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Research Article

Chemical Reaction and Thermal Radiation Effects on Heat Mass Transfer Flow with Temperature Dependent Thermal Conductivity and Viscosity

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Abstract

A numerical solution of unsteady heat mass transfer flow past an infinite vertical porous plate with temperature dependent viscosity and thermal conductivity is presented, taking into consideration the effects of chemical reaction and thermal radiation. The dimensionless governing equations which are coupled and nonlinear were solved numerically using the implicit finite difference scheme. Graphical results for the velocity, temperature and concentration profiles based on the numerical solutions are presented and discussed. Effects of various parameters on the skin friction, rate of heat and mass transfer were also discussed from the tabular results. Figure 3 pointed that, the velocity increase whenever porosity parameter increases. Similarly, Figure 4 shows that, the velocity increase with increasing thermal Grashof number just like Figure 5 which reveals that, the velocity increase when the mass Grashof number increased. In Figure 7, it is observed that, the concentration decrease with an increase in the Schmidt number and likewise Figure 8 shows that, the concentration decrease with an increase in the suction parameter. Figure 10 shows that, the temperature decreases with an increase in the Prandtl number. Also, Figure 11 indicates that the temperature decrease with an increase of the radiation parameter.

Keywords: Heat Transfer, Mass Transfer, Thermal conductivity, Viscosity, Chemical Reaction, Thermal Radiation.

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Introduction

Natural convection flow occurs frequently in nature. It occurs due to temperature differences as well as concentration differences or the combination of these two. For example, in atmospheric flows, there exists differences in water concentration and hence the flow is influenced by such concentration difference. Boundary layer convection heat and mass transfer flows abound in many areas of chemical engineering. Example, in the molecular evaporator, combined heat and mass transfer exerts a significant role in liquid film performance characteristics (Lutisan *et al.*, 2002). Convective flows with simultaneous heat and mass transfer under the influence of magnetic field and chemical reaction arise in many transport processes both naturally and artificially in many branches of science and engineering applications. This phenomenon plays an important role in the chemical industry, power and cooling industry for drying, chemical vapour deposition on surfaces, cooling of nuclear reactors and petroleum industries.

The study of heat and mass transfer with chemical reaction is of great practical importance in many branches of science and engineering. Anjalidevi and Kandasamy, (1999) studied the effects of chemical reaction, heat and mass transfer on laminar flow along a semi-infinite horizontal plate. Recently, intensive studies have been carried out to investigate the effects of chemical reaction on different flow types as reported by Seddeek *et al.* (2007), Salem and Abd El-Aziz (2008), Ibrahim *et al.* (2008) and Mohamed (2009).

When technological processes take place at higher temperatures, thermal radiation heat transfer become very important and its effects cannot be neglected, Siegel and Howell (2001). The effect of radiation on MHD flow, heat and mass transfer become more important industrially. Many processes in engineering areas occur at high temperature and knowledge of radiation heat transfer becomes very important for the design of pertinent equipment. The quality of the final product depends to a great extent on the heat controlling factors and the knowledge of radiative heat transfer in the system can lead to a desired product with sought qualities. Different researchers analyze the effects of thermal radiation on different flows among which are Cortell (2008), Bataller (2008) Ibrahim *et al.* (2008), Shateyi (2008) which was later extended by Shateyi and Motsa (2009), Aliakba *et al.* (2009), Shateyi *et al.* (2010), Hayat, (2010) and Cortell (2010).

In the recent years, the effect of magnetic field on heat and mass transfer flows through a porous medium has stimulated considerable interest owing to diverse applications in film vaporization in combustion chambers, transpiration cooling of re-entry vehicles, solar wafer absorbers, manufacture of gels, magnetic materials processing, astrophysical flows and hybrid MHD power generators. Interesting analyses of hydromagnetic flow in porous media include the studies by Al-Nimr and Hader (1999) concerning open ended vertical porous channels, Iliuta and Larachi (2003) on multi-phase porous media hydromagnetics under spatially uniform magnetic field gradients in a process intensification context, Dahikar and Sonolikar (2006) who consider hydromagnetic flows in a circulating fluidized bed, Takhar and Bég (1997) that studied numerically the effects of Hartmann number and inertial porous drag on flat plate hydromagnetic boundary layer convection while Geindreau and Auriault (2002) derived a modified permeability tensor for magnetohydrodynamic flow in a Darcian porous medium. Bég *et al.* (2001) used a numerical difference method to analyze the two dimensional steady free convection magneto-viscoelastic flows in a Darcy-Brinkman porous medium. Recently, Bég *et al.* (2008a) used the network thermodynamic simulation approach to study the hydromagnetic convection flow from an isothermal sphere to a non-Darcian porous medium with heat generation or absorption effects. Extensive studies also materialized pertaining to the effects of chemical reaction on coupled heat and mass transfer flows in porous media owing to potential applications in drying technologies, distribution of temperature and moisture over agricultural fields and groves of fruit trees, energy transfer in wet cooling towers, flow in desert coolers and the drying and/or burnout of processing aids in the colloidal processing of advanced ceramic materials. Zueco *et al.* (2008) recently examined the influence of chemical reaction on the hydromagnetic heat and mass transfer boundary layer flow from a horizontal cylinder in a Darcy-Forchheimer regime using network simulation. Bég *et al.* (2007) have analyzed the chemical reaction rate effects on steady buoyancy-driven dissipative micropolar free convective heat and mass transfer in a Darcian porous regime. Many chemical engineering and industrial processes invoke simultaneous convective and radiative heat transfer modes including combustion chambers, glass production and metallurgy. Makinde (2005) studied the free convection flow with thermal radiation and mass transfer past a moving vertical porous plate. Sattar and Kalim (1996) investigated the transient natural convection-radiation boundary layer flow along a vertical porous plate. Chamkha *et al.* (2001) used the Blottner difference method to study laminar free convection flow of air past a semi-infinite vertical plate in the presence of chemical species concentration and thermal radiation effects. Duwairi and Damseh (2004) analyzed the combined effects of forced and natural convection heat transfer in the presence of transverse magnetic field from a vertical surface with radiation heat transfer.

Another effect which bears great importance on heat transfer processes is viscous dissipation. The determination of the temperature distribution when the internal friction is not negligible is of great significance in different industrial fields such as chemical and food processing, oil exploration and bio-engineering. In such scenarios, the effects of viscous dissipation must be included in the energy equation. Several authors recently studied numerically viscous dissipation effects in purely fluid and porous media regimes. Zueco (2007) considered the transient magnetohydrodynamic natural convection boundary layer flow with suction, viscous dissipation and thermal radiation effects. Bég *et al.* (2008b) presented the first analysis of dissipative third grade viscoelastic flow in a Darcy-Forchheimer porous domain using finite elements method. Rapits (1998) discussed the steady flow of two dimensional free convection bounded by a vertical infinite porous plate in the presence of thermal radiation effects. The problem of the unsteady free convection flow of water near 40^0C in the laminar boundary layer over a vertical moving porous plate is investigated by Rapits (2002). Recently, in his pioneering work, Rajeswari *et al.* (2009) included the effects of chemical reaction on heat and mass transfer in non-linear MHD boundary layer flow with vertical porous surface in the presence of suction.

In spite of all the above aforementioned studies, the unsteady MHD free convection heat and mass transfer with temperature dependent viscosity and thermal conductivity in the presence of reacting species over an infinite permeable plate has received little attention. Hence, the main objective of this study is to investigate the effects of thermal radiation and chemical reaction of electrically conducting fluid past an infinite vertical porous plate subjected to variable suction. The plate is assumed to be embedded in a uniform porous medium and moves with a constant velocity in the flow direction in the presence of transverse magnetic field.

The dimensionless governing equations which are coupled and nonlinear were solved numerically using the implicit finite difference scheme. This method has been extensively developed in recent years and remains the simplest as well as one of the best methods for solving partial differential equations.

Graphical results for the velocity, temperature and concentration profiles based on the numerical solutions are presented and discussed. Effects of various parameters on the skin-friction, rate of heat and mass transfer were also discussed from the tabular results.

Problem Formulation

Consider the flow along an infinite vertical plate that is embedded in a porous medium. Let u' and v' be the velocity component along the x' - and y' -directions respectively. If x' - axis is chosen along the plate in the vertically upward direction and y' - axis perpendicular to it, then the investigated flow does not depends on x'. Hence, the continuity equation becomes

$$\frac{\partial v'}{\partial y'} = 0 \tag{1}$$

Initially, the plate and the fluid are at same temperature T'_∞ with concentration level C'_∞. At time t' > 0, the plate temperature and the mass concentration is raised to T'_w and C'_w causing the presence of temperature and concentration difference $T'_w - T'_\infty$ and $C'_w - C'_\infty$ respectively. It is assumed that both the thermal conductivity and the nth order chemical reaction are not constant and the MHD term is derived from an order-of-magnitude analysis of the full Navier-Stokes equations while the porous medium is regarded as an assembly of small identical spherical particles fixed in space. Under these conditions and assuming variation of density in the body force term (Boussinesq's approximation), the problem can be governed by the following set of equations:

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \frac{\partial}{\partial y'}\left(\text{«}\left(T'\right)\frac{\partial u'}{\partial y'}\right) - \frac{\pm B_0^2 u'}{\circ} - \frac{\text{«}\left(T'\right)u'}{k^*} + g \quad \left(T' - T'_\infty\right) + g \quad ^*\left(C' - C'_\infty\right) \tag{2}$$

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - R^*\left(C' - C'_\infty\right)^n \tag{3}$$

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{1}{\circ C_p}\frac{\partial}{\partial y'}\left(K\left(T'\right)\frac{\partial T'}{\partial y'}\right) - \frac{1}{\circ C_p}\frac{\partial q_r}{\partial y'} + \frac{\text{«}\left(T'\right)}{C_p}\left(\frac{\partial u'}{\partial y'}\right)^2 \tag{4}$$

Subject to the initial and boundary conditions

$$\left.\begin{array}{lllll} t' \le 0, & u' = 0, & T' = T'_\infty, & C' = C'_\infty & \text{for all } y' \\ t' > 0, & u' = U_0, & T' = T'_w, & C' = C'_w & \text{at } y' = 0 \\ & u' \to 0, & T' \to T'_\infty, & C' \to C'_\infty & \text{as } y' \to \infty \end{array}\right\} \tag{5}$$

where ³ is the kinematic viscosity of the grey fluid, ± is the Stefan-Boltzmann constant, B_0 is the constant magnetic field intensity, ° is density, k^* is the permeability, g is the gravitational constant, β is the thermal expansion coefficient, * is the concentration

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expansion coefficient, T' is the temperature, C' is the mass concentration, D is the chemical molecular diffusivity, R^* is the chemical reaction, C_p is the specific heat at constant pressure, q_r is the radiative heat flux, u' and v' are velocity components in x and y directions respectively, t' is time, K(T') is the thermal conductivity, «(T′) is the viscosity and n is the reaction order while T'_w is the wall temperature, T'_∞ is the free stream temperature, C'_w is the species concentration at the plate surface, C'_∞ is the free stream concentration.

From the continuity equation (1), it is clear that the suction velocity is either a constant or a function of time. Hence, on integrating equation (1), the suction velocity normal to the plate is assumed in the form, $v' = -¬_0$ where $¬_0$ is a scale of suction velocity which is non-zero positive constant. The negative sign indicates that the suction is towards the plate and $¬_0 > 0$ corresponds to steady suction velocity normal at the surface.

Assuming the radiative heat flux from the Rosseland approximation to have the form

$$\frac{\partial q_r}{\partial y'} = -4\pm a^* \left(T_\infty'^4 - T'^4\right) \tag{6}$$

where σ is the Stefan-Boltzmann constant, a^* is the mean absorption effect for thermal radiation constant. Assuming that the temperature differences within the flow are sufficiently small such that T'^4 can be expanded in a Taylor series about T'_∞ and neglecting higher order terms gives

$$T'^4 \cong 4T'T_\infty'^3 - 3T_\infty'^4 \tag{7}$$

The thermal conductivity and viscosity depends on temperature. It is used by Makinde and Chinyoka (2011) as

$$«\left(T'\right) = «_\infty e^{-¥\left(T'-T'_\infty\right)}, \quad K\left(T'\right) = k_0 e^{-¥\left(T'-T'_\infty\right)} \tag{8}$$

where ¥ is a viscosity variation parameter and $«_\infty$ is the initial fluid dynamic viscosity at temperature $T_\infty{}'$ and k_0 is the thermal conductivity of the ambient fluid.

Method of Solution

To solve the governing equations in dimensionless form, we introduce the following non-dimensional quantities:

$$U=\frac{u'}{U_0},y=\frac{y'U_0}{«_\infty},t=\frac{t'U_0^2}{«_\infty},\bar{}=\frac{T'-T'_\infty}{T'_w-T'_\infty},C=\frac{C'-C'_\infty}{C'_w-C'_\infty},²=¥\left(T'_w-T'_\infty\right),\sim=\frac{¬_0}{U_0},$$

$$Sc=\frac{«_\infty}{D},\Pr=\frac{«_\infty °c_p}{k_0},Ec=\frac{U_0^2}{c_p\left(T'_w-T'_\infty\right)},Gr=\frac{g\ \ «_\infty\left(T'_w-T'_\infty\right)}{U_0^3},Gc=\frac{g\ \ ^*«_\infty\left(C'_w-C'_\infty\right)}{U_0{}^3},$$

$$K=\frac{k^*U_0{}^2}{«_\infty^2},N=\frac{16a±^*T_\infty'^3«_\infty}{k_0U_0},M=\frac{«_\infty±B_0^2}{°U_0{}^2},Kr=\frac{«_\infty R^*\left(C'_w-C'_\infty\right)^{n-1}}{U_0^2}$$

(9)

The governing equations on using (9) into (1), (2), (3), (5) and using (6) - (9) into (4) reduce to

$$\frac{\partial U}{\partial t}-\sim\frac{\partial U}{\partial y}=e^{-²\bar{}}\frac{\partial^2U}{\partial y^2}-²e^{-²\bar{}}\frac{\partial\bar{}}{\partial y}\frac{\partial U}{\partial y}-\mathrm{M}U-\frac{e^{-²\bar{}}}{\mathrm{K}}U+Gr\bar{}+GcC \tag{10}$$

$$\frac{\partial C}{\partial t}-\sim\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2C}{\partial y^2}-KrC^n \tag{11}$$

$$\frac{\partial\bar{}}{\partial t}-\sim\frac{\partial\bar{}}{\partial y}=\frac{e^{-²\bar{}}}{\Pr}\frac{\partial^2\bar{}}{\partial y^2}-\frac{²e^{-²\bar{}}}{\Pr}\left(\frac{\partial\bar{}}{\partial y}\right)^2-\frac{N\bar{}}{\Pr}+Ece^{-²\bar{}}\left(\frac{\partial U}{\partial y}\right)^2 \tag{12}$$

The initial and boundary conditions become

$$\begin{array}{llllll} t\le 0, & U=0, & \bar{}=0, & C=0 & \text{for all } y & \\ t>0, & U=1, & \bar{}=1, & C=1 & \text{at } y=0 & (13)\\ & U\to 0, & \bar{}\to 0, & C\to 0 & \text{as } y\to\infty & \end{array}$$

where Pr is the Prandtl number, Sc is Schmidt number, Ec is Eckert number, Gr is thermal Grashof number, Gc is mass Grashof number, M is magnetic field, K is porosity, N is the radiation, ~ is suction, ² is the viscosity, Kr is the chemical reaction and n is the reaction order parameters.

Numerical Procedure

Equations (10) - (12) are unsteady coupled non-linear partial differential equations and are to be solved under the initial and boundary condition of equation (13). However, exact or approximate solutions are not possible for these set of equations and hence were solved by the implicit finite difference scheme. Equations (10) - (12) yields

$$-qr_1U_{i-1}^{j+1}+(1+2qr_1)U_i^{j+1}-qr_1U_{i+1}^{j+1}=qr_2U_{i-1}^{j}+(1-2qr_2-\text{¥}r_3-qr_4-r_5)U_i^{j}+(qr_2+\text{¥}r_3)U_{i+1}^{j}$$
$$-qr_3^2\left(\bar{}_{i+1}^{\,j}-\bar{}_{i}^{\,j}\right)\left(U_{i+1}^{j}-U_i^{j}\right)+\Delta tGr\bar{}_{i}^{\,j}+\Delta tGcC_i^{j} \qquad (14)$$

$$-r_1C_{i-1}^{j+1}+(Sc+2r_1)C_i^{j+1}-r_1C_{i+1}^{j+1}=r_2C_{i-1}^{j}+(Sc-2r_2-\text{¥}r_3Sc)C_i^{j}+(r_2+\text{¥}r_3Sc)C_{i+1}^{j}$$
$$-KrSc\Delta t\left(C_i^{j}\right)^n \qquad (15)$$

$$-qr_1\bar{}_{i-1}^{\,j+1}+(\Pr+2qr_1)\bar{}_{i}^{\,j+1}-qr_1\bar{}_{i+1}^{\,j+1}=qr_2\bar{}_{i-1}^{\,j}+(\Pr-2qr_2-\text{¥}r_3\Pr-r_7)\bar{}_{i}^{\,j}+(qr_2+\text{¥}r_3\Pr)\bar{}_{i+1}^{\,j}$$
$$-q^2r_6\left(\bar{}_{i+1}^{\,j}-\bar{}_{i-1}^{\,j}\right)^2+qr_6\Pr Ec\left(U_{i+1}^{j}-U_{i-1}^{j}\right)^2 \qquad (16)$$

where $r_1=\frac{\sim\Delta t}{(\Delta y)^2}, r_2=\frac{(1-\sim)\Delta t}{(\Delta y)^2}, r_3=\frac{\Delta t}{\Delta y}, r_4=\frac{\Delta t}{K}, r_5=\Delta tM, r_6=\frac{\Delta t}{4(\Delta y)^2}, r_7=N\Delta t, q=e^{-^2\bar{}_1^{\,j}}$.

The mesh sizes along y- direction and time t-direction are Δy and Δt respectively while the index i refers to space y and j refers to time t. The finite difference equations (14) - (16) at every internal nodal point on a particular n-level constitute a tridiagonal system of equations which are solved by using the Thomas algorithm.

In each time step, the concentration and temperature profiles have been computed first from equations (15) and (16). The computed values are used to obtain the velocity profile which meets the convergence criteria.

The shear stress, rate of heat and mass transfer in terms of skin friction, Nusselt number and Sherwood number respectively are given by

$$C_f=\left(\frac{\partial U}{\partial y}\right)_{y=0},\quad \mathrm{Nu}=\left(\frac{\partial \bar{}}{\partial y}\right)_{y=0},\quad \mathrm{Sh}=\left(\frac{\partial C}{\partial y}\right)_{y=0}$$

Results and Discussion

The numerical solutions are simulated for different values of the Prandtl number (Pr), Schmidt number (Sc), Eckert number (Ec), thermal Grashof number (Gr), mass Grashof number (Gc), radiation (N), magnetic field (M), porosity (K), thermal conductivity (²), suction (~), reaction order (n) and chemical reaction (Kr), parameters. The following parameter values are fixed throughout the calculations except where otherwise stated, Pr = 0.71, Sc = 0.62, Ec = 0.01, M = 1, K = 1, Gr = 1, Gc = 1, N = 0.1, ~ = 1, ^{2} = 0.1, Kr = 0.1 and n = 1.

Figures 1 to 6 illustrates the velocity profiles for different values of Prandtl number (Pr = 0.01, 0.22, 0.71, 7), thermal Grashof number (Gr = 10, 20, 30, 40), mass Grashof number (Gc = 10, 20, 30, 40), magnetic field (M = 1, 5, 10, 15), porosity (K = 0.1, 0.3, 0.5, 0.7) and suction (~ = 2, 4, 6, 8).

Figure 1 shows that the velocity decreases with increasing Prandtl number. Likewise, Figure 2 indicates that, the velocity decrease with increase in the magnetic field parameter. But, Figure 3 pointed that, the velocity increase whenever porosity parameter increases. Similarly, Figure 4 shows that, the velocity increase with increasing thermal Grashof number just like Figure 5 which reveals that, the velocity increase when the mass Grashof number increased. While from Figure 6, it shows that, the velocity decrease with increasing suction parameter.

Figures 7 to 9 represents the concentration profiles for different values of Schmidt number (Sc = 0.62, 0.78, 1, 2.63), suction (~ = 2, 4, 6, 8) and chemical reaction (Kr = 1, 10, 20, 30) parameters as in Figures 4.4.7, 4.4.8, and 4.4.9 respectively.

In Figure 7, it is observed that, the concentration decrease with an increase in the Schmidt number and likewise Figure 8 shows that, the concentration decrease with an increase in the suction parameter. Similarly, Figure 9 reveals that, the concentration decrease whenever the chemical reaction parameter increased.

The temperature profiles have been studied and illustrated in Figures 10 to 13 for different values of Prandtl number (Pr = 0.71, 2.18, 3, 7), radiation (N = 1, 5, 10, 15), suction (~ = 2, 4, 6, 8) and thermal conductivity (^{2} = 0.1, 0.5, 1, 1.5), parameters shown in Figures 10, 11, 12 and 13 respectively.

Figure 10 shows that, the temperature decrease with an increase in the Prandtl number. Also, Figure 11 indicates that the temperature decrease with an increase of the radiation parameter and similarly for the suction parameter, Figure 12 reveals that, the temperature decrease whenever the suction parameter increased. Likewise, Figure 13 shows that, the temperature decrease with an increase of the thermal conductivity parameter.

Tables 1 to 3 are for the skin friction coefficient, Nusselt number and Sherwood number for the numerical solution.

Table 1 illustrates the skin friction for different values of Prandtl number Pr, Schmidt number Sc, chemical reaction Kr, suction ~ , magnetic field M, radiation N and thermal conductivity ^{2} parameters. From the Table, it is noticed that increase in all the parameters leads to decrease of the skin friction.

Table 2 represents the Nusselt number for different values of Prandtl number Pr, thermal conductivity ^{2} , radiation N and suction ~ parameters. In the Table, it is observed that the Nusselt number decreases whenever any of the parameters increased. Similarly, the Sherwood number is demonstrated in Table 3 for different values of Schmidt number Sc, chemical reaction Kr and suction ~ , parameters. Results from the Table shows that the Sherwood number decreases with increase of any of the parameters.

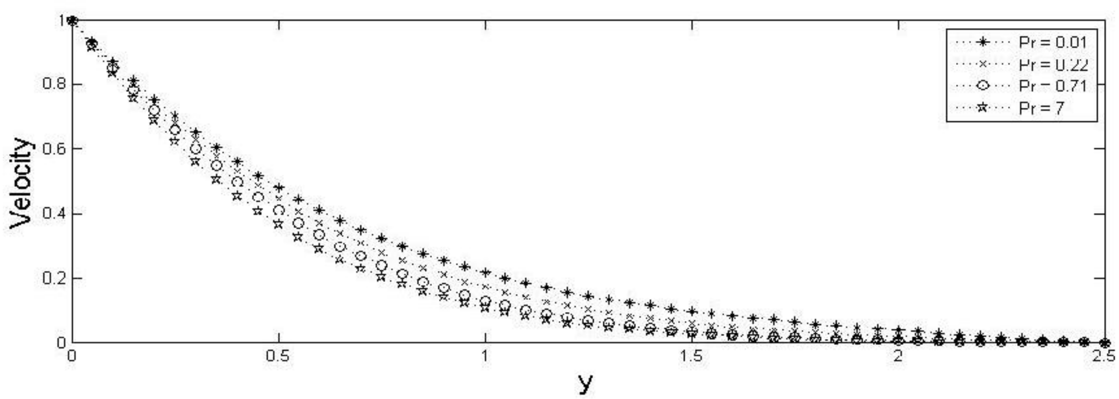

Figure 1: Variation of Velocity against y for different values of Pr.

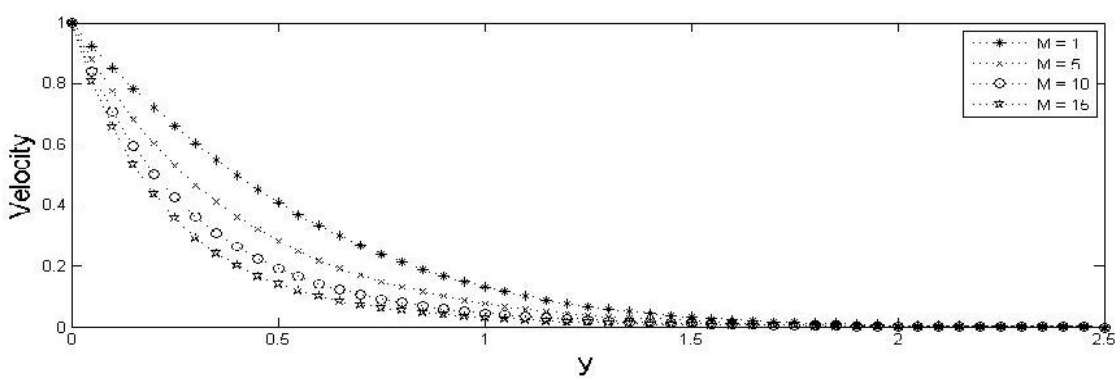

Figure 2: Variation of Velocity against y for different values of M.

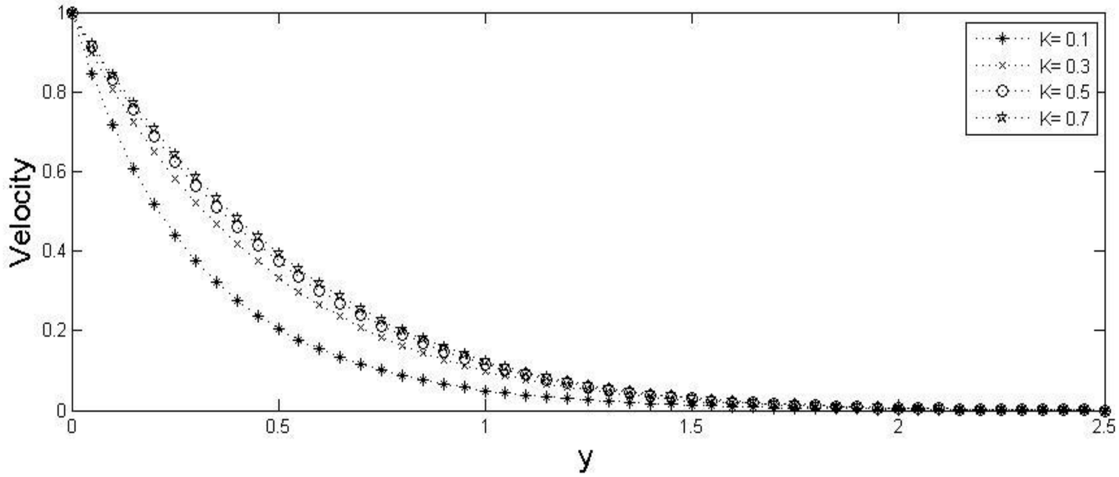

Figure 3: Variation of Velocity against y for different values of K.

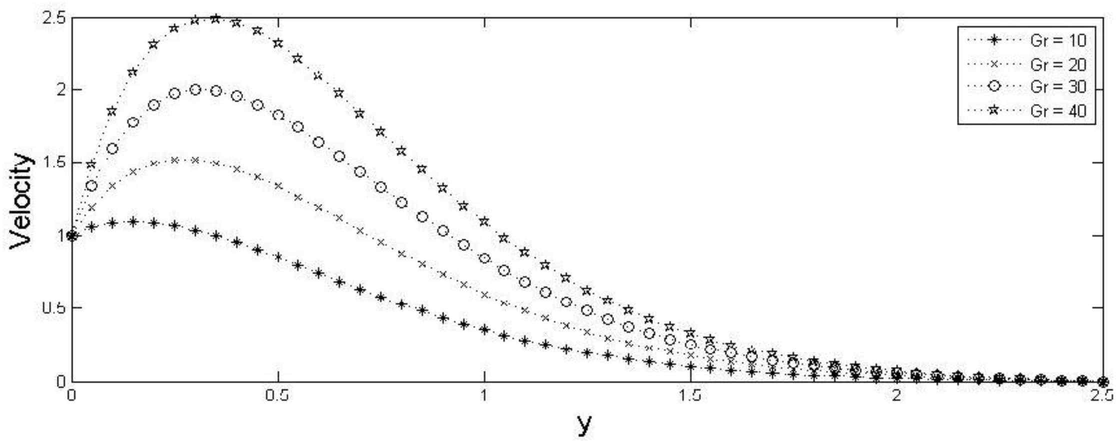

Figure 4: Variation of Velocity against y for different values of Gr.

