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

Applied Mathematics

Elixir Appl. Math. 92 (2016) 39250-39256

ISSN: 2229-712X

Effects of Thermal Radiation, Heat Generation on Dissipative MHD Flow through a Porous Medium over an Exponential Stretching Sheet with Chemical Reaction

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ARTICLE INFO

Article history:

Received: 6 February 2016;

Received in revised form:

21 March 2016;

Accepted: 26 March 2016;

Keywords

Exponentially Stretching Sheet,

Radiation,

Chemical Reaction.

ABSTRACT

This paper investigate the effects of radiation and first order homogeneous chemical reaction on MHD boundary layer flow of a viscous incompressible radiating fluid towards a porous exponential stretching sheet in the presence of heat generation and viscous dissipation. The governing non linear partial differential equations are transformed into ordinary differential equations by using similarity variables. The resultant system of equations is solved numerically by using Runge-Kutta method along with shooting technique. The effects of governing parameters on the dimensionless velocity, temperature and concentration are discussed graphically while the skin friction coefficient, Nusselt number, Sherwood number are presented in tables. Moreover, the results thus obtained are also compared with the existing literature and were found to be in good agreement for special cases of previous literature

1. Introduction

The boundary layer flow of an electrically conducting fluid in the presence of magnetic field has wide applications in many engineering problems such as MHD generator, plasma studies, nuclear reactors, geothermal energy extraction, and oil exploration. The effect of thermal radiation on the heat transfer processes has various applications such as nuclear reactor cooling system, gas turbines, missiles, satellites and space vehicles. In recent times, the study of MHD boundary layer flow over a stretching sheet has received considerable attention due to its wide range of applications in industry, for example, in manufacturing process such as wire drawing, hot rolling, glass fiber and paper production, the cooling of a metallic plate in a cooling bath. Crane (1970) was the first researcher who considered the boundary layer flow over a stretching sheet. Carragher and crane (1982) investigated the heat transfer aspect of the problem by considering the difference in temperature between the surface and the ambient fluid. It is proportional to the power of the distance from a fixed point. Andersson(1992) reported the flow of a viscoelastic fluid past a stretching sheet in the presence of transverse magnetic field. Vajravelu*et al.*(1993) analyzed the heat transfer characteristics in the laminar boundary layer of a viscous fluid over a linearly stretching sheet in the presence of viscous dissipation and internal heat generation. Siddeshwar(2005) discussed the MHD flow with heat transfer in a viscoelastic liquid over a stretching sheet. Liu (2005) studied the heat and mass transfer of a hydromagnetic fluid past a stretching sheet in the presence of a uniform transverse magnetic field.

Kandaswamy *et al.*(2006) analyzed the effects of chemical reaction, radiation, heat and mass transfer on boundary layer flow over a porous wedge surface in the presence of suction or injection. Joneidi *et al.*(2010) investigated the effect of chemical reaction on MHD free convection flow over a stretching sheet.

The study of heat generation is important in problems dealing with chemical reactions and these are concerned with dissociating fluids. Possible heat generation effects may alter the temperature distribution; consequently, the particle deposition rate in nuclear reactors, electronic chips and semiconductor wafers. Again flows through porous media are of principal interest because these are quite prevalent in nature. Such type of flow finds its applications in a broad spectrum of disciplines covering chemical engineering to geophysics. Cortell(2008) studied the effect of heat generation on fluid flow and heat transfer in a porous medium over a stretching surface. Seddeek(2010) analyzed the effects of radiation, chemical reaction, magnetic field and variable viscosity on MHD flow. Kazem(2011) analyzed steady laminar flow in a porous medium of an incompressible viscous fluid effect on a permeable stretching surface with heat generation. EnamulKarim*et al.*(2012) investigated the effect of Dufour and Soret on MHD free convection flow of viscous and incompressible fluid past an inclined stretching porous plate in the presence of a thermal radiation and heat generation. Vidyasagar *et al.* (2013) presented the MHD convective heat and mass transfer flow over a permeable stretching surface with suction and internal heat generation/absorption.

Most of the available literature investigates the study of boundary layer flow over a linear stretching sheet but most of the practical situations involve a nonlinear stretching sheet. Heat transfer characteristics on the flow past an exponential stretching sheet have wider applications in technology. Magyari and Keller (1999) investigated the steady boundary layers on an exponentially stretching continuous surface with an exponential temperature distribution. Elbashbey (2001) studied the heat transfer over an exponential stretching sheet with suction. Partha *et al.*(2005)discussed the effect of viscous dissipation on the boundary layer flow along vertical exponential stretching sheet.

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Khan (2006) examined the viscoelastic boundary layer fluid flow over an exponentially stretching continuous sheet. Sanjayanand *et al.*(2006) investigated the flow of viscoelastic fluid and heat transfer over an exponentially stretching sheet with viscous dissipation. Sajid*et al.*(2008) investigated the effect of thermal radiation on a boundary layer flow over an exponentially stretching sheet by using Homotopy analysis method. Muthucumaraswamy *et al.*(2008) discussed the mass transfer effects on exponentially accelerated isothermal vertical plate. The effect of radiation on MHD flow of viscous fluid caused by stretching sheet was given by Ishak(2011). Bhattacharyya and Pop (2011) analyzed the effect of external magnetic field on the flow over an exponentially shrinking sheet. Kameswaran(2012) presented a numerical solution of boundary layer flow past an exponential stretching sheet in the presence of viscous dissipation. Jat*et al.*(2013)studied the MHD boundary layer flow over an exponentially stretching sheet with viscous dissipation and radiation effect. And ersson (1992) studied MHD flow of a viscoelastic fluid past a stretching surface.

In view of above investigations, the object of present paper is to investigate effect of various parameters such as heat generation, viscous dissipation and chemical reaction, joule effect, heat and mass transfer characteristics on radiative MHD boundary layer flow of an incompressible viscous fluid over exponentially stretching porous sheet embedded in porous medium. The mathematical formulation of the problem with appropriate boundary conditions is given in section 2. The method of solution of the governing equations is presented in section 3. The Results and Discussion studying the influence of governing parameters on the flow is presented in section 4. The conclusions are given in section 5.

2. Mathematical Formulation

Assuming the two dimensional steady magneto-hydrodynamic boundary layer flow of a dissipative viscous electrically conducting fluid past exponentially stretching sheet embedded in porous medium with the influence of thermal radiation, heat generation, Joule dissipation and chemical reaction, the x-axis is taken along the stretching surface in the direction of the motion and y-axis is perpendicular to it as shown in Figure 1. We assume that the wall temperature $T_w > T_\infty$ where T_∞ is the uniform ambient temperature. We consider that a variable magnetic field $B(x) = B_0 e^{\frac{x}{2L}}$ is applied normal to the sheet and that the induced magnetic field is neglected, which is justified for MHD flow at small magnetic Reynolds number.

Under the above assumptions, the governing boundary layer equations are

Equation of continuity

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y} = 0 \tag{1}$$

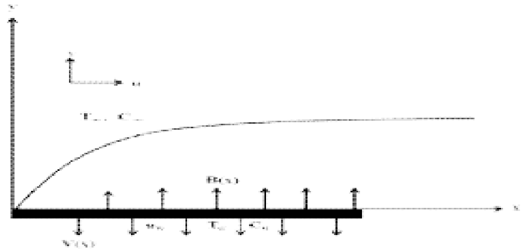

Figure 1. Physical Configuration

Equation of momentum

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y} = \nu\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B^2(x)}{\rho}\,u - \frac{\nu}{K'}u \tag{2}$$

Equation of energy

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y}+\frac{\sigma B^2(x)}{\rho c_p}+\frac{\nu}{c_p}\left(\frac{\partial u}{\partial y}\right)^2 + \frac{Q(x)}{\rho c_p}(T-T_\infty) \tag{3}$$

Equation of mass diffusion

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2}-K_1(C-C_\infty) \tag{4}$$

where u and v are the velocity components along the x and y directions, ν is the kinematic viscosity, σ is the electric conductivity of the fluid, ρ is the density, $K' = K_0\, e^{-x/L}$ is the permeability of the porous medium , T is the temperature, C is the concentration, T_∞ is the temperature far away from the plate, C_∞ is the Species concentration of the ambient fluid, α is the thermal diffusivity, $Q(x) = Q_0\, e^{-x/L}$ is the heat generation parameter, D is the mass diffusivity, q_r is the radiative heat flux and $K_1 = \gamma_1\, e^{x/L}$ is the chemical reaction rate constant. The second, third, fourth and fifth terms on the right hand side of the energy equation (3) represent the Radiative heat flux, Joule dissipation, viscous dissipation and Heat generation effects respectively. The effect of Joule heating is usually characterized by the product of the Eckert number and the Magnetic parameter. The second term on the right hand side of the concentration Eq. (4) represents chemical reaction effect.

The boundary conditions of the flow is given by

$$u = u_w = u_0\, e^{\frac{x}{L}},\ v = 0,\quad T = T_w = T_\infty + T_0\, e^{\frac{x}{2L}},$$
$$C = C_w = C_\infty + C_0\, e^{\frac{x}{2L}} \quad \text{at } y = 0 \tag{5a}$$

$$u \to 0,\ T \to T_\infty,\ C \to C_\infty \ \text{as } y \to \infty \tag{5b}$$

where the subscripts w and ∞ refer to the surface and ambient conditions, u_0 is the characteristic velocity, T_0 is the reference temperature, C_0 is the reference concentration and L is the reference length.

By using the Rosseland approximation (Brewster 1992), we can write the radiative heat flux q_r as

$$\frac{\partial q_r}{\partial y} = -\frac{4}{3}\frac{\sigma^*}{s^*}\frac{\partial T^4}{\partial y} \tag{6}$$

Where σ^* is the Stephen Boltzmann is constant, s^* is the mean absorption coefficient.

We assume that the temperature differences within the flow are sufficiently small so that T^4 can be expanded in a Taylor series about T_∞ and neglecting higher order terms result in

$$T^4 = 4\,T_\infty^3\ T - 3\,T_\infty^4) \tag{7}$$

Substituting equations (6) and (7) into (3) , we get

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{16\sigma^* T_\infty^3}{3s^*\rho c_p}\frac{\partial^2 T}{\partial y^2}+\frac{\sigma B_0^2}{\rho c_p}u^2+\frac{\nu}{c_p}\left(\frac{\partial u}{\partial y}\right)^2+\frac{Q(x)}{\rho c_p}(T-T_\infty) \quad (8)$$

3 Method of Solution

Introducing the stream function ψ such that

$$u=\frac{\partial\psi}{\partial y}$$

and

$v=-\frac{\partial\psi}{\partial x}$ the continuity equation (1) is satisfied automatically.

The momentum, energy and concentration equations were transformed to ordinary differential equations using the following similarity variables:

$$u=u_0\,e^{\frac{x}{L}}\,f'(\eta),$$

$$v=-\left(\frac{\nu u_0}{2L}\right)^{\frac{1}{2}} e^{\frac{x}{2L}}\left[\eta\ f'(\eta)+f(\eta)\right],$$

$$T=T_\infty+T_0\,e^{\frac{x}{2L}}\,\theta(\eta),\quad C=C_\infty+C_0\,e^{\frac{x}{2L}}\,\phi(\eta) \quad (9)$$

Where η is the similarity variable, $f(\eta)$ is the dimensionless stream function, $\theta(\eta)$ is the dimensionless temperature, $\phi(\eta)$ is the dimensionless concentration and prime denotes differentiation with respect to η

Using (9), the governing partial differential equations are transformed to following equations

$$f'''+ff''-2(f')^2-(M+K)f'=0 \quad (10a)$$

$$\left(1+\frac{4R}{3}\right)\theta''+Pr[f\theta'-f'\theta+MEc\left(f'\right)^2+Ec(f'')^2+Q_H\theta]=0 \quad (10b)$$

$$\phi''+Sc[f\phi'-f'\phi-\gamma\phi]=0 \quad (10c)$$

Where

$M=\frac{2L\sigma B_0^2}{\rho u_0}$ is Magnetic parameter,

$K=\frac{2\nu L}{K_0 u_0}$ is Porous parameter,

$Pr=\frac{\rho c_p \nu}{k^*}$ is Prandtl number,

R= $\frac{4\sigma^* T_\infty^3}{s^*\ k^*}$ is Radiation parameter,

$Ec=\frac{u_0^2}{c_p T_0}$ is Eckert number,

$Q_H=\frac{2LQ_0}{u_0\rho c_p}$ is Heat generation parameter,

Sc = $\frac{\nu}{D}$ is Schmidt number,

$\gamma=\frac{2\gamma_1 L}{u_0}$ is Chemical reaction parameter

The corresponding boundary conditions are

$f'=1,\ f=0,\ \theta=1,\ \phi=1$ when $\eta=0$ (11a)

$f'\to 0,\ \theta\to 0,\ \phi\to 0$ as $\eta\to\infty$ (11b)

The most important physical quantities for the problem are skin-friction coefficient (C_f),local Nusselt number (Nu_x) and local Sherwood number (Sh_x) which are defined by

$$Re_x^{1/2}\,C_f=f''(0)$$

$$Re_x^{-1/2}\,Nu=-\theta'(0)$$

$$Re_x^{-1/2}\,Sh=-\phi'(0)$$

where $Re_x=x\,u_w(x)/\nu$ is the local Reynolds number

4. Discussion of the Results

The flow equations 10(a)-10(c) constitute a nonlinear non homogeneous differential equation for which closed-form solution cannot be obtained and hence we are required to solve the problem numerically using Runge Kutta fourth order shooting technique. In the present study, our main aim is to analyze the effects of various physical parameters with the help of some important graphs.

From the process of numerical computation, the main physical quantities of interest, namely, the local skin friction coefficient, the local Nusselt number and the local Sherwood numbers were worked out and their numerical results are presented in Tables. A comparative study of the present result with the existing results is performed and the results are showed in Table 1. It is clearly seen from this table that present results coincide very well with previous results (Bidin and Nazur (2009), MagyariKellar (1999), El Aziz (2009)).

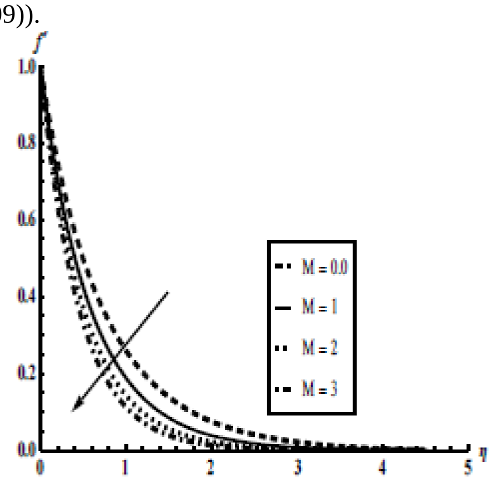

Figure 2. Velocity Profiles for different values of M for K = 0.5, R = 1, Ec = 0.1, Pr = 1, Q_H = 0.1, Sc = 0.24, γ = 0.5

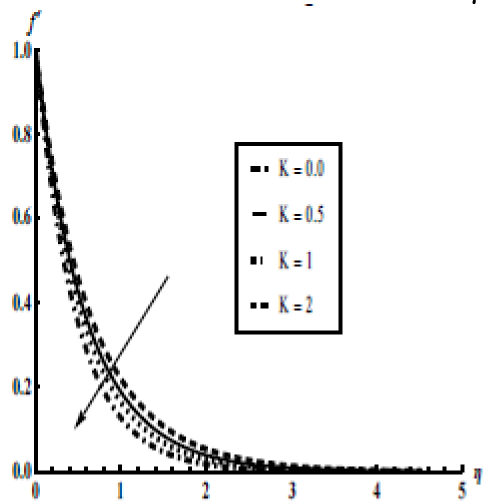

Figure 3. Velocity Profiles for different values of K for M = 1, R = 1, Ec = 0.1, Pr = 1, Q_H = 0.1, Sc = 0.24, γ = 0.5

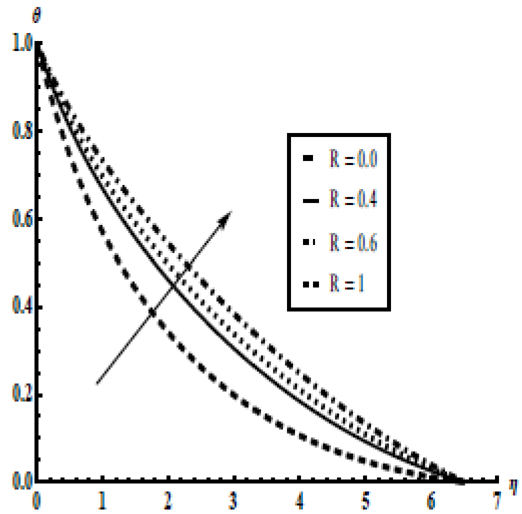

Figure 4. Temperature Profiles for different values of R for M = 1, K = 0.5, Ec = 0.1, Pr = 1, Q_H = 0.1, Sc = 0.24, γ = 0.5

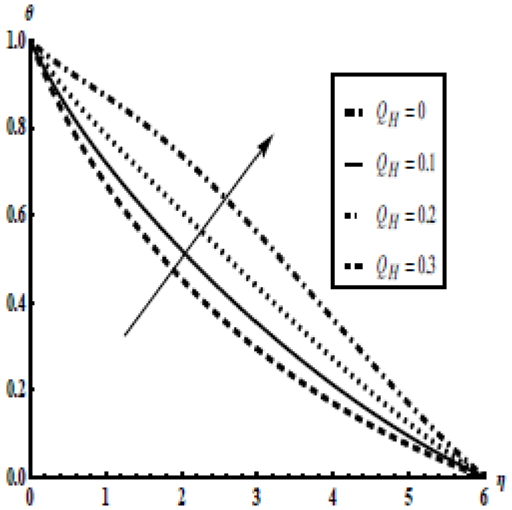

Figure 5. Temperature Profiles for different values of Q_H for M = 1, K = 0.5, R = 1, Ec = 0.1, Pr = 1, Sc = 0.24, γ = .5

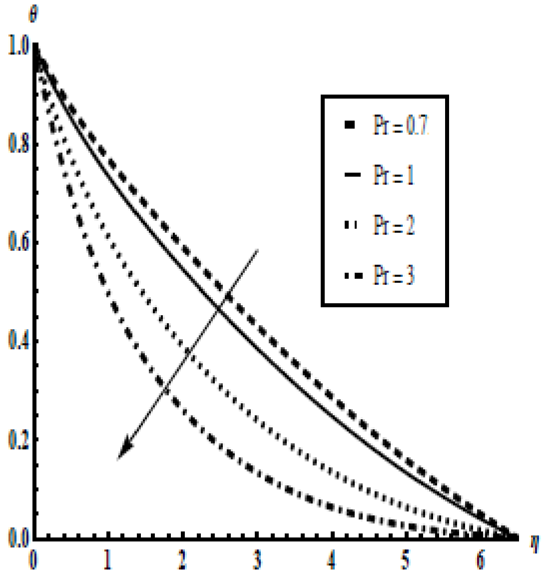

Figure 6. Temperature Profiles for different values of Pr for M = 1, K = 0.5, R = 1, Ec = 0.1, Q_H = 0.1, Sc = 0.24, γ = 0.5

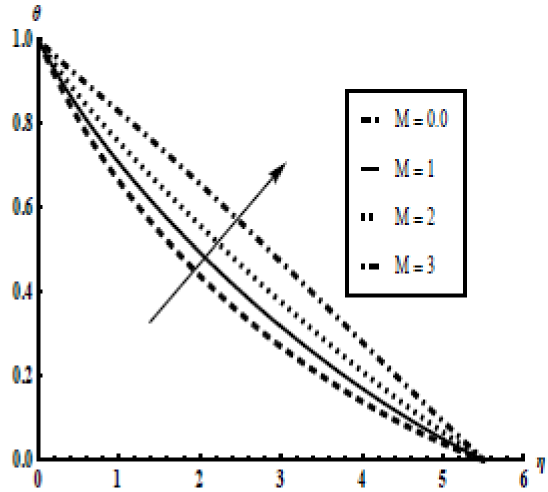

Figure 7. Temperature Profiles for different values of M for K = 0.5, R = 1, Ec = 0.1, Pr = 1, Q_H = 0.1, Sc = 0.24, γ = 0.5

From table 2, it is observed that increasing the Radiation parameter (R) decreases the rate of heat transfer at the surface. However, the skin friction coefficient (C_f) and the rate of mass transfer (Sh) are not affected by the radiation parameter. The magnetic parameter (M) is observed to increase the skin friction coefficient at the surface due to the Lorenz force but it reduces the heat and mass transfer rate at the boundary. Conversely, the rate of mass transfers at the surface increases with increasing values of chemical reaction (γ) and Schmidt number (Sc) while the rate of heat transfer decreases with increasing values of the Eckert number. It is evident from the table that a rise in the values of Prandtl number (Pr) improves the heat transfer rate.

Figure 2 depicts the behavior of velocity profiles for different values of Magnetic parameter M. It is clearly seen that the rate of flow considerably reduces because the transverse magnetic field opposes the fluid transport due to Lorentz force associated with increasing magnetic parameter. Figure 3 represents the effect of porosity parameter K on velocity. It is observed that the velocity decreases with increasing in porosity parameter. Figure 4 shows the variation temperature profiles for different values of the thermal radiation parameter R. This figure indicates that the effect of thermal radiation is to enhance heat transfer because of the fact that thermal boundary layer thickness increases with increase in the thermal radiation parameter. Figure 5 illustrates the variation of temperature profiles for different values of heat generation parameter Q_H. It is observed that the temperature increases as $Q_H$increases. Figure 6 gives the effect Prandtl number on temperature profiles. From this figure it is observed that the temperature decreases with increasing the values of the Prandtl number Prin the thermal boundary layer. From this plot, it is evident that temperature in the boundary layer falls very quickly for large value of the Prandtl number because boundary layer thickness decreases with increase in the value of the Prandtl number. But there is a reverse trend we observed in case of magnetic parameter (figure 7). Figure 8 depicts the temperature profiles for various values of porous parameter (K). It is seen that temperature decreases throughout the boundary layer by increasing the values of K due to the fact that thermal boundary layer decreases with increase in the value of K. Figure 9 shows the graph of non-dimensional temperature profile for different values of Eckert number Ec. The effect of Eckert number Ec is to increase the temperature distribution in flow region. This is due to the fact that heat energy is stored in the liquid due to the frictional heating. Thus the effect of increasing Ec is to enhance the temperature at any point.

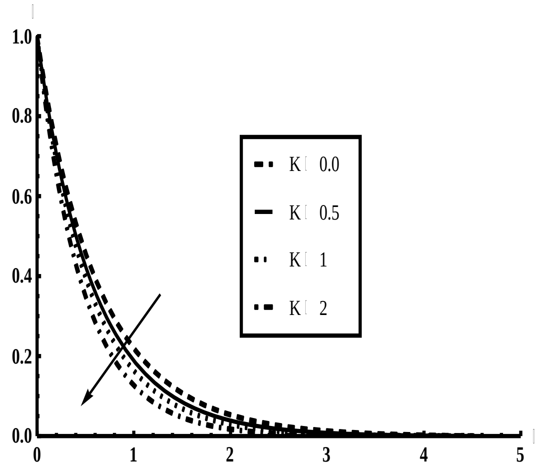

Figure 8. Temperature Profiles for different values of K for M = 1, R = 1, Ec = 0.1, Pr = 1, Q_H = 0.1, Sc = 0.24, γ = 0.5

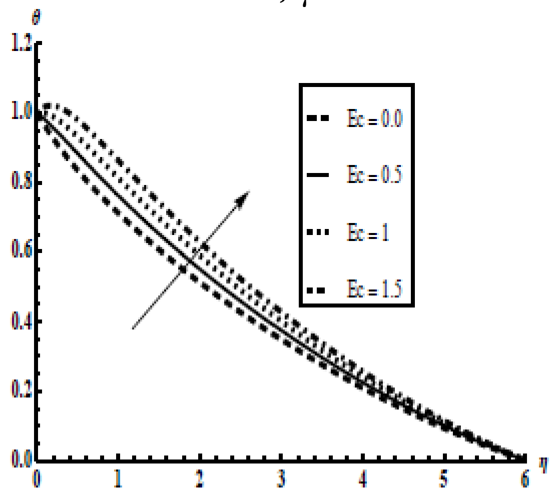

Figure 9. Temperature Profiles for different values of Ec for M = 1, K = 0.5, R = 1, Pr = 1, Q_H = 0.1, Sc = 0.24, γ = 0.5

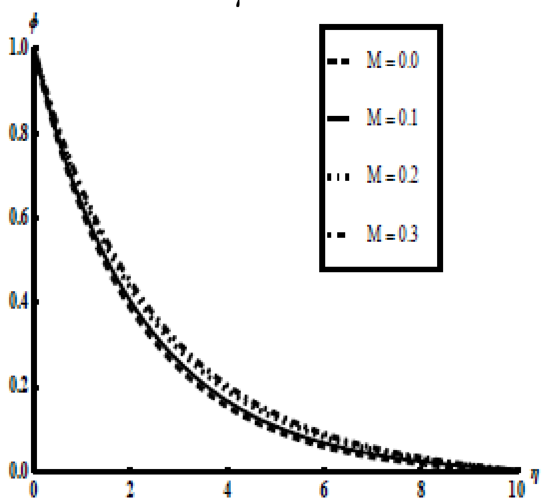

Figure 10. Concentration Profiles for different values of M for K = 0.5, R = 1, Ec = 0.1, Pr = 1, Q_H = 0.1, Sc = 0.24, γ = 0.5

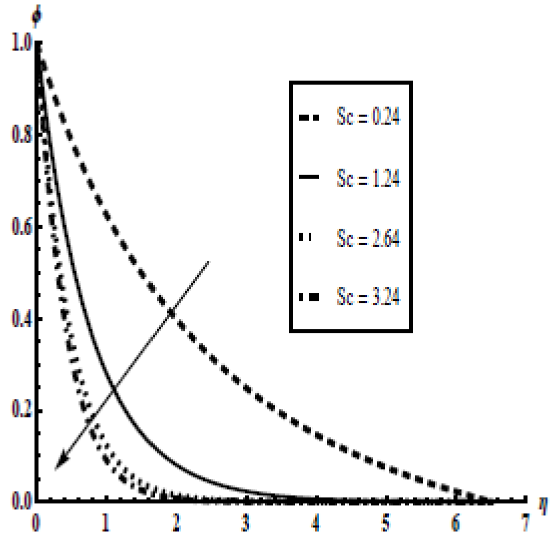

Figure 11. Concentration Profiles for different values of Sc for M = 1, K = 0.5, R = 1, Ec = 0.1, Pr = 1, Q_H = 0.1, γ = 0.5

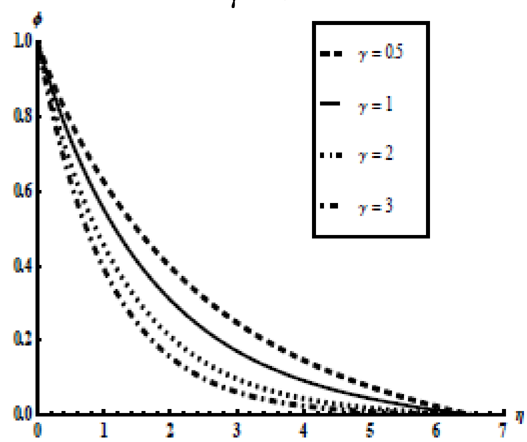

Figure 12. Concentration Profiles for different values of γ when M = 1, K = 0.5, R = 1,Ec = 0.1, Pr = 1, Q_H = 0.1, Sc = 0.24

The effect of magnetic parameter on concentration profiles is shown in figure 10. It is seen that there is a slight increase with increasing Magnetic parameter (M). Figures 11 and 12 give the effects of Schmidt number (Sc) and Chemical reaction (γ) on the solute concentration. The solute concentration within boundary layer naturally decreases with an increase in the chemical reaction. It is observed that the effect of increasing the value of Schmidt number is to decrease the concentration of the diffusive species.

Table 1. Comparison of $-\theta'(0)$ for several values of Prandtl number, Magnetic Parameter, Radiation parameter when Ec = 0, S = 0, Q_H = 0

M	K	Pr	MagyariKellar (1999)	El-Aziz (2009)	Bidin and Nazar (2009)	Present study
0	0	1	0.954782	0.954785	0.9548	0.9548
		2			1.4714	1.4715
		3	1.869075	1.869074	1.8691	1.8691
		5	2.500135	2.500132		2.5001
		10	3.660379	3.660372		3.6604
1		1				0.8611
0	1				0.5315	0.5312
1						0.4505

Table 2. Numerical values of the skin-friction coefficient, Nusselt Number, Sherwood Number for different values of governing parameters

K	M	R	Pr	Ec	Q_H	Sc	γ	$-f''(0)$	$\theta'(0)$	$\phi'(0)$
0	1	1	1	0.1	0.1	0.24	0.5	1.62919	0.412827	0.52258
0.5	1	1	1	0.1	0.1	0.24	0.5	1.77667	0.389037	0.513543
1	1	1	1	0.1	0.1	0.24	0.5	1.91262	0.369075	0.506101
2	1	1	1	0.1	0.1	0.24	0.5	2.15874	0.336997	0.494401
0.5	0	1	1	0.1	0.1	0.24	0.5	1.46669	0.471696	0.54116
0.5	1	1	1	0.1	0.1	0.24	0.5	1.77668	0.408826	0.521476
0.5	2	1	1	0.1	0.1	0.24	0.5	2.03943	0.363954	0.508119
0.5	3	1	1	0.1	0.1	0.24	0.5	2.27175	0.329211	0.49821
0.5	1	0	1	0.1	0.1	0.24	0.5	1.77666	0.618472	0.501751
0.5	1	0.4	1	0.1	0.1	0.24	0.5	1.77666	0.451565	0.501751
0.5	1	0.6	1	0.1	0.1	0.24	0.5	1.77666	0.405132	0.501751
0.5	1	1	1	0.1	0.1	0.24	0.5	1.77666	0.344852	0.501751
0.5	1	1	0.71	0.1	0.1	0.24	0.5	1.77666	0.28717	0.501751
0.5	1	1	1	0.1	0.1	0.24	0.5	1.77666	0.344852	0.501751
0.5	1	1	2	0.1	0.1	0.24	0.5	1.77666	0.550386	0.501751
0.5	1	1	3	0.1	0.1	0.24	0.5	1.77666	0.749839	0.501751
0.5	1	1	1	0	0.1	0.24	0.5	1.77666	0.403195	0.504354
0.5	1	1	1	0.1	0.1	0.24	0.5	1.77666	0.357746	0.504354
0.5	1	1	1	0.5	0.1	0.24	0.5	1.77666	0.175954	0.504354
0.5	1	1	1	0.8	0.1	0.24	0.5	1.77666	0.039609	0.504354
0.5	1	1	1	0.1	0	0.24	0.5	1.77666	0.426694	0.504354
0.5	1	1	1	0.1	0.1	0.24	0.5	1.77666	0.357746	0.504354
0.5	1	1	1	0.1	0.2	0.24	0.5	1.77666	0.272763	0.504354
0.5	1	1	1	0.1	0.3	0.24	0.5	1.77666	0.160959	0.504354
0.5	1	1	1	0.1	0.1	0.24	0.5	1.77666	0.344852	0.501751
0.5	1	1	1	0.1	0.1	1.24	0.5	1.77666	0.344852	1.31615
0.5	1	1	1	0.1	0.1	2.64	0.5	1.77666	0.344852	2.02981
0.5	1	1	1	0.1	0.1	3.24	0.5	1.77666	0.344852	2.27726
0.5	1	1	1	0.1	0.1	0.24	0	1.77666	0.344852	0.330161
0.5	1	1	1	0.1	0.1	0.24	0.5	1.77666	0.344852	0.501751
0.5	1	1	1	0.1	0.1	0.24	1	1.77666	0.344852	0.623973
0.5	1	1	1	0.1	0.1	0.24	2	1.77666	0.344852	0.808007

5. Conclusions

The present chapter deals with analyzing the effect of thermal radiation and chemical reaction on MHD boundary layer flow over an exponentially stretching sheet embedded in a porous medium in the presence of heat generation, Joule dissipation. The equations governing the flow are transformed to ordinary differential equations using similarity variables. The ultimate resulting equations obtained are solved by Runge -Kutta fourth Order along with shooting technique. The present investigation can be concluded as follows:

- The velocity decreases with increasing magnetic parameter.
- Temperature of the fluid decreases with the increasing values of Prandtl number Pr, heat generation parameter.
- Concentration field decreases with increase of Schmidt number and chemical reaction parameter.
- The surface shear stress increases with increasing magnetic parameter.
- The rate of mass transfers at the surface decreases with increasing values of chemical reaction and Schmidt number.
- The rate of heat transfer decreases with increasing values of the Eckert number.
- Heat transfer rate increases with Prandtl number

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