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Chemical Reaction and Radiation Effects on MHD Free Convection Flow past an Exponentially Accelerated Vertical Porous Plate

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Abstract

The present work investigated the effects of chemical reaction and radiation on MHD flow past an exponentially accelerated vertical plate through porous medium in presence of heat generation/absorption. The flow is assumed to be in x-direction which is taken along the infinite vertical plate in upward direction and y-axis is taken normal to the plate and the plate is exponentially accelerated with velocity$u = u_0 e^{at}$. A uniform magnetic field applied normal to the flow. The dimensionless governing equations are unsteady and non linear partial differential equations. The solutions of governing equations are obtained by using perturbation technique. The effects of chemical reaction (Kr), Magnetic parameter (M), radiation parameter (F) on the velocity, temperature and concentration fields are discussed with the help of graphs.

Keywords: *MHD*, *Heat generation/absorption, Radiation, Chemical reaction, porous medium.*

1. Introduction

The phenomenon of free convection arises in the fluid when temperature changes cause density variation leading to buoyancy forces acting on the fluid elements. Free convection flow involving heat transfer occurs frequently in an environment where difference between land and air temperature can give rise to complicated flow patterns. Gupta *et al.* [1] studied free convection effects on the flow past an accelerated vertical plate in an incompressible dissipative fluid. Kafousias*et al.* [2] obtained mass transfer and free convection effects on the flow past an accelerated vertical infinite plate with variable suction or injection. Singh *et al.* [3] studied free convection flow past an exponentially accelerated vertical plate. Soundalgekar*et al.* [4] discussed mass transfer effects on the flow past an impulsively started infinite vertical plate with variable temperature or constant heat flux. Hossain *et al.* [5] analyzed the Skin friction in the unsteady free convection flow past an accelerated plate. Jha*et al.* [6] are presented mass transfer effects on the flow past an exponentially accelerated vertical plate with constant heat flux. Jha B.K [7] was studied MHD free-convection and mass transfer flow through a porous medium. Kim [8] examined unsteady MHD convective Heat transfer past a semi-infinite vertical porous moving plate with variable suction. Chamkha A. J. [9] was studied unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption. Muthucumaraswamy*et al.* [10] investigated Mass transfer effects on exponentially accelerated isothermal vertical plate.Ramana Reddy et al.[11] obtained MHD flow over a vertical moving porous plate with heat generation by considering double diffusive convection. M. C. Raju*et al.* [12] discussed analytical study of MHD free convictive, dissipative boundary layer flow past a porous vertical surface in the presence of thermal radiation, chemical reaction and constant suction. M. C.

Rajuet *al.* [13] analyzed Soret effects due to natural convection in a non-Newtonian fluid flow in porous medium with heat and mass transfer.Ramana Reddyet *al.*[14] are studied Siimilarity transformation of heat and mass transfer effects on steady MHD free convection dissipative fluid flow past an inclined porous surface wih chemical reaction. B. Mamathaet *al.* [15] are examined thermal diffusion effect on MHD mixed convection unsteady flow of a micro polar fluid past a semi-infinite vertical porous plate with radiation and mass transfer. Theoretical investigation of an unsteady MHD free convection heat and mass transfer flow of a non-Newtonian fluid flow past a permeable moving vertical plate in the presence of thermal diffusion and heat sink was presented by Ravikumar [16]. Lakshmi *et al.* [17] are discussed thermal radiation and variable viscosity on steady MHD free convective flow over a stretching sheet in Presence of heat source, dissipation and chemical reaction. Harinath Reddy *et al.* [18] investigated unsteady MHD free convection flow of a Kuvshinski fluid past a vertical porous plate in the presence of chemical reaction and heat source/sink. Harinath Reddy *et al.* [19] was studied the Soret and Dufour effects on radiation absorption fluid in the presence of exponentially varying temperature and concentration in conducting field. Veereshet *al.* [20] discussed thermal diffusion effects on unsteady MHD boundary layer slip flow past a vertical permeable plate. Jhansi Rani *et al.* [21] obtained heat and mass transfer effects on MHD free convection flow over an inclined plate embedded in a porous medium. Ramana Reddy *et al.* [22] discussed radiation and chemical reaction effects on MHD flow along a moving vertical porous plate. Recently Ramamohan Reddy *et al.* [24] examined chemical reaction and thermal radiation effects on MHD micropolar fluid past a stretching sheet embedded in a non-Darcian porous medium.Gnanewarareddyet *al.*[25] are studied Influence of non-uniform heat source on Casson and Carreau fluid flow over a stretching sheet with slip and convective conditions. Sreedeviet *al.* [26]are discussed Soret and Dufour effects on MHD flow with heat and mass transfer past a permeable stretching sheet in presence of thermal radiation.Harikrishnaet *al.* [27]analysedEffects of radiation and chemical reaction on MHD flow past an oscillating inclined porous plate with variable temperature and mass diffusion.The present study is aimed at analyzing the effects chemical reaction and radiation on unsteady MHD free convection flow near a moving vertical plate through a porous medium in presence of heat generation/ absorption. A general exact solution for the partial differential equations governing the flow is obtained with a closed analytical method. Also the applications of general solution for the important cases of the flow field are discussed in detail.

2. Formulation of the Problem

We have considered the unsteady flow of an incompressible and electrically conducting viscous fluid past an infinite vertical plate with variable temperature embedded in porous medium in presence of chemical reaction and heat absorption. A magnetic field of uniform strength B_0 is applied transversely to the plate. The induced magnetic field is neglected as the magnetic Reynolds number of the flow is taken to be very small. The viscous dissipation is assumed to be negligible. The flow is assumed to be in x^*-direction which is taken along the vertical plate in the upward direction. The y^* -axis is taken to be normal to the plate. Initially the plate and the fluid are at the same temperature T_∞^* in the stationary condition with concentration level C_∞^* at all points. At time $t^*>0$ the plate is exponentially accelerated with a velocity $u=u_0e^{a^*t^*}$ in its own plane and the plate temperature is raised linearly with time t and the level of concentration near the plate is raised to C_{w}^*.The fluid considered here is a gray, absorbing/emitting radiation but a non-scattering medium.

In this analysis we made the following assumptions:

- It is assumed that there is no applied voltage which implies the absence of an electrical field.
- The transversely applied magnetic field and magnetic Reynolds number are assumed to be very small so that the induced magnetic field and the Hall Effect are negligible.
- Viscous dissipation and Joule heating terms are neglected.
- As the plate is infinite in extent, the physical variables are functions of y′ and t′ only.
- It is assumed that the effect of viscous dissipation is negligible in the energy equation.
- There is a first order chemical reaction between the diffusing species and the fluid.
- The fluid considered here is a gray, absorbing emitting radiation but a non-scattering medium.
- Thermo diffusion effect is considered.

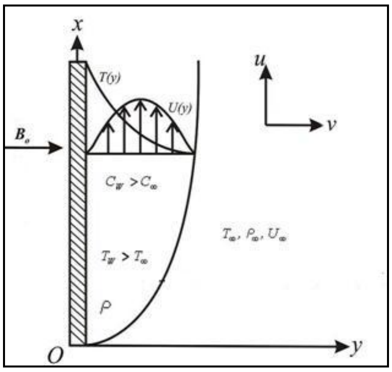

Fig. Physical model

Using the above assumptions and the usual Bossinesq's approximation, the unsteady flow is governed by the following equations:

Momentum equation:

$$\frac{\partial u^*}{\partial t^*} = v\frac{\partial^2 u^*}{\partial y^{*2}} + g\beta_T\left(T^* - T^*\right) + g\beta_c\left(C^* - C^*\right) - \frac{\sigma B_0^2}{\rho}u^* - \frac{\vartheta}{k^*}u^* \quad (1)$$

Energy equation:

$$\frac{\partial T^*}{\partial t^*} = \frac{k}{\rho C_P}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho C_P}\frac{\partial q_r}{\partial y^*} - \frac{Q}{\rho C_P}\left(T^* - T_\infty^*\right) \quad (2)$$

Concentration equation:

$$\frac{\partial C^*}{\partial t^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} + D_1\left(\frac{\partial^2 T^*}{\partial y^{*2}}\right) - K_c^*\left(C^* - C_\infty^*\right) \quad (3)$$

The initial and boundary conditions are

$$u^* = 0,\ T^* = T_\infty^*, C^* = C_\infty^*,\ forall\ y^*, t^* \le 0$$

$$u^* = u\,e^{a^* t^*},\ T^* = T_\infty^* + (T_w^* - T_\infty^*)At^*, C^* = C_w^*\ at\ y^* = 0, t^* > 0$$

$$u^* = 0,\ T^* = T_\infty^*, C^* = C_\infty^*\ as\ y \to \infty, t^* > 0$$

(4)