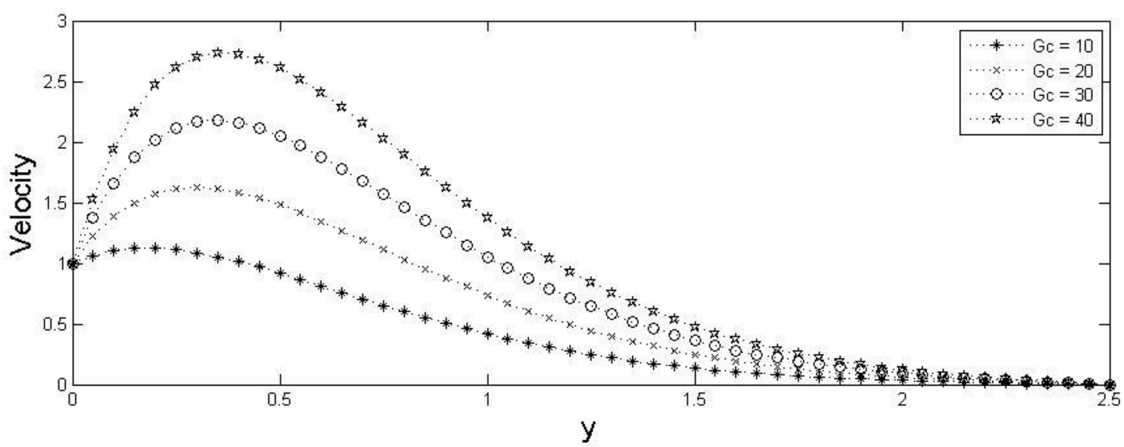

Figure 5: Variation of Velocity against y for different values of Gc.

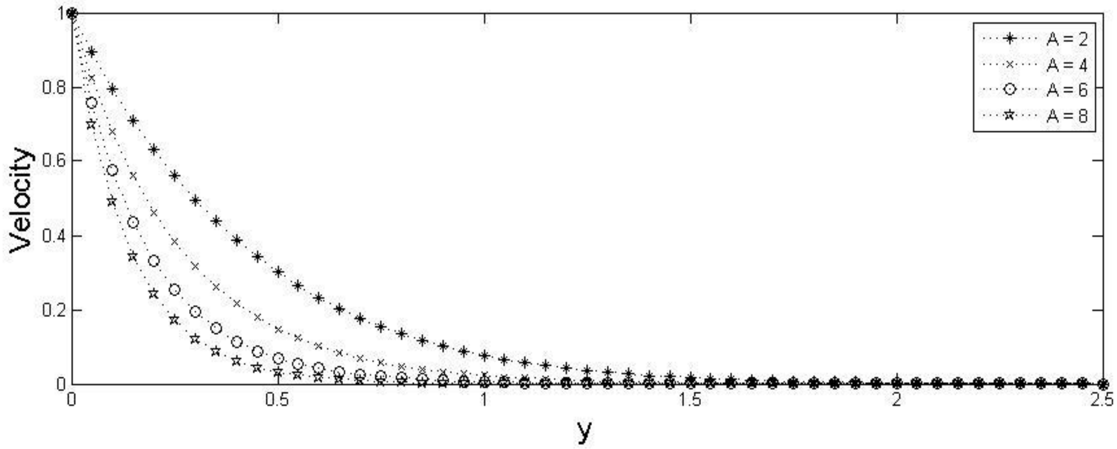

Figure 6: Variation of Velocity against y for different values of~ .

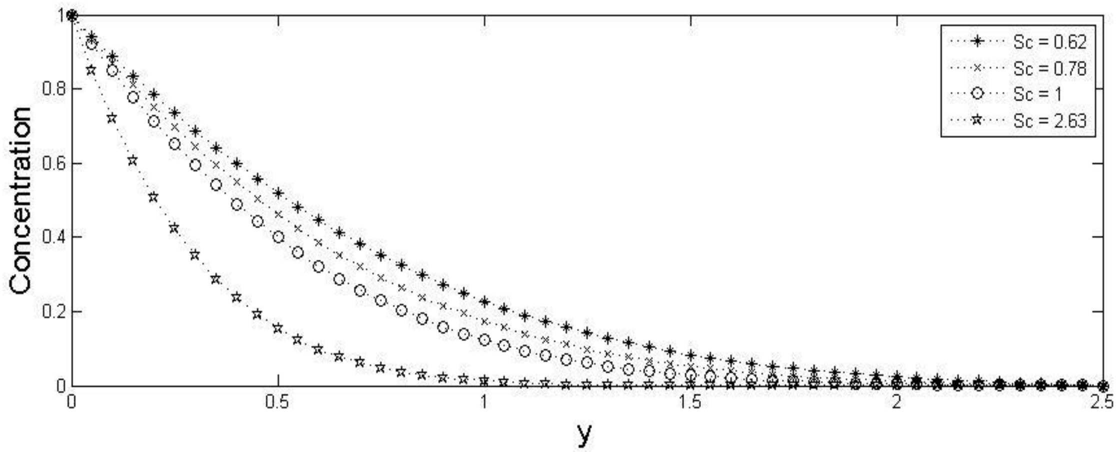

Figure 7: Variation of Concentration against y for different values of Sc.

