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

Mechanical Engineering

Elixir Mech. Engg. 60 (2013) 16274-16282

ISSN: 2229-712X

Chemical reaction and radiation effects on MHD free convection flow of dissipative fluid past an exponentially accelerated vertical plate embedded in a porous medium

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ARTICLE INFO

Article history:

Received: 11 May 2013;
Received in revised form:
24 June 2013;
Accepted: 8 July 2013;

Keywords

MHD,
Free convection,
Viscous dissipation,
Implicit finite difference method,
Exponentially accelerated plate,
Variable temperature and chemical reaction.

ABSTRACT

A numerical study is presented on the effects of chemical reaction and magnetic field on the unsteady free convection flow, heat and mass transfer characteristics in a viscous, incompressible and electrically conducting fluid past an exponentially accelerated vertical plate embedded in a porous medium by taking into account the heat due to viscous dissipation. The problem is governed by coupled non-linear partial differential equations. The dimensionless equations of the problem have been solved numerically by the implicit finite difference method of Crank – Nicolson's type. The effects of governing parameters on the flow variables are discussed quantitatively with the aid of graphs for the flow field, temperature field, concentration field, skin-friction, Nusselt number and Sherwood number. It is found that under the influence of chemical reaction, the flow velocity as well as concentration distributions reduce, while the velocity reduces as porous medium increases. Viscous dissipation parameter leads to increase the temperature.

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. Hydromagnetic flows and heat transfer have become more important in recent years because of its varied applications in agricultural engineering and petroleum industries.

Recently, considerable attention has also been focused on new applications of magneto-hydrodynamics (MHD) and heat transfer such as metallurgical processing. Melt refining involves magnetic field applications to control excessive heat transfer rate. