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CHEMICAL REACTION EFFECTS ON UNSTEADY MHD FREE CONVECTIVE FLOW ALONG A VERTICAL POROUS PLATE EMBEDDED IN A POROUS MEDIUM

N. VEDAVATHI, K. JAYARAMI REDDY, K. RAMAKRISHNA[a] and S. V. SUBRAHMANYAM*

Department of Mathematics, K. L. University, GUNTUR – 522502 (A.P.) INDIA
[a]Department of Mechanical Engineering, Dean (Academics), K. L. University, GUNTUR – 522502 (A.P.) INDIA

ABSTRACT

This work deals with the study of a two-dimensional laminar unsteady hydromagnetic free convective flow of dissipative, chemical reacting fluid along a vertical porous plate immersed in a porous medium with heat generation and variable suction. The governing partial differential equations are reduced to a system of self-similar equations using the similarity transformations. The resultant equations are then solved numerically using the Runge-Kutta method along with shooting technique. The effects of governing physical parameters on velocity, temperature and concentration as well as skin-friction coefficient, Nusselt number and Sherwood number are computed and presented in graphical and tabular forms. Comparisons with previously published work are performed and the results are found to be in excellent agreement.

Key words: Unsteady, MHD, Chemical reaction, Heat generation, Variable suction, Viscous dissipation.

INTRODUCTION

The study of free convection with heat and mass transfer is very useful in fields such as chemistry, agriculture and oceanography. A few representative fields of interest in which combined heat and mass transfer play an important role are the design of chemical processing equipment, formulation and dispersion of fog, distribution of temperature and moisture over agriculture fields and groves of fruits trees, damage of crops due to freezing, and pollution of the environment. This technique is used in the cooling processes of plastic sheets, polymer fibers, glass materials, and in drying processes of paper. Gebhart and Pera[1]

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*Author for correspondence; E-mail: subrahmanyam@kluniversity.in

studied the nature of vertical natural convection flows resulting from the combined buoyancy effects of thermal and mass diffusion.

Flow and heat and mass transfer of an incompressible viscous fluid over a vertical porous plate appeared in several technological processes of industries such as nuclear science, fire engineering, combustion modeling, geophysical etc. Ostrich[2] obtained similarity solution of free convection flow along vertical plate. Soundalgekar and Wavre[3] investigated heat and mass transfer effects on unsteady free convective flow along vertical porous plate with constant suction. Rapits and Tzivanidis[4] studied mass transfer effects on heat transfer along an accelerated vertical plate. Hossain and Begum[5] observed the effect of mass transfer and free convection past a vertical porous plate. Sharma[6] investigated free convection effects on the flow past a porous medium bounded by a vertical infinite surface with constant suction and constant heat flux-II. Sattar et al.[7] analyzed analytical and numerical solutions for free convection flow along a porous plate with variable suction in porous medium. Ferdows et al.[8] found free convection flow with variable suction in presence of thermal radiation. Sharma and Mishra[9] observed unsteady flow and heat transfer along a porous vertical surface bounded by porous medium.

Magnetoconvection plays an important role in agriculture, petroleum industries, geophysics and in astrophysics. Important applications in the study of geological formations, in exploration and thermal recovery of oil, in the assessment of aquifers, geothermal reservoirs and underground nuclear waste storage sites. MHD flow has application in metrology, solar physics and in motion of earth's core. Also it has applications in the field of stellar and planetary magnetospheres, aeronautics, chemical engineering and electronics. Sparrow and Cess[10] investigated effect of magnetic field on free convective heat transfer. The effects of transversely applied magnetic field, on the flow of an electrically conducting fluid past an impulsively started infinite isothermal vertical plate was studied by Soundalgekar et al.[11] MHD effects on impulsively started vertical infinite plate with variable temperature in the presence of transverse magnetic field were studied by Soundalgekar et al.[12] The dimensionless governing equations were solved using Laplace transform technique. The effects of MHD on free convection flow has been studied by many researchers such as Gupta[13], Lykoudis[14] and Nanda and Mohanty[15].

In recent years, the problems of free convective heat and mass transfer flows through a porous medium under the influence of a magnetic field have been attracted the attention of a number of researchers because of their possible applications in many branches of science and technology, such as its applications in transportation cooling of re-entry vehicles and rocket boosters, cross-hatching on ablative surfaces and film vaporization in combustion chambers. In view of these applications, many researchers have studied MHD free convective heat and mass transfer flow in a porous medium. Raptis and Kafoussias[16] studied free convection and mass transfer flow through a porous medium in the presence of transverse magnetic field. Sattar[17] investigated the effects of heat and mass transfer on unsteady MHD free convection flow near an infinite vertical porous plate with hall current and variable suction. Kim[18] investigated the heat and mass transfer effects on MHD micropolar flow over a vertical moving porous plate embedded in a porous medium.

The effect of a chemical reaction depends on whether the reaction is homogeneous or heterogeneous. 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. Chambre and Young[19] have analyzed a first order chemical reaction in the neighborhood of a horizontal plate. Das et al.[20] have studied the effect of homogeneous first order chemical reaction on the flow past an impulsively started infinite vertical plate with uniform heat flux and mass transfer. Again, mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction were studied by Das et al.[21]

The dimensionless governing equations were solved by the usual Laplace-transform technique and the solutions are valid only at lower time level. Combined heat and mass transfer with chemical reaction are of importance in many processes and have, therefore, received a considerable amount of attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. We are particularly interested in cases in which diffusion and chemical reaction occur at roughly the same speed. When diffusion is much faster than chemical reaction, then only chemical factors influence the chemical reaction rate; when diffusion is not much faster than reaction, the diffusion and kinematics and kinetics interact to produce very different effects. Deka et al.[22] analyzed the effect of the first order homogeneous chemical reaction on the process of an unsteady flow past an infinite vertical plate with a constant heat and mass transfer. Muthucumaraswamy and Ganesan[23] studied effect of the chemical reaction and injection on the flow characteristics in an unsteady upward motion of an isothermal plate.

The study of heat generation or absorption in moving fluids is important in problems dealing with chemical reactions and those concerned with dissociating fluids. Heat generation effects may alter the temperature distribution and this in turn can affect the particle deposition rate in nuclear reactors, electronic chips and semi conductor wafers. Although exact modeling of internal heat generation or absorption is quite difficult, some simple mathematical models can be used to express its general behavior for most physical situations. Heat generation or absorption can be assumed to be constant, space-dependent or temperature-dependent. Crepeau and Clarksean[24] have used a space-dependent exponentially decaying heat generation or absorption in their study on flow and heat transfer from a vertical plate. Khandelwal[25] proposed the unsteady free convection flow of water at 4^oC and heat transfer through a porous medium bounded by isothermal porous vertical surface with variable suction and heat generation. Sharma and Gupta[26] analyzed unsteady flow and heat transfer along a hot vertical porous plate in the presence of periodic suction and heat source. Sharma and Singh[27] studied unsteady MHD free convective flow and heat transfer along a vertical porous plate with variable suction and internal heat generation. Several interesting computational studies of reactive MHD boundary layer flows with heat and mass transfer in the presence of heat generation or absorption have appeared in recent years[28-31].

Viscous dissipation changes the temperature distribution by playing a role like an energy source, which leads to affect heat transfer rates. The merit of the effect of viscous dissipation depends on whether the sheet is being cooled or heated. Gebhart and Mollendroff[32] considered the effects of viscous dissipation for external natural convection flow over a surface. Sattar et al.[33] obtained similar solutions of MHD free convection and mass transfer flow with viscous dissipation. Soundalgekar[34] studied the viscous dissipation effects on free convection flow past an infinite vertical porous plate with variable suction. Ibrahim[35] studied chemical reaction effects on MHD free convective heat and mass transfer flow along a stretching surface in presence of radiation, heat generation and radiation.

However, the study of the combined effects of heat and mass transfer on unsteady MHD free convection flow of a dissipative fluid has received a little attention. Hence, the object of the present paper is to analyze the combined effects of heat and mass transfer on unsteady MHD laminar free convection flow of an electrically conducting fluid past a vertical porous flat plate immersed in porous medium, by taking viscous dissipation, heat generation and chemical reaction under influence of variable suction. The governing partial differential equations are reduced to a system of self-similar equations using the similarity transformations. The resultant equations are then solved numerically using the Runge-Kutta fourth order technique along with shooting method. The effects of governing physical parameters on the velocity, temperature and concentration as well as skin-friction coefficient, Nusselt number and Sherwood number are computed and presented in graphical and tabular forms. To verify the obtained results, we have compared the present numerical results with previous work by Sattar et al.[7] and Sharma and Singh[27]. The comparison of results show a good agreement and we are confident that our present numerical results are accurate.

Formulation of the problem

Consider the unsteady laminar two-dimensional free convection boundary layer flow of an incompressible viscous electrically conducting fluid along a vertical porous plate. Let *x*-axis is taken along the plate and *y*-axis is normal to the plate. Magnetic field of intensity B_0 is applied in *y*-direction. A homogeneous first order chemical reaction between fluid and the species concentration is considered, in which the rate of chemical reaction is directly proportional to the species concentration. The fluid is assumed to be slightly conducting, and hence, the magnetic field is negligible in comparison with the applied magnetic field. It is further assumed that there is no applied voltage, so that electric field is absent. It is also assumed that all the fluid properties are constant except that of the influence of the density variation with temperature and concentration in the body force term (Boussinesq's approximation). Under these assumptions along with the boundary layer approximation and considering the viscous dissipation, the governing boundary layer equations for continuity, momentum, heat and mass transfer in the presence of heat generation and chemical reaction take the following form of the governing equations is given by –

$$\frac{\partial v}{\partial y}=0 \Rightarrow v \text{ is independent of } y \Rightarrow v=v(t), \quad \ldots(1)$$

$$\frac{\partial u}{\partial t}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+g\beta\left(T-T_\infty\right)+g\beta^*\left(C-C_\infty\right)-\frac{\sigma B_0^2}{\rho}u-\frac{\nu}{K^*}u \quad \ldots(2)$$

$$\frac{\partial T}{\partial t}+v\frac{\partial T}{\partial y}=\frac{\kappa}{\rho c_p}\frac{\partial^2 T}{\partial y^2}+\frac{Q_0\left(T-T_\infty\right)}{\rho c_p}+\frac{\mu}{\rho c_p}\left(\frac{\partial u}{\partial y}\right)^2 \quad \ldots(3)$$

$$\frac{\partial C}{\partial t}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}-Kr^*\left(C-C_\infty\right) \quad \ldots(4)$$

where *u* and *v* are the velocity components along *x* – and *y* – directions, respectively. *t* is the time variable, *ν* is the kinematic viscosity, ρ is the fluid density, *g* is the acceleration due to gravity of the earth, σ is the electrical conductivity, β is the volumetric expansion coefficient for heat transfer, β^* is the volumetric expansion coefficient for mass transfer, K^* is the permeability of the porous medium, C_p is the specific heat at constant pressure, μ is the dynamic viscosity, *T* is temperature of the fluid in the boundary layer, *C* is the concentration of the fluid in the boundary layer, K is the thermal conductivity, the term Q_0 $(T–T_\infty)$ is assumed to be amount of heat generated or absorbed per unit volume and Q_0 is a constant, which may take on either positive or negative values, T_∞ is the heat temperature far away from the plate, C_∞ is the mass temperature far away from the plate, *D* is the molecular diffusivity and Kr^* is chemical reaction parameter.

The boundary conditions for velocity, temperature and concentration fields for $(t \rightarrow 0)$ are given by –

$$u = 0,\ v = v(t),\ T = T_w,\ C = C_w \text{ at } y = 0,$$

$$u \rightarrow 0,\ T \rightarrow T_\infty,\ C \rightarrow C_\infty \text{ as } y \rightarrow \infty \quad \ldots(5)$$

where T_w be the fluid temperature at plate.

Method of solution

Define time dependent similarity parameter *h* (Schlichting and Gersten[36]) having length scale as –

$$h = \{= h(t)\} = 2\sqrt{\nu t} \quad \ldots(6)$$

Specially used for unsteady boundary layer problems. In terms of *h(t),* a convenient solution of Eq. (1) is given by –

$$v = v(t) = -f_w \frac{\nu}{h(t)} \quad \ldots(7)$$

where f_w is suction parameter.

The momentum, energy and concentration equations can be transformed into the corresponding differential equations by introducing the following similarity variables and non-dimensional parameters:

$$\eta = \frac{y}{h},\ u = Uf(\eta),\ \ \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty},\ \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty} \quad \ldots(8)$$

into the Eqs. (2) to (4), we get –

$$f'' + \left(2\eta + f_w\right) f' + Gr\theta + Gc\phi - \left(M + \frac{1}{K}\right) f = 0 \quad \ldots(9)$$

$$\theta'' + (2\eta + f_w)\Pr\theta' + \Pr Q\theta + \Pr Ec(f'')^2 = 0 \quad \text{...(10)}$$

$$\phi'' + (2\eta + f_w)Sc\phi' - ScKr\phi = 0 \quad \text{...(11)}$$

where η is the similarity variable, U is the uniform characteristic velocity, f is the dimensionless stream function, $Gr = \frac{g\beta h^2 (T_w - T_\infty)}{\nu U}$ is the Grashof number for heat transfer, $Gc = \frac{g\beta^* h^2 (C_w - C_\infty)}{\nu U}$ is the Grashof number for mass transfer, $M = \frac{\sigma B_0^2 h^2}{\nu\rho}$ is the magnetic parameter, $K = \frac{K^*}{h^2}$ is the permeability parameter, $\Pr = \frac{\mu c_p}{\kappa}$ is the Prandtl number, $Q = \frac{h^2 \kappa Q^*}{\mu c_p}$ is the heat generation parameter, $Ec = \frac{U^2}{c_p (T_w - T_\infty)}$ is the Eckert number, $Sc = \frac{\nu}{D}$ is the Schmidt number and $Kr = \frac{Kr^* \nu h}{D U}$ is the chemical reaction parameter.

The reduced corresponding boundary conditions are

$$f(0) = 0,\ \theta(0) = 1,\ \phi(0) = 1$$

$$f(\infty) = 0,\ \theta(\infty) = 0,\ \phi(\infty) = 0 \quad \text{...(12)}$$

The governing Eqs. (9) to (11) are second ordered linear differential equations and solved under the boundary conditions (12) using Rugne-Kutta fourth order method (Krisnamurthy and Sen)[37] along with shooting technique (Conte and Boor[38] and Sharma and Singh[27].

The parameters of engineering interest for the present problem are the skin-friction coefficient, the Nusselt number and the Sherwood number, which are given respectively by the following expressions. Knowing the velocity field, the skin-friction at the plate can be obtained, which in non-dimensional form is given by –

$$C_f = \frac{2\nu}{Uh} f'(0) \quad \text{...(13)}$$

Knowing the temperature field, the rate of heat transfer coefficient can be obtained, which in non-dimensional form, in terms of Nusselt number, is given by –

$$Nu = \frac{2q\sqrt{\nu t}}{\kappa\left(T_w - T_\infty\right)} = -\theta'(0) \qquad \ldots(14)$$

where q is heat flux per unit area.

Knowing the concentration field, the rate of mass transfer coefficient can be obtained, which in non-dimensional form, in terms of Sherwood number, is given by –

$$Sh = \frac{J\sqrt{\nu t}}{D\left(C_w - C_\infty\right)} = -\phi'(0) \qquad \ldots(15)$$

where J is mass transfer coefficient.

Where $\mathrm{Re} = \frac{U_0 x}{\upsilon}$ is the Reynold’s number.

RESULTS AND DISCUSSION

The governing Eqs. (9) to (11) with the boundary conditions (12) are solved using Runge-Kutta fourth order method along with shooting technique for different values of the parameters taking step size 0.005. The numerical calculations are presented in the form of tables and graphs for different values of parameters.

Table 1: Numerical values of –θ' (0) for various values of Pr and f_w are compared with the results obtained by Sattar et al.[7] and Sharma and Singh[27]

Pr	f_w	–θ' (0)		
		Sattar et al.[7]	**Sharma and Singh[27]**	**Present work**
0.71	0.5	0.9134	0.9134	0.913434
1.0	0.5	1.1411	1.1410	1.141014
1.0	1.0	1.5252	1.5251	1.525125

In order to get a physical insight into the problem, a representative set of numerical results are shown in Figs. 1-19, which illustrate the influence of physical parameters viz., the Grashof number, modified Grashof number, magnetic field parameter, permeability parameter, Prandtl number, heat generation parameter, Eckert number, Schmidt number, chemical reaction parameter, Suction parameter on the velocity $f(\eta)$, temperature $\theta(\eta)$ and concentration $\phi(\eta)$ profiles, skin-friction coefficient $f'(\eta)$, Nusselt number $-\theta'(\eta)$ and Sherwood number $-\phi'(\eta)$ are shown in the Tables 2-4.

Table 2: Skin-friction coefficient, local Nusselt number and local Sherwood number when *Pr* = 0.71, *Ec* = 0.5, *Q* = 0.5, *Sc* = 0.6, *Kr* = 0.5, f_w = 0.5

Gr	*Gc*	*M*	*K*	f_w	C_f	*Nu*	*Sh*
1.0	1.0	0.5	0.5	0.5	0.666291	0.663917	1.2221
0.1	1.0	0.5	0.5	0.5	0.352615	0.934579	1.2221
0.5	1.0	0.5	0.5	0.5	0.488699	0.836936	1.2221
1.0	0.1	0.5	0.5	0.5	0.367045	0.92738	1.2221
1.0	0.5	0.5	0.5	0.5	0.499146	0.829766	1.2221
1.0	1.0	0.1	0.5	0.5	0.709052	0.626755	1.2221
1.0	1.0	0.3	0.5	0.5	0.68662	0.646489	1.2221
1.0	1.0	0.5	0.1	0.5	0.408517	0.850075	1.2221
1.0	1.0	0.5	0.3	0.5	0.587165	0.727732	1.2221
1.0	1.0	0.5	0.5	0.1	0.675127	0.50283	1.07068
1.0	1.0	0.5	0.5	0.3	0.671397	0.580746	1.14507

Table 3: Skin-friction coefficient, local Nusselt number and local Sherwood number when *Gr = 1.0, Gc = 1.0, M = 0.5, K = 0.5, Sc = 0.6, Kr = 0.5,* f_w = 0.5

Pr	*Q*	*Ec*	C_f	*Nu*	*Sh*
0.71	0.5	0.5	0.666291	0.663917	1.2221
1.0	0.5	0.5	0.636569	0.776826	1.2221
2.0	0.5	0.5	0.571317	1.16417	1.2221
0.71	0.1	0.5	0.653688	0.807677	1.2221
0.71	0.3	0.5	0.659778	0.737477	1.2221
0.71	0.5	0.1	0.652318	0.968981	1.2221
0.71	0.5	0.3	0.659133	0.819144	1.2221

Table 4: Skin-friction coefficient, local Nusselt number and local Sherwood number when $Gr = 1.0, Gc = 1.0, M = 0.5, K = 0.5, Pr = 0.71, Q = 0.5, Ec = 0.5, f_w = 0.5$

Sc	*Kr*	C_f	*Nu*	*Sh*
0.6	0.5	0.666291	0.663917	1.2221
0.22	0.5	0.737172	0.617456	0.775033
0.5	0.5	0.682162	0.653331	1.10941
0.6	0.1	0.676053	0.656403	1.11946
0.6	0.3	0.671043	0.660264	1.17166

Throughout the calculations, the parametric values are fixed to be, Gr = 2.0, Gc = 2.0, M = 0.5, K = 0.5, Pr = 0.71, Ec = 0.5, Q = 0.5, Sc = 0.6, Kr = 0.5 and f_w = 0.5, unless otherwise indicated.

From the Figs. 1 and 2, respectively, it is clear that the velocity profiles increase Grashof number for heat transfer *Gr* or Grash of number for mass transfer *Gc* increases. Figs. 3 and 4 present the velocity and temperature for different values of the magnetic parameter *M,* respectively. Application of a transverse magnetic field results in a drag-like force called the Lorentz force. This force tends to slow down the movement of the fluid along surface. This is evident in the decreases in the velocity profiles as magnetic field parameter *M* increases. It is observed from the Fig. 4 that temperature profile decreases slowly, when magnetic parameter *M* increases.

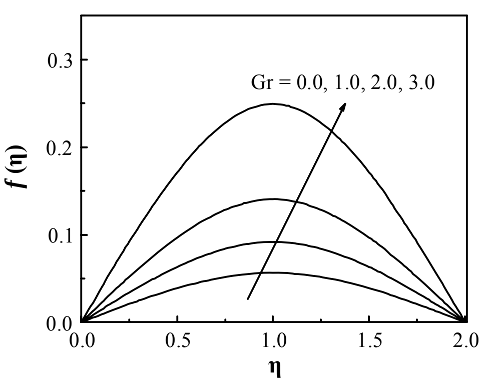

Fig. 1: Velocity profiles for different values of *Gr*

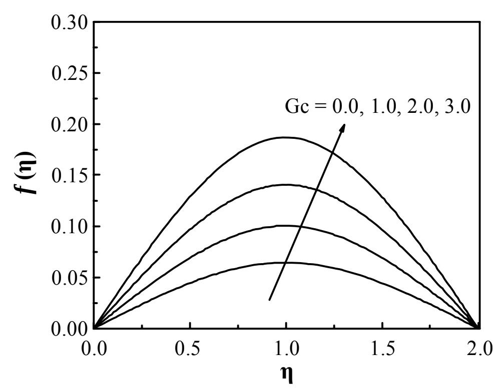

Fig. 2: Velocity profiles for different values of *Gc*

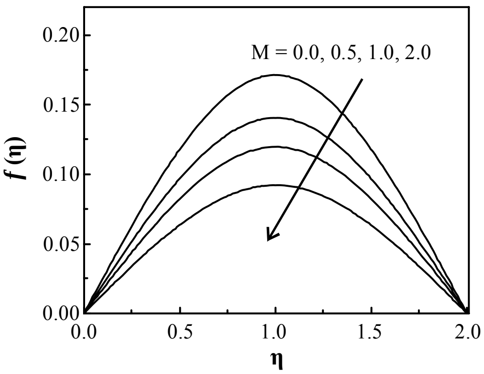

Fig. 3: Velocity profiles for different values of *M*

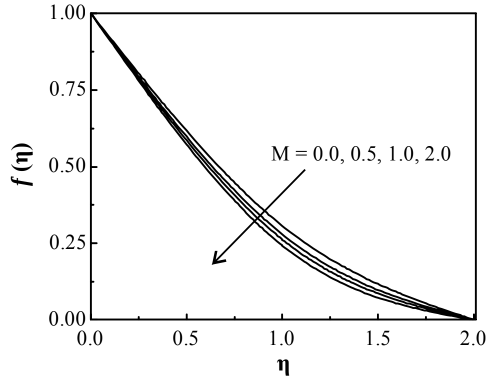

Fig. 4: Temperature profiles for different values of *M*

Figs. 5 and Fig. 6 demonstrate that the effect of permeability of porous medium on velocity and temperature profiles. From these, it is observed that the velocity as well as temperature profiles increases rapidly as increases permeability of porous medium *K*.

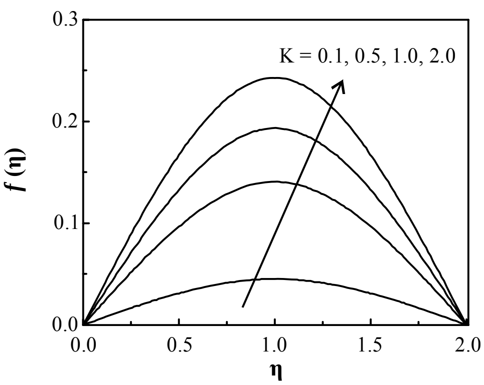

Fig. 5: Velocity profiles for different values of *K*

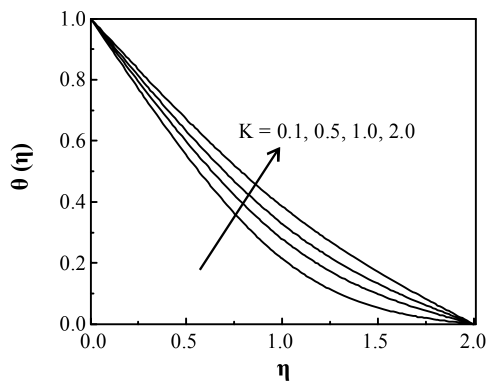

Fig. 6: Temperature profiles for different values of *K*

Figs. 7 and 8 illustrate the variation of velocity and temperature profiles for different values of Prandtl number *Pr*. From these figures, it is seen that the velocity and temperature decreases with increasing the values of the Prandtl number *Pr* in the boundary layer. From these plots, it is evident the temperature in the boundary layer falls very quickly for large values of the Prandtl number because the thickness of the boundary layer decreases with an increase in the value of Prandtl number *Pr*.

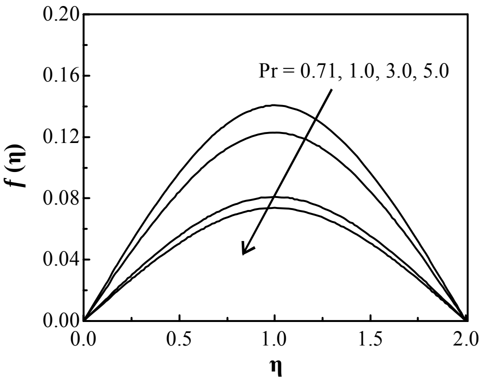

Fig. 7: Velocity profiles for different values of *Pr*

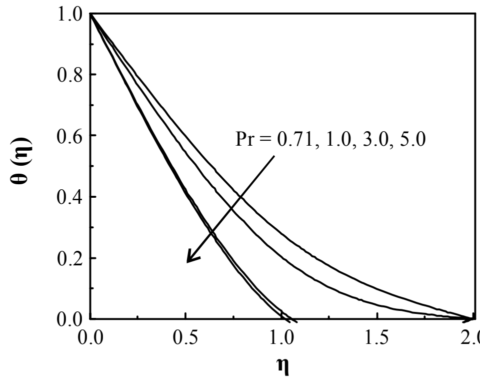

Fig. 8: Temperature profiles for different values of *Pr*

Fig. 9 depicts that heat generation *Q* assists the flow considerably, as velocity profiles in the presence of heat generation are higher in comparison to absence of heat generation. Fluid temperature increases in the presence of heat generation; hence, the magnitude of temperature profiles are higher in presence of heat generation as is shown in Fig. 10. Boundary layer and thermal boundary layer thicknesses increase considerably in presence of heat generation.

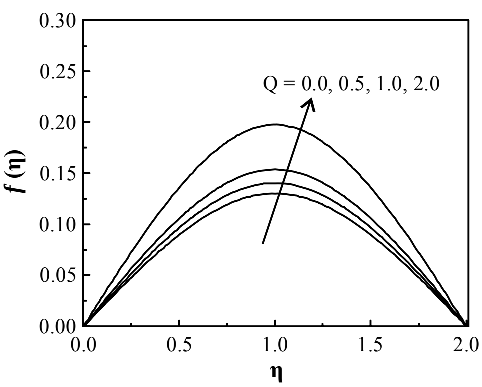

Fig. 9: Velocity profiles for different values of *Q*

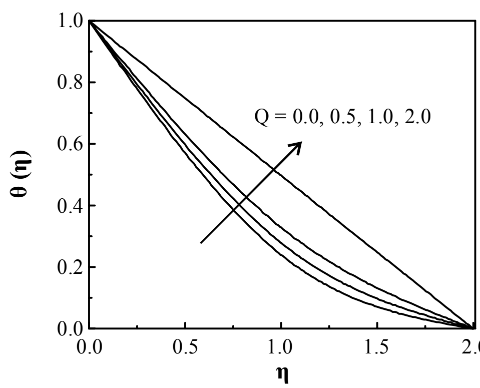

Fig. 10: Temperature profiles for different values of *Q*

Figs. 11 and 12 show the influence of the Eckert number *Ec*, on the velocity, and temperature profiles, respectively. By analyzing these figures, it is clearly revealed that the effect of Eckert number is to increase both; the velocity and the temperature distributions in the flow region. This is due to the fact that the heat energy is stored in liquid due to the frictional heating. Thus, the effect of increasing *Ec* is to enhance the temperature at any point as well as the velocity.

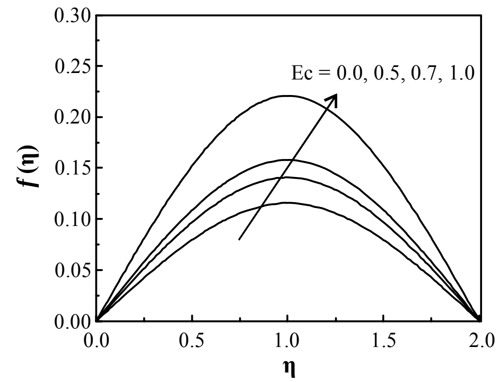

Fig. 11: Velocity profiles for different values of *Ec*

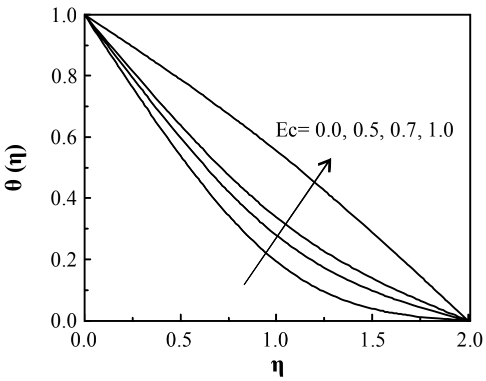

Fig. 12: Temperature profiles for different values of *Ec*

The influence of the Schmidt number *Sc* on velocity and concentration profiles are plotted in Figs. 13 and 14. The Schmidt number *Sc* embodies the ratio of the momentum to the mass diffusivity. It is noticed that as the Schmidt number *Sc* increases, the velocity as well as concentration decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity.

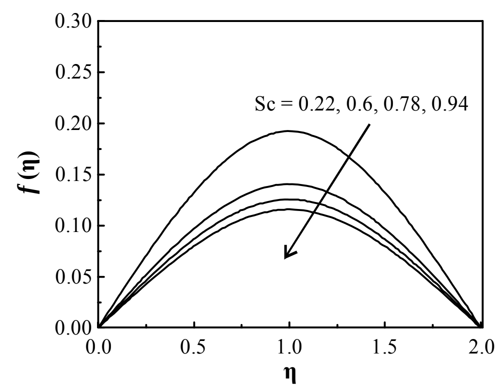

Fig. 13: Velocity profiles for different values of *Sc*

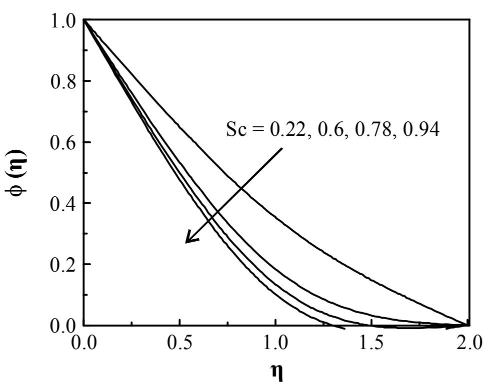

Fig. 14: Concentration profiles for different values of *Sc*

The effects of chemical reaction parameter *Kr* on the velocity and concentration distributions are displayed in Figs. 15 and 16, respectively. It is observed from these figures that an increase in the chemical reaction parameter *Kr* leads to the decrease of the velocity and concentration profiles.

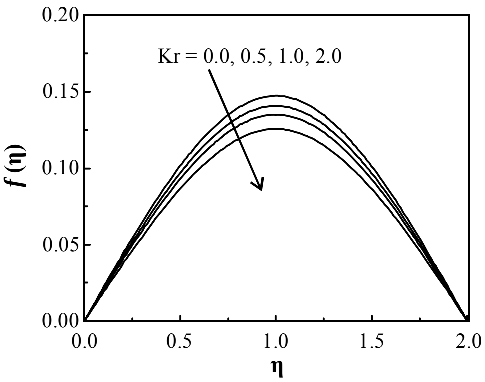

Fig. 15: Velocity profiles for different values of *Kr*

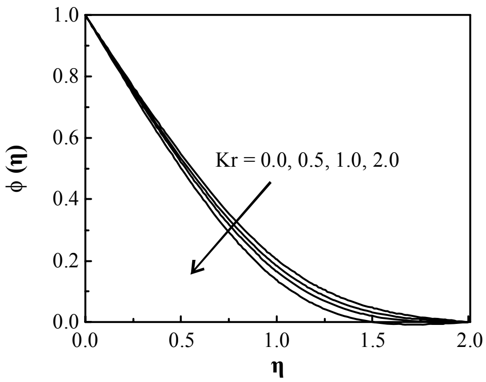

Fig. 16: Concentration profiles for different values of *Kr*

The effects of suction parameter f_w on the velocity profiles are shown in Fig. 17. It is found from this figure that the velocity profiles decrease with the increase of suction parameter indicating the usual fact that suction stabilizes the boundary layer growth. The effect of suction parameter on the temperature and concentration field is displayed in Figs. 18 and 19, respectively and we see that both; the temperature and concentration decrease with the increase of suction parameter. Suction of the decelerated fluid particles through the porous wall reduces the growth of the hydrodynamic, thermal and concentration boundary layers.

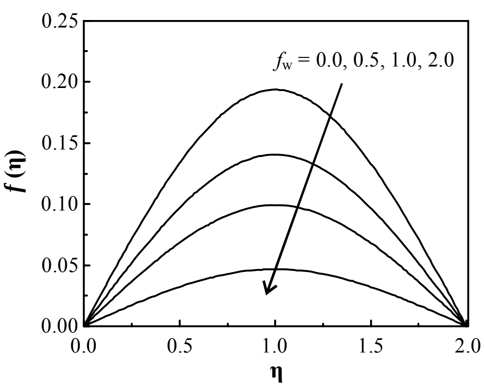

Fig. 17: Velocity profiles for different values of f_w

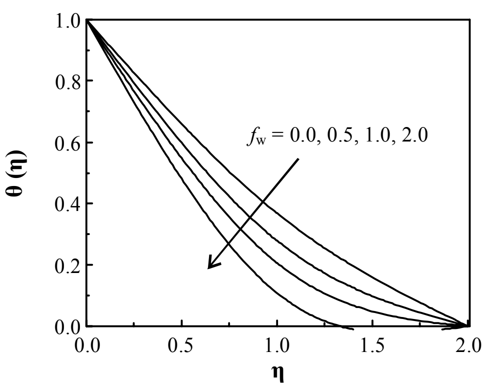

Fig. 18: Temperature profiles for different values of f_w

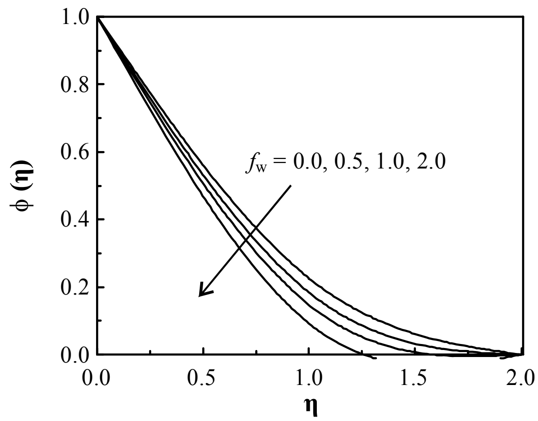

Fig. 19: Concentration profiles for different values of f_w

It is found from the Table 1 that the numerical values of $-\theta'(0)$ for various values of Pr and f_w presented in present paper are in good agreement with those obtained by Sattar et al.[7] and Sharma and Singh[27].

It is observed from Tables 2-4 that on increasing Grashof number *Gr*, modified Grashof number *Gr*, permeability of porous medium *K,* Eckert number *Ec* and heat generation parameter *Q* skin friction coefficient increases while on increasing magnetic parameter *M*, suction parameter f_w, Prandtl number *Pr*, Schmidt number *Sc* and chemical reaction parameter *Kr*, skin friction coefficient decreases. The Nusselt number *Nu* increases on increasing magnetic parameter *M*, suction parameter f_w, Prandtl number *Pr*, Schmidt number *Sc* and chemical reaction *Kr*. On the contrary, Nusselt number *Nu* decreases, when permeability of porous medium *K*, Eckert number *Ec*, Grashof number *Gr*, modified Grashof number *Gc* and heat generation parameter *Q* increase. Sherwood number increases as suction parameter f_w, Schmidt number *Sc* and chemical reaction parameter *Kr* increase.

CONCLUSION

The effects of chemical reaction on unsteady free convective flow of an electrical conducting fluid past a vertical porous flat plate immersed in a porous medium, by taking the viscous dissipation, heat source and variable suction into account. The governing partial differential equations are reduced to a system of self-similar equations using the similarity transformations. The resultant equations are then solved numerically using the Runge-Kutta method along with shooting technique. The effects of governing physical parameters on the velocity, temperature and concentration as well as skin-friction coefficient, Nusselt number and Sherwood number are computed and presented in graphical and tabular forms. It is observed that the velocity and temperature increases as the heat generation or Eckert number increases. However the exact opposite behavior was predicted as the magnetic field strength was increased. It should be noted the velocity and concentration decreases as the Schmidt number or chemical reaction parameter increases. As suction parameter increases, skin-friction coefficient decreases while Nusselt number and Sherwood number increases. It was found that the chemical reaction was increased; all of the Nusselt number and Sherwood number were increased while it decreased the skin-friction coefficient.

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