To reduce the above equations into non-dimensional form, we introduce the following dimensionaless variables and parameters

$$y = \frac{U_0 y^*}{\phi \nu},\ u = \frac{u^*}{U_0},\ \theta = \frac{T^* - T_\infty^*}{T_w^* - T_\infty^*},\ t = \frac{t^* U_0^2}{\nu},$$
$$F = \frac{16 a^* \nu^2 T_\infty^*}{k U_0^2},\ C = \frac{C^* - C_\infty^*}{C_w^* - C_\infty^*},\ \Pr = \frac{\mu c_p}{k},$$
$$G_r = \frac{\nu g \beta_T (T_w^* - T_\infty^*)}{U_0^2},\ G_m = \frac{\nu g \beta_c (C_w^* - C_\infty^*)}{U_0^2},$$
$$K_c = \frac{\nu K_c^*}{U_0^2},\ M = \frac{\sigma B_0^2 \nu}{\rho U_0^2},\ k = \frac{U_0^2 k^*}{\nu^2},\ a = \frac{a^* \nu}{U_0^2},$$
$$S_c = \frac{\nu}{D},\ S_0 = \frac{D_1 (T_w^* - T_\infty^*)}{\nu (C_w^* - C_\infty^*)},\ H = \frac{Q \nu^2}{k U_0^2}. \quad (5)$$

where $A = \frac{u_0^2}{\nu}$, The local radiant for the case of an optically thin gray gas is expressed by

$$\frac{\partial q_r}{\partial y^*} = -4 a^* \sigma \left(T_\infty^{*4} - T^{*4} \right) \quad (6)$$

It is assumed that the temperature differences with in the flow are sufficiently small that T^{*4} may be expressed as a linear function of the temperature. This is accomplished by expanding T^{*4} in a Taylor's series about and neglecting the higher order terms, thus T_∞^*

$$T^{*4} = 4 T_\infty^{*3} T^* - 3 T_\infty^{*4} \quad (7)$$

With the help of above equations governing equations (1)-(3) reduced to

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} - Gr\,\theta - Gm\,C - M_1 u \quad (8)$$

$$\Pr \frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} - F_1 \theta \quad (9)$$

$$Sc \frac{\partial C}{\partial t} = \frac{\partial^2 C}{\partial y^2} + S_0\, Sc \frac{\partial^2 \theta}{\partial y^2} - Kc\, Sc\, C \quad (10)$$

The corresponding initial and boundary conditions in non-dimensional form are

$$u = 0,\ \theta = 0,\ C = 0\ \ forall\ \ y^* \ge 0,\ t^* \le 0$$
$$u = e^{at},\ \theta = 1,\ C = 1\ \ at\ \ y = 0,\ t^* > 0$$
$$u \to 0,\ \theta \to 0,\ C \to 0\ as\ y \to \infty,\ t^* > 0 \quad (11)$$

3. Solution of the problem

Equations (8) – (10) are coupled and nonlinear partial differential equations . In order to reduce the system of partial differential equations to a system of ordinary differential equations in dimension less form, we may represent the velocity, temperature and concentration as

$$u = u_0 \, e^{i\varpi t} \quad (12)$$

$$\theta = \theta_0 \, e^{i\varpi t} \quad (13)$$

$$C = C_0 \, e^{i\varpi t} \quad (14)$$

Substituting equations (12), (13) and (14) in equations (8), (9) and (10), we obtain

$$u_0'' - A_3^2 \, u_0 = Gr\,\theta_0 + Gm\,C_0 \quad (15)$$

$$\theta_0'' - A_1^2 \, \theta_0 = 0 \quad (16)$$

$$C_0'' + S_0 \, S_c \, \theta_0'' - (K_c + i\,w) S_c \, C_0 = 0 \quad (17)$$

The corresponding boundary conditions can be written as

$$u_0 = e^{(a - i\varpi)t},\ \theta_0 = e^{-i\varpi t},\ C_0 = e^{-i\varpi t}\ \ at\ \ y = 0,$$
$$u_0 \to 0,\ \theta_0 \to 0,\ C_0 \to 0\ as\, y \to \infty \quad (18)$$

The analytical solutions of equations (15) to (17) with satisfying the boundary conditions are given by

$$u = e^{-A_3 y}(1 - m_3 - m_4) + m_3 e^{-A_1 y} + m_4\, e^{-A_2 y} \quad (19)$$

$$\theta = e^{-A_1 y} \quad (20)$$

$$C = (1 - m_2) e^{-A_2 y} + m_2 e^{-A_1 y} \quad (21)$$

It is now important to calculate the physical quantities of primary interest, which are the local wall shear stress, local surface heat and mass flux. Given velocity field in the boundary layer, we calculate the local wall shear stress (skin friction), from temperature field the rate of heat transfer, from concentration field we study the mass transfer. The values of these physical quantities are present here as in table.

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Variations in pertinent parameters		Skin friction	Nusselt number	Sherwood number
M	0.5 1 1.5 2	-3.9755 -3.3099 -2.7899 -2.3624	-	-
Gm	5 10 15 20	-2.3624 -5.0161 -7.6699 -10.3237	-	-
Gr	5 10 15 20	-2.3624 -3.804 -5.2456 -6.6872	-	-
K	1 1.5 2 2.5	-2.3624 -2.6389 -2.7899 -2.8853	-	-
Kc	0.5 1 1.5	-2.5557 -2.3624 -2.3271	-	-0.2994 -0.1278 0.0036
So	2 4 6 8	-2.3624 -2.753 -3.1436 -3.5343	-	-0.1278 -0.7269 -1.326 -1.9251
Sc	0.22 0.3 0.6	-2.3624 -2.3892 -2.5132	-	-0.1278 -0.2382 -0.6553
F	2 4 6 8	-2.2996 -2.2133 -2.1543 -2.1102	2.0003 2.4497 2.8285 3.1624	-0.2408 -0.4324 -0.5952 -0.7394
Pr	0.1 0.71 7 15	-2.3628 -2.3624 -2.338 -2.2782	1.7321 1.7325 1.7763 1.9030	-0.1275 -0.1278 -0.1459 -0.1974

4. Results and discussion:

Numerical evaluation of the analytical results reported in the previous section was performed and a representative a set of results is reported graphically in figures 1-18.these results are obtained to illustrate the influence of the magnetic parameter (M), the Grashof number (Gr), the modified Grashof number (Gm), the time (t), the radiation parameter (F), the heat absorption (Q), the Schmidt number (Sc), the Prandtl number (Pr), the Soret number (So), and the chemical reaction parameter (Kc). The values of the Prandtl number are chosen Pr = 7 (water) and Pr = 0.71 (air). The values of Schmidt number are chosen to represent the presence of species by hydrogen (0.22), water vapour (0.60), ammonia (0.78), Ethyl benzene (2.01) and carbon dioxide (0.96). From fig.1 Hartmann number (M) increases then velocity decreases. This is because an increase in applied magnetic field strength causes greater interaction between the fluid motion and magnetic field and hence an increase in Lorentz force, since this force opposes the buoyancy force velocity will be decreased.Fig.2 illustrates the variation of velocity distribution of the flow field for different values of Grashof number. Grashof number (Gr) increases then velocity increases this is because of increasing values of Grashof number implies the increasing strength of the flow.Fig.3 shows velocity profiles for different values of mass Grashof number (Gm). From the figure it is evident that velocity distribution increases with an increase in parameter (Gm). Fig.4 illustrates the velocity profile for various values of permeability parameter (K). it can be clearly seen that as K increases velocity increases because when permeability increases then flow resistance decreases which leads to increase the velocity.Fig. 12&5 represents temperature and velocity profiles of heat absorption parameter (Q). the presence of heat absorption (thermal sink) effect has the tendency to reduce the fluid temperature. This causes the thermal buoyancy effects to decrease resulting in a net reduction in the fluid velocity. These behaviors are clearly obvious from figures 12&5, in which both velocity and temperature distributions decreases as Q increases. Fig.6 illustrates the effects of thermal radiation parameter (F). it is clear that as the radiation parameter (F) increases then velocity decreases.Fig.7& 14 represents velocity and concentration profiles of Soret number (So). From figure it is clear that both velocity and concentration increases as So increases.Fig.8 shows velocity profiles for different values of chemical reaction parameter (Kc). It is observed that velocity decreases with the higher values of chemical reaction parameter (Kc).From fig. 15 & 9 as Schmidt number increases the concentration and velocity profiles are decreases.Fig.10& 13 represents the velocity and temperature profiles of Prandtl number. Clearly as Prandtl number increases velocity profiles and temperature profiles decreases.Fig.11 shows the temperature profiles of thermal radiation parameter (F), from figure increase in radiation parameter decreases the heat transfer because the higher values of radiation parameter increases the absorption coefficient.Fig.16 shows concentration profiles for different values of chemical reaction parameter (Kc). It can be seen from Fig.16 the concentration notably decreases for higher values of the chemical reaction parameter, which indicates that the diffusion rates can be changed by the chemical reaction parameter.