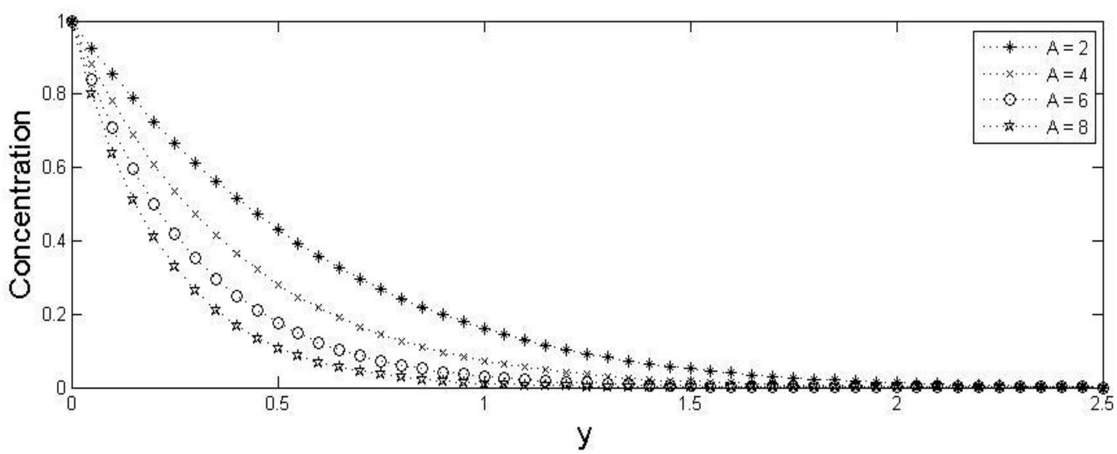

Figure 8: Variation of Concentration against y for different values of~ .

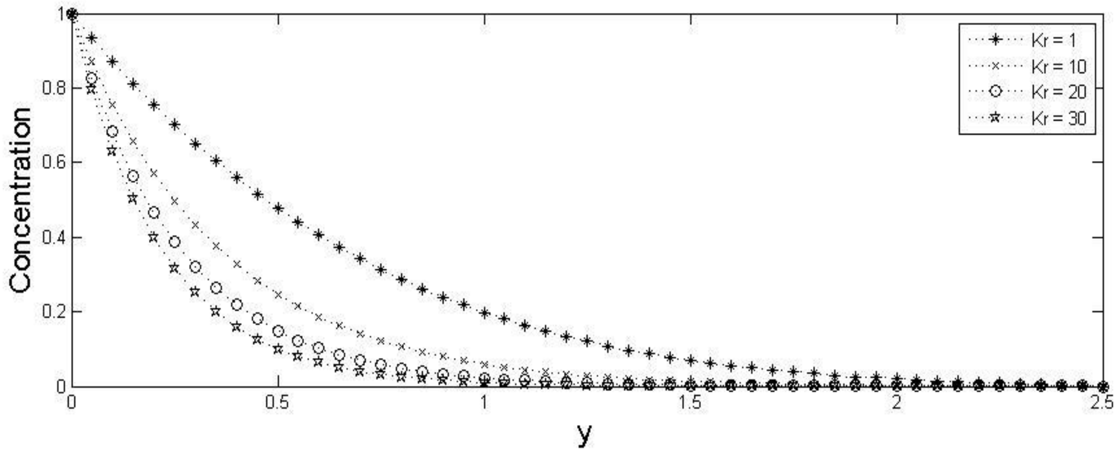

Figure 9: Variation of Concentration against y for different values of Kr.

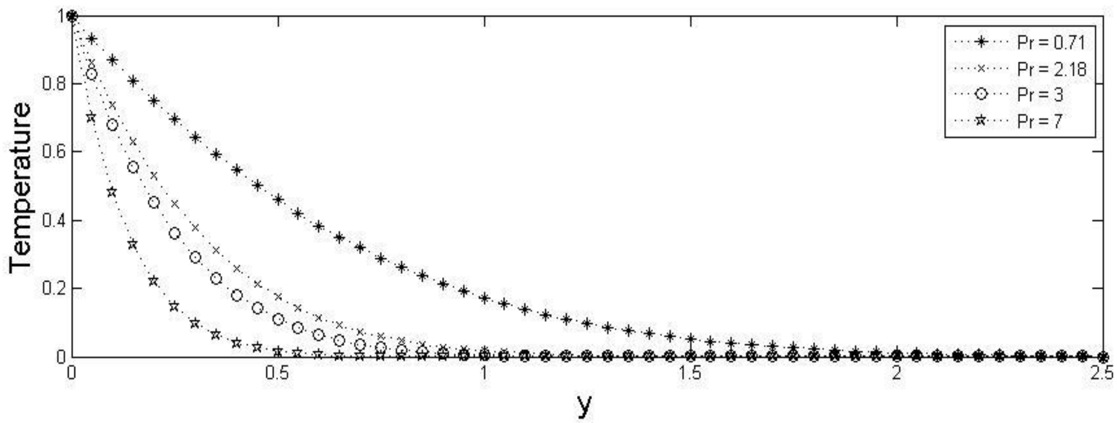

Figure 10: Variation of Temperature against y for different values of Pr.

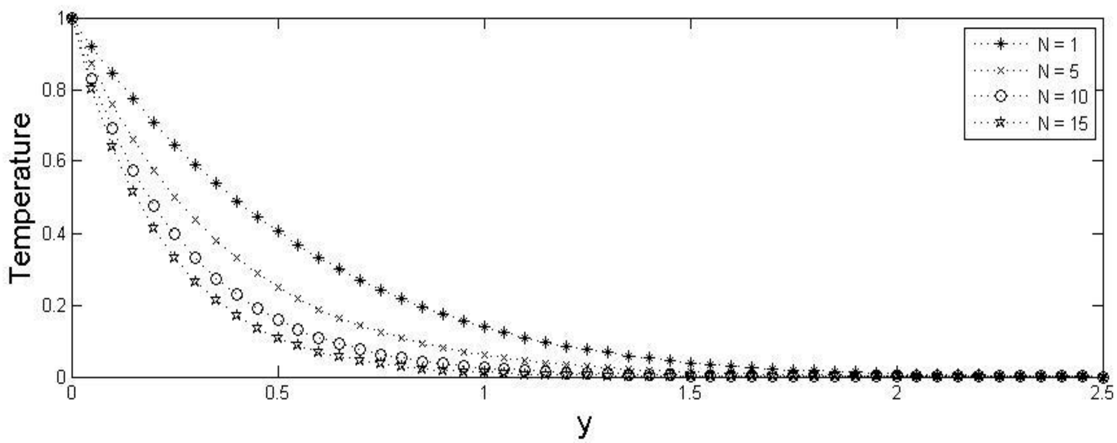

Figure 11: Variation of Temperature against y for different values of N.

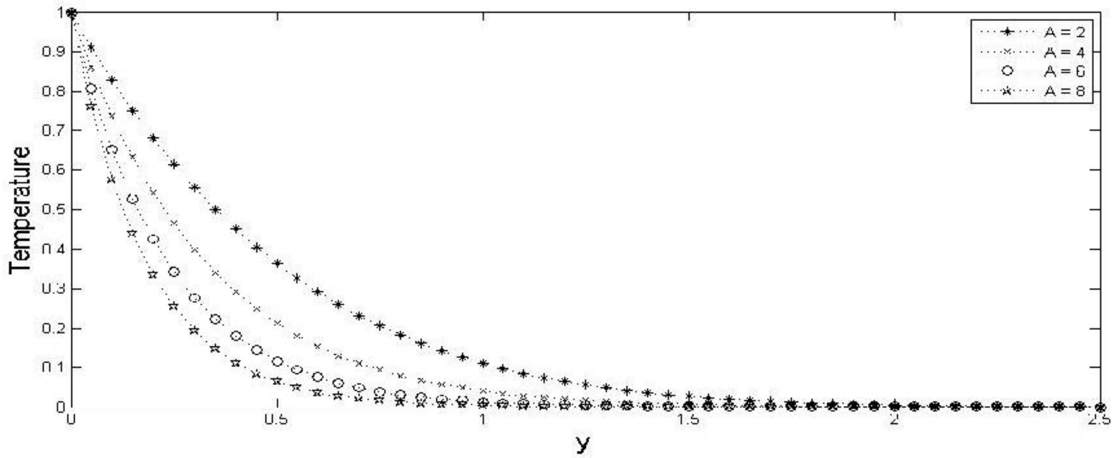

Figure 12: Variation of Temperature against y for different values of ~ .

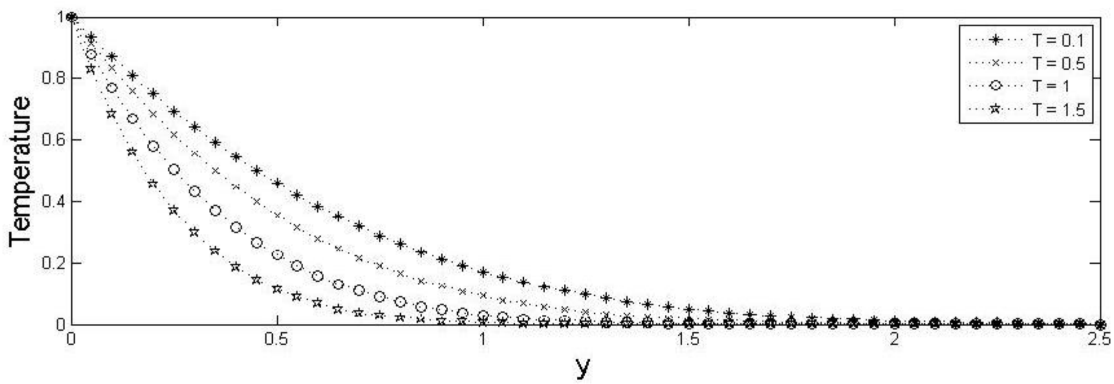

Figure 13: Variation of Temperature against y for different values of ² .

Table 1: Skin friction for different values of Pr, Sc, Kr, ~ , M, N and ² .

Pr	Sc	Kr	~	M	K	²	$-(C_f)$
0.71	0.62	0.1	1	1	1	0.1	1.5579
7	0.62	0.1	1	1	1	0.1	1.7635
0.71	2.63	0.1	1	1	1	0.1	1.9298
0.71	0.62	1	1	1	1	0.1	1.7992
0.71	0.62	0.1	2	1	1	0.1	2.4998
0.71	0.62	0.1	1	5	1	0.1	2.7435
0.71	0.62	0.1	1	1	5	0.1	1.5772
0.71	0.62	0.1	1	1	1	0.1	1.7870
0.71	0.62	0.1	1	1	1	1	2.9181

Where the parameters in the table are: Prandtl number Pr, Schmidt number Sc, chemical reaction Kr, suction ~ , magnetic field M, radiation N and thermal conductivity ² .

Table 2: Nusselt number for different values of Pr, ^{2} , N and ~ .

Pr	^{2}	N	~	-(Nu)
0.71	0.1	0.1	1	1.3660
7	0.1	0.1	1	8.8247
0.71	1	0.1	1	15.0439
0.71	0.1	1	1	8.8815
0.71	0.1	0.1	2	13.2897

Table 3: Sherwood number for different values of Sc, Kr and ~ .

Sc	Kr	~	-(Sh)
0.62	0.1	1	1.1604
2.63	0.1	1	3.1588
0.62	1	1	1.3640
0.62	0.1	2	1.5514

Conclusions

The chemical reaction and thermal radiation effects on heat mass transfer flow with temperature dependent thermal conductivity and viscosity has been studied.

The conclusion from the results shows that:

- The velocity increase whenever the thermal Grashof number, mass Grashof number and porosity parameters increases but decrease with increasing Prandtl number, magnetic field and suction parameters.
- The temperature decrease with increasing Prandtl number, radiation, suction and thermal conductivity parameters.
- The concentration decrease with increase in Schmidt number, suction and chemical reaction parameters.
- The skin friction decrease with increase of Prandtl number, Schmidt number, chemical reaction, suction, magnetic field, radiation and thermal conductivity parameters. Similarly, the Nusselt number decreases whenever the Prandtl number, thermal conductivity, radiation and suction parameters increased like the Sherwood number which decrease with increase of any of Schmidt number, chemical reaction and suction parameters.

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