.78	**2.74324**	**-2.47614**
0.94	**2.70254**	**-2.74145**
1.2	**2.63933**	**-3.115464**

Table 1.5 Effects of M on skin friction

M	**Cf**
1	**2.77731**
2	**2.64626**
3	**2.52998**
4	**2.42986**

1.5. Conclusions

The governing equations for MHD free convection flow through porous medium bounded by two vertical porous plates in presence of radiationand chemical reaction is formulated. The resulting partial differential equations were transformed into a set of ordinary differential equations using a two term series and solved in closed form. Numerical computations of the closed form results are performed and some graphical results were obtained to illustrate the details of the flow and heat and mass transfer characteristics and their dependence on some of the physical parameters. It is found that velocity decreases with the increase in M, Kr and Pr. Temperature decreases with the increasing values of Pr. However concentration decreases with an increase in Kr.

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