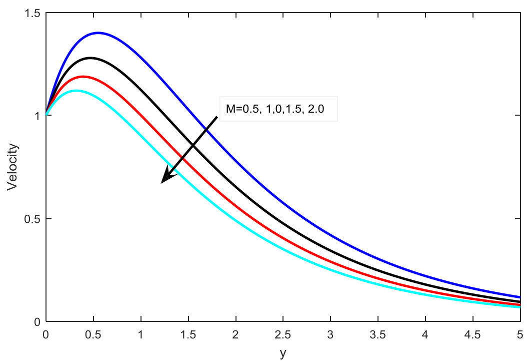

Fig. 1. Velocity profiles for different values of Hartmann number (M)

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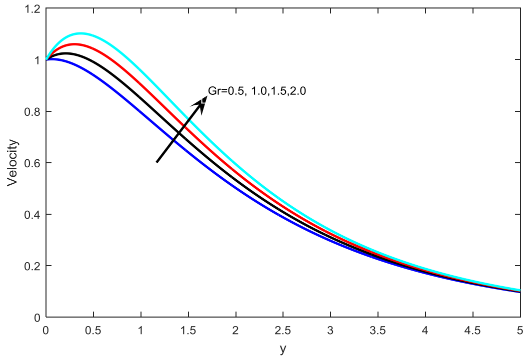

Fig. 2. Velocity profiles for different values of Grashof number (Gr)

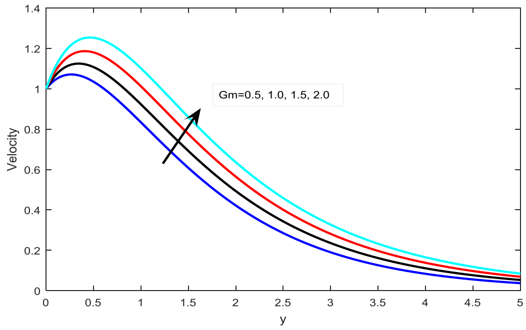

Fig. 3. Velocity profiles for different values of Modified Grashof number (Gm)

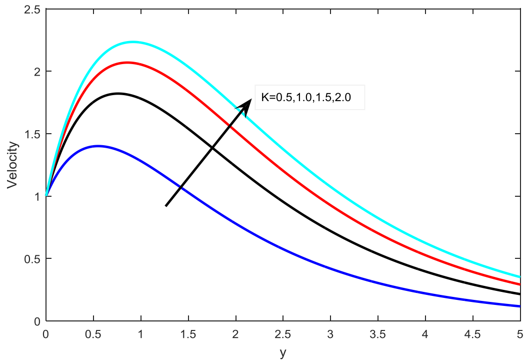

Fig. 4. Velocity profiles for different values of porosity parameter (K)

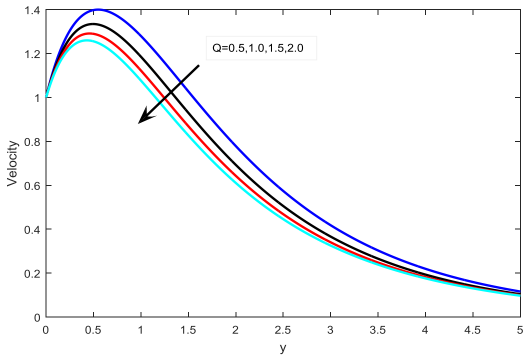

Fig.5. Velocity profilesfor different values of Heat absorption parameter (Q)

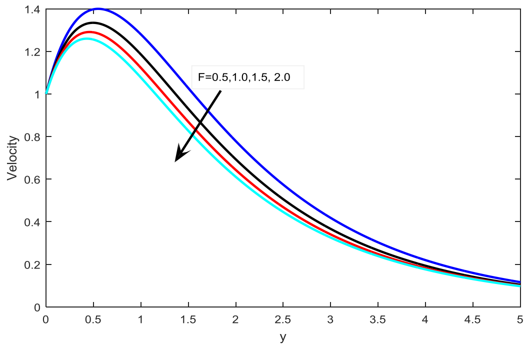

Fig. 6. Velocity profiles for different values of Radiation parameter (F)

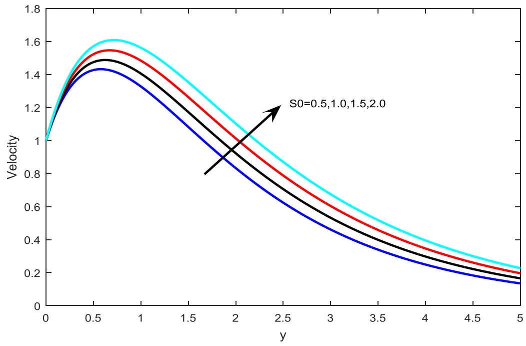

Fig.7. Velocity profiles for different values of in Soret number (So)

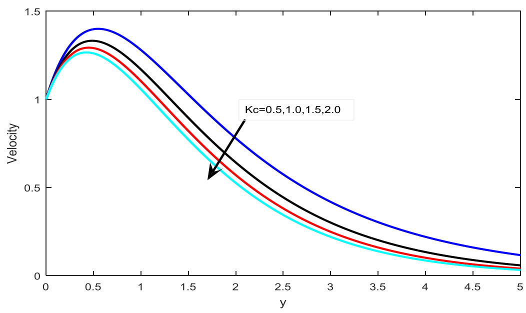

Fig. 8 Velocity profiles for different values of chemical reaction parameter (Kc).

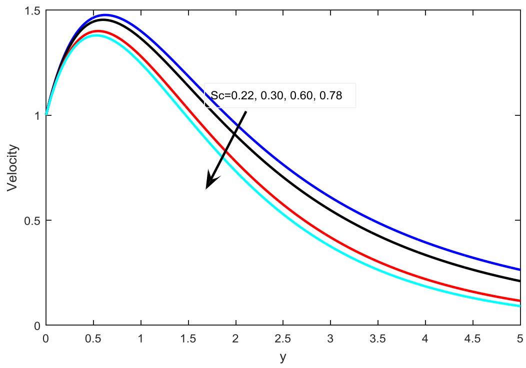

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Fig.9. Velocity profiles for different values of Schmidt number (Sc)

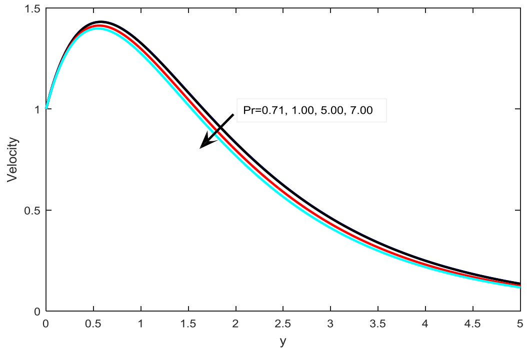

Fig.10. Velocity profiles for different values of Prandtl number Pr

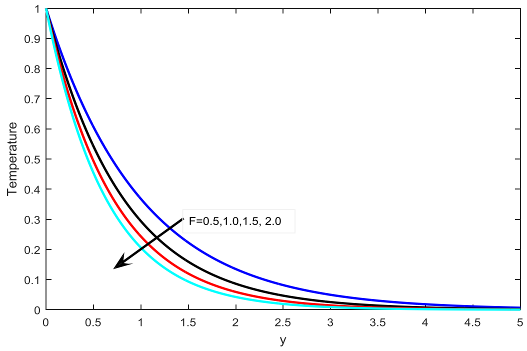

Fig. 11. Temperature profiles for different values of Radiation parameter (F)

