Available online at www.elixirpublishers.com (Elixir International Journal)

Applied Mathematics

ISSN: 2229-712X

Elixir Appl. Math. 73 (2014) 25927-25934

Unsteady MHD free convective flow along a vertical porous plate embedded in a porous medium with heat generation, variable suction and chemical reaction effects

S Mohammed Ibrahim

Department of Mathematics, Priyadarshini College of Engineering & Technology, Nellore, Andhra Pradesh, India – 524004.

ARTICLE INFO

Article history:

Received: 28 March 2014;

Received in revised form:

20 July 2014;

Accepted: 29 July 2014;

Keywords

Free convection,

Unsteady; MHD,

Chemical reaction,

Heat generation,

Variable suction,

Porous medium.

ABSTRACT

A two-dimensional laminar unsteady MHD free convective heat and mass transfer flow past a vertical porous plate immersed in a porous medium has been studied numerically in presence of chemical reaction, 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.

Introduction

Free convection flow involving coupled heat and mass transfer occurs frequently in nature and in industrial processes. A few representative fields of interest in which combined heat and mass transfer plays an important role are designing chemical processing equipment, formation and dispersion of fog, distribution of temperature and moisture over agricultural fields and groves of fruit trees, crop damage due to freezing, and environmental pollution. Gebhart and Pera [1] studied the nature of vertical natural convection flows resulting from the combined buoyancy effects of thermal and mass diffusion.

Coupled heat and mass transfer by natural convection in a fluid saturated porous medium has received great attention during the last decades due to the importance of this process which occurs in many engineering, geophysical and natural systems of practical interest such as geothermal energy utilization, thermal energy storage and recoverable systems and petroleum reservoirs. 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.

The study of Magnetohydrodynamic (MHD) flows have stimulated considerable interest due to its important applications in cosmic fluid dynamics, meteorology, solar physics and in the motion of Earth’s core (Cramer & Pai [10]). In a broader sense, MHD has applications in three different subject areas, such as astrophysical, geophysical and engineering problems. In light of these applications, MHD free convective flow past a heated vertical flat plate has been studied by many researchers such as Gupta [11], Lykoudis [12], and Nanda and Mohanty [13]. Sparrow et al. [14] 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.[15]. MHD effects on impulsively started vertical infinite plate with variable temperature in the presence of transverse magnetic field were studied by Soundalgekar et al. [16]. The dimensionless governing equations were solved using Laplace transform technique

In many engineering applications such as combustion systems, solar collectors, metallurgy and chemical engineering there are many transport processes that are governed by both thermal and mass diffusion in the presence of chemical reaction effect. In nature, the presence of pure air or water is impossible. Some foreign mass may be present either naturally or mixed with the air or water. The equation of motion for gas or water flow, taking into account in the presence of a foreign mass of low level were derived by Gebhart [17] and Gebhart and Pera [1] have studied the effect of the presence of a foreign mass on the free convection flow past a semi-infinite vertical plate. Furthermore, the presence of a foreign mass in air or water is causes some kind of chemical reaction. During a chemical

Tele:

E-mail addresses: ibrahimsvu@gmail.com

reaction between two species heat is also generated. The chemical reaction can occur in the interior of the ambient fluid (homogeneous chemical reaction) or at the surface in contact with the ambient fluid (heterogeneous chemical reaction).

Convective flows with simultaneous heat and mass transfer under the influence of a magnetic field and chemical reaction arise in many transport processes both naturally and artificially in many branches of science and engineering applications. The study of heat and mass transfer with chemical reaction is of great practical importance in many branches of science and engineering. Deka et al. [18] 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 [19] studied effect of the chemical reaction and injection on the flow characteristics in an unsteady upward motion of an isothermal plate.

The effect of heat source on heat transfer is of immense importance in several physical problems. In literature there are many others using the importance of temperature dependent heat source on the heat transfer of various fluids. However, they ignored space dependent heat source effect which is of immense important in the heat transfer analysis. Some authors have studied and presented the significance of space dependent heat source in addition to the temperature dependent heat source. Heat generation or absorption can be assumed to be constant, space-dependent or temperature-dependent. (Crepeau & Clarksean [20]) have used a space-dependent exponentially decaying heat generation or absorption in their study on flow and heat transfer from a vertical plate. Khandelwal [21] proposed the unsteady free convection flow of water at 4^0 C and heat transfer through a porous medium bounded by isothermal porous vertical surface with variable suction and heat generation. Sharma and Gupta [22] analyzed unsteady flow and heat transfer along a hot vertical porous plate in the presence of periodic suction and heat source. Sharma and Singh [23] 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 (see for example Patil and Kulkarni, [24]; Salem and El-Aziz [25]; Samad and Mohebujjaman, [26]; Mahdy, [27]; Mohammed Ibrahim and Lavanya [28]).

However, the study of the combined effects of heat and mass transfer on unsteady MHD free convection flow of a chemical reacting 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 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 [23]. The comparison results show a good agreement and we 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

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

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

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

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

where *u*,*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, T is temperature of the fluid in the boundary layer, C is the concentration of the fluid in the boundary layer, κ 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 ($t \to 0$) are given by

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

$$u \to 0,\ T \to T_\infty,\ C \to C_\infty \ as\ y \to \infty \quad (5)$$

where T_w be the fluid temperature at plate.

Method of Solution

Define time dependent similarity parameter *h* (Schlichting and Gersten [29]) having length scale as,

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

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

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

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:

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

into the equations (2) to (4), we get

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

$$\theta'' + (2\eta + f_w)\Pr\theta' + \Pr Q\theta = 0 \quad (10)$$

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

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 , $Sc = \frac{\nu}{D}$ is the Schmidt number and $Kr = \frac{Kr^* \nu h}{DU}$ is the chemical reaction parameter.

The reduced corresponding boundary conditions are

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

$$f(\infty) = 0,\ \theta(\infty) = 0,\ \phi(\infty) = 0 \quad (12)$$

The governing equations (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 [30]) along with shooting technique (Conte and Boor [31] and Sharma and Singh [23].

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

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

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

$$Nu = \frac{2q\sqrt{\nu t}}{\kappa (T_w - T_\infty)} = -\theta'(0)$$, where *q* is heat flux per unit area.

(14)

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

$$Sh = \frac{J\sqrt{\nu t}}{D(C_w - C_\infty)} = -\phi'(0)$$, where J is mass transfer coefficient.

(15)

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

Results and Discussion

The governing equations (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.

In order to get a physical insight into the problem, a representative a set of numerical results are shown in Figures 1 - 17, which illustrate the influence of physical parameters viz., the Grashof number, modified Grashof number, magnetic field parameter, permeability parameter, Prandtl number, heat generation parameter, Schmidt number, chemical reaction parameter, Suction parameter on the velocity $f(\eta)$, temperature $\theta(\eta)$ and concentration $\phi(\eta)$ profiles. And skin-friction coefficient $f'(\eta)$, Nusselt number $-\theta'(\eta)$ and Sherwood number $-\phi'(\eta)$ are shown in the Tables 2 – 4, 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, Q = 0.5, Sc = 0.6, Kr = 0.5,* f_w = 0.5, unless otherwise indicated.

From the Figure 1 and Figure 2 respectively that the velocity profiles increase Grashof number for heat transfer *Gr* or Grashof number for mass transfer *Gc* increases. Figure 3 and Figure 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 Figure 4 that temperature profile decreases slowly when magnetic parameter *M* increases.

Figure 5 and Figure 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*

Figures 7 and Figure 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.*

Figure 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.

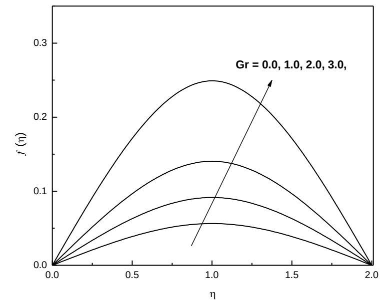

Figure 1: Velocity profiles for different values of *Gr*

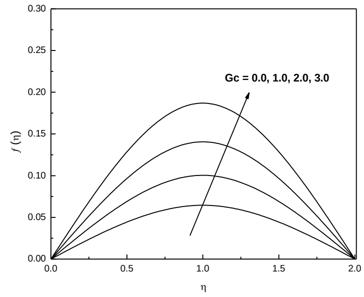

Figure 2: Velocity profiles for different values of *Gc*

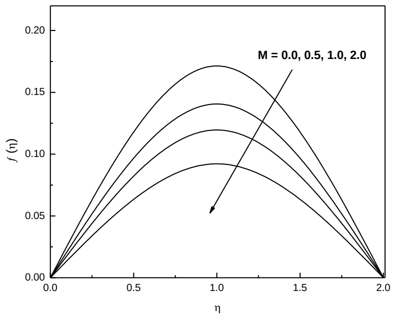

Figure 3: Velocity profiles for different values of *M*

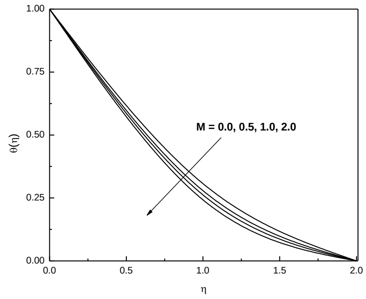

Figure 4: Temperature profiles for different values of *M*

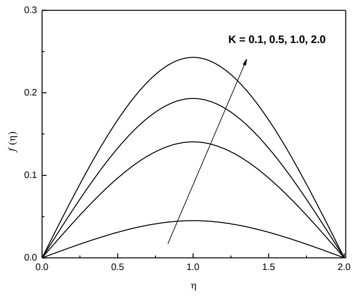

Figure 5: Velocity profiles for different values of *K*

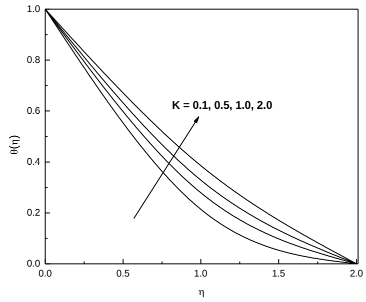

Figure 6: Temperature profiles for different values of *K*

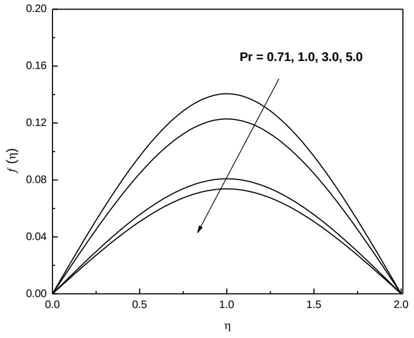

Figure 7: Velocity profiles for different values of *Pr*

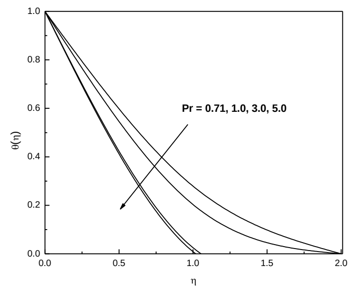

Figure 8: Temperature profiles for different values of *Pr*

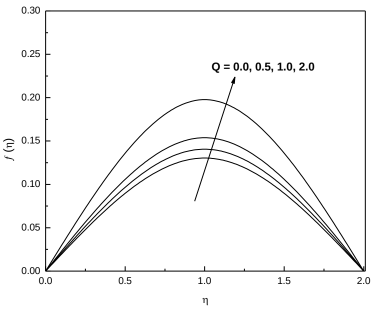

Figure 9: Velocity profiles for different values of *Q*

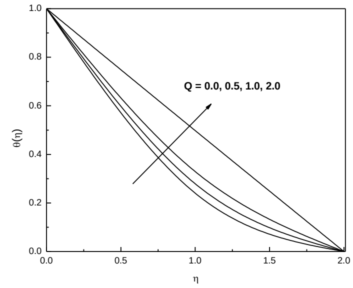

Figure 10: Temperature profiles for different values of *Q*

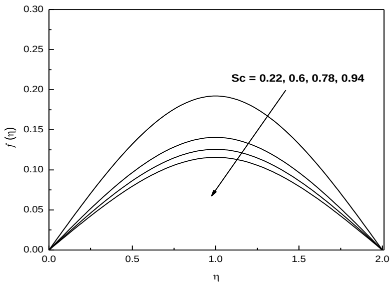

Figure 11: Velocity profiles for different values of *Sc*

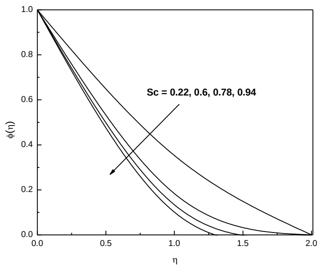

Figure 12: Concentration profiles for different values of *Sc*

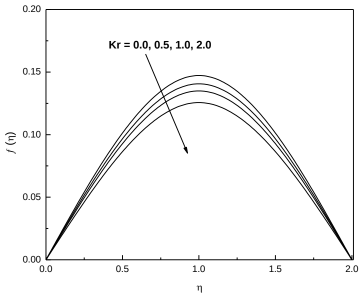

Figure 13: Velocity profiles for different values of *Kr*

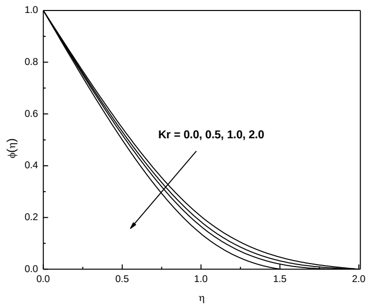

Figure 14: Velocity profiles for different values of *Kr*

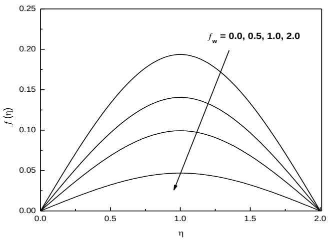