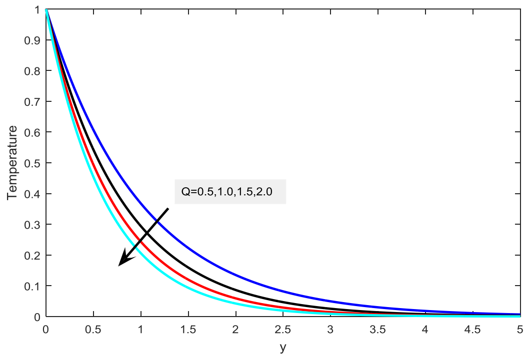

Fig.12.Temperature profiles for different values of heat absorption parameter (Q)

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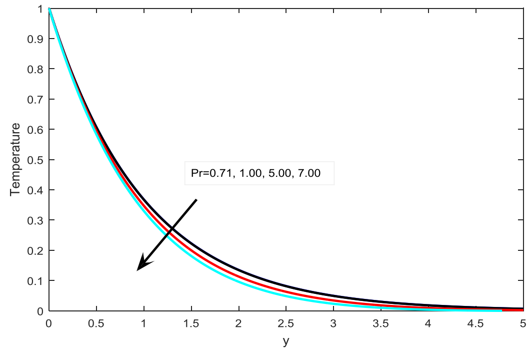

Fig.13. Temperature profiles for different values of Prandtl number Pr

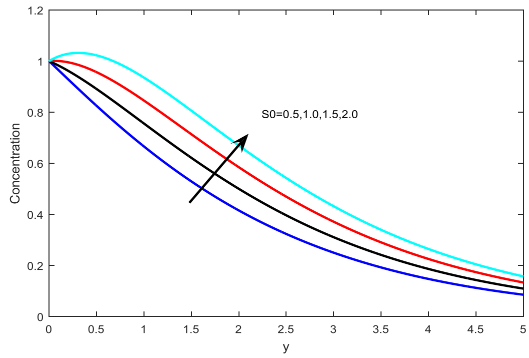

Fig.14. Concentration profiles for different values of Soret Number So

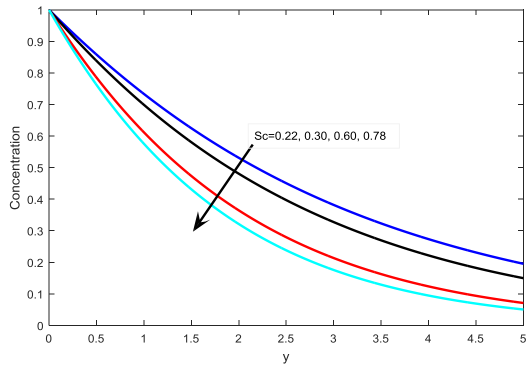

Fig.15. Concentration profiles for different values of Schmidt number Sc

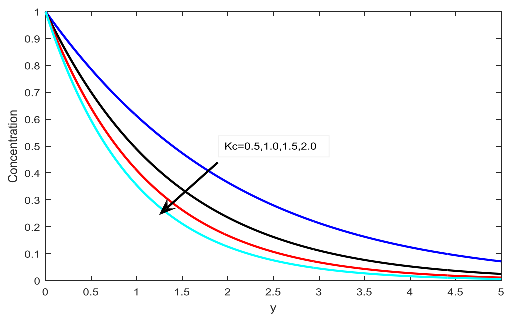

Fig.16 Concentration profiles for different values of chemical reaction (Kr)

5. Conclusions:

1. Velocity decrease with the increase in the Magnetic parameter M, the radiation parameter F, the coefficient of heat absorption Q, Schmidt number Sc, Prandtl number Pr.
2. Velocity increase with increase in Grashof number Gr, modified Grashof number Gm, Soret number So.
3. Temperature decrease with the increase in the Radiation parameter F, the coefficient of heat absorption Q, Prandtl number Pr.
4. Concentration decrease with the increase in the Schmidt number Sc, Chemical reaction parameter Kc and with the decrease in the Soret number So.
5. Skin friction decrease with increase in Grashof number Gr, modified Grashof number Gm, Permeability parameter K, Soret number So, Schmidt number Sc.
6. Skin friction increase with increase in Magnetic parameter M, Chemical reaction parameter Kc, Radiation parameter F, Prandtl number Pr.
7. Nusselt number increase with increase in Radiation parameter F, Prandtl number Pr.
8. Sherwood number decrease with the increase in Soret number So, Schmidt number Sc, Radiation parameter F, Prandtl number Pr.
9. Sherwood number increase with the increase in Chemical reaction parameter Kc.

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