Figure 15: Velocity profiles for different values of f_w

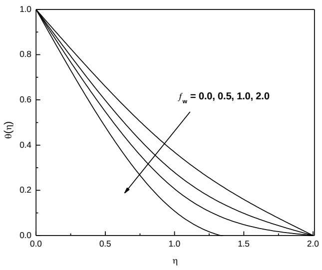

Figure 16: Temperature profiles for different values of f_w

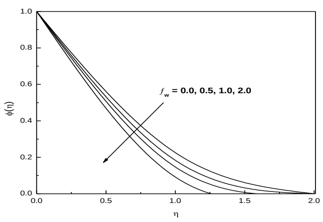

Figure 17: Concentration profiles for different values of f_w

Table 1. Numerical values of $-\theta'(0)$ for various values of Pr and f_w are compared with the results obtained by Sattar et.al [7] and Sharma and Singh [23]

		$-\theta'(0)$		
Pr	f_w	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

Table 2. Skin-friction coefficient, local Nuselt number and local Sherwood number when *Pr = 0.71, 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 Nuselt 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*	C_f	Nu	Sh
0.71	*0.5*	0.666291	0.663917	1.2221
1.0	*0.5*	0.636569	0.776826	1.2221
2.0	*0.5*	0.571317	1.16417	1.2221
0.71	*0.1*	0.653688	0.807677	1.2221
0.71	*0.3*	0.659778	0.737477	1.2221

Table 4. Skin-friction coefficient, local Nuselt number and local Sherwood number when *Gr = 1.0, Gc= 1.0, M = 0.5, K = 0.5, Pr = 0.71, Q = 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

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 figure 10. Boundary layer and thermal boundary layer thicknesses increase considerably in presence of heat generation *Q*.

The influence of the Schmidt number *Sc* on velocity and concentration profiles are plotted in Figure 11 and Figure 12. 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.

The effects of chemical reaction parameter *Kr* on the velocity and concentration distributions are displayed in Figures 13 and Figure 14 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.

The effects of suction parameter f_w on the velocity profiles are shown in Figure. 15. 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 Figures. 16 and Figure 17 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.

It is found from the Table 1 the numerical values of $-\theta'(0)$ for *K = Q = Kr = 0.0* $h = \{= h(t)\} = 2\sqrt{\nu t}$ presented in present paper are in good agreement with those obtained by Sattar et. al. [7] and Sharma and Singh [23].

It is observed from Tables 2 – 4 that on increasing Grashof number *Gr*, modified Grashof number *Gr*, permeability of porous medium *K* 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*, 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 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.

It is found from the Table 1 the numerical values of $-\theta'(0)$ for *K = Q = Kr = 0.0* $h = \{= h(t)\} = 2\sqrt{\nu t}$ presented in present paper are in good agreement with those obtained by Sattar et. al. [7] and Sharma and Singh [23].

It is observed from Tables 2 – 4 that on increasing Grashof number *Gr*, modified Grashof number *Gr*, permeability of porous medium *K* 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*, 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.

Conclusions

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 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 parameter 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.

References

[1] Gebhart B and Pera L (1971), “The Nature of Vertical Natural Convection Flows Resulting from the Combined Buoyancy Effects of Thermal and Mass Diffusion”, *Int. J. Heat Mass Transfer*, 14, pp. 2025-2050.

[2] Ostrach ,S. (1952) An analysis of laminar free convective flow and heat transfer about a flat plate parallel to direction of the generation body force. *NACA Technical Report* 1111.

[3] Soundalgekar, V.M. and Wavre P.D., (1977), "Unsteady free convection flow past an infinite vertical plate with constant suction and mass transfer." *International Journal of Heat and Mass Transfer*, Vol.20, pp. 1363-1373.

[4] Rapits, A.A. and Tzivandis, G.J., (1981). "Mass transfer effects on the flow past an accelerated infinite vertical plate with variable heat transfer", *Acta Mechanica*, Vol. 39, pp. 43-50.

[5] Hossian, M.A. and Begum ,R.A., (1984). "Effect of mass transfer and free convection on the flow past a vertical plate". *ASME Journal of Heat Transfer*,Vol. 106, pp. 664-668.

[6] Sharma,P.R. (1992),Free Convection effects on the flow past a porous medium bounded by a vertical infinite surface with constant suction and constant heat flux- II.J.Phys.D: Appl.phys.,England(UK),Vol.25,pp.162-166.

[7] Sattar ,H.A., Rahman, M.M. and Alam, M.M. (2000). "Free convection flow and heat transfer through a porous vertical plate immersed in a porous medium with variable suction." *Journal of Energy, Heat and Mass Transfer*,Vol. 21, pp. 17-21.

[8] Ferdows ,M.; Sattar, M.A. and Siddiki, M.N.A., (2004)" Numerical approach on parameters of the thermal radiation intersection with convection in boundary layer flow at a vertical plate with variable suction." *Thammasat International Journal of Science and Technology*, Vol.9,pp. 19-28.

[9] Sharma,P.R. and Mishra,U.,(2005),"Unsteady flow and heat transfer along a porous vertical surface bounded by porous medium. *Proc.Nat. Acad.Sci.*,India,Vol.75(A),pp.45-49.

[10] Cramer, K. R. and Pai, S. I. (1973): Magnetofluid dynamics for Engineers and applied Physicists, McGraw-Hill Co., New York.

[11] Gupta, A. S. (1961): Steady and transient free convection of an electrically conducting fluid from a vertical plate in the presence of magnetic field, Appl. Sci. Res., Vol. 9A, pp. 319-333.

[12] Lykoudis, P. S. (1962), Natural convection of an electrically conducting fluid in the presence of a magnetic field, *Int. J. Heat Mass Transfer*, Vol. 5, pp. 23-34.

[13] Nanda, R. S. and Mohanty, H. K. (1970), Hydromagnetic free convection for high and low Prandtl numbers, *J. Phys. Soc. Japan*, Vol. 29, pp. 1608-1618.

[14] Sparrow, E. and Cess, R. 1961. Effect of magnetic field on free convection heat transfer, *International Journal of Heat and Mass Transfer* 3: 267–270.

[15] Soundalgekar V.M, Gupta S.K and Aranake R.N : Free convection currents on MHD Stokes problem for a vertical plate, Nuclear Engg. Design, 51(1979, pp.403-407.

[16] Soundalgekar V.M, Gupta S.K and Birajdar N.S : Effects of Mass transfer and free convection currents on MHD Stokes problem for a vertical plate, Nuclear Engineering Design, Vol.53(1979), pp.339-346.

[17] B. Gebhart. Heat Transfer, McGraw Hill, New York; 1971.

[18] Deka R.K, Das U.N and Soundalgekar V.M (1994), “Effects on Mass Transfer on Flow Past an Impulsively Started

Infinite Vertical Plate with Constant Heat Flux and Chemical Reaction", *Forschungim Ingenieurwesen*, 60, pp. 284-209.

[19] Muthucumaraswamy R and Ganesan (2001), "Effect of the Chemical Reaction and Injection on the Flow Characteristics in an Unsteady Upward Motion of an Isothermal Plate", *J Appl. Mech. Tech. Phys*., 42, pp. 665-671.

[20] Crepeau, J.C. & Clarksean, R. (1997). Similarity solutions of natural convection with internal heat generation *J. Heat Transfer*, 119, 183-185.

[21] Khandelwal R (2013) Unsteady free convective flow of water at 4 degree C and heat transfer through porous medium bounded by a isothermal porous vertical surface in the presence of variable suction and heat generation absorption, *International Journal of Scientific & Engineering Research*, Volume 4, Issue 4, April-2013.

[22] Sharma,P.R. and Gupta, I.(2006),Unsteady flow and heat transfer along a hot vertical porous plate in the presence of periodic suction and heat source. *Model Meas.& Control 'B',AMSE J.,France* , Vol.75(2),pp.61-82.

[23] Sharma, P.R. and Singh G., (2008), Unsteady MHD Free Convective flow and heat transfer along a vertical porous plate with variable suction and internal heat generation, *International Journal of Appl. Math. and Mech.*,Vol. 4 (5), pp. 1-8.

[24] Patil P.M., & Kulkarni, P.S. (2008). Effects of chemical reaction on free convective flow of a polar fluid through a porous medium in the presence of internal heat generation. *International Journal of Thermal Sciences*, 47, 1043-1054.

[25] Salem, M.A., & Abd El-Aziz, M. (2008). Effect of Hall currents and chemical reaction on hydromagnetic flow of a stretching vertical surface with internal heat generation/absorption. *Applied Mathematical Modelling*, 32, 1236-1254.

[26] Samad, M.A., & Mohebujjaman, M. (2009). MHD Heat and Mass Transfer Free Convection Flow anong a Vertical Stretching Sheet in Presence of Magnetic Field with Heat Generation. *Research Journal of Applied Science, Engineering and Technology*, 1(3), 98-106.

[27] Mahdy, A. (2010). Effect of chemical reaction and heat generation or absorption on double-diffusive convection from a vertical truncated cone in a porous media with variable viscosity. *International Communications in Heat and Mass Transfer*, 37, 548-554.

[28] Mohammed Ibrahim S and Lavanya B (2012), Radiation and chemical reaction effects on MHD convective flow over a porous plate through a porous medium with heat generation, International Journal of Fluid Mechanics, Vol. 4, No.2, pp.135-149.

[29] Schlichting H., Gersten K., Boundary Layer Theory, McGraw-Hill Book Co., New York, USA, (2000).

[30] Krishnamurthy, E. V., Sen S. K., Numerical Algorithms, Affiliated East-West Press Pvt. Ltd., New Delhi, India, (1986).

[31] Conte, S. D., Boor, C., Elementary Numerical Analysis, McGraw-Hill Book Co., New York, (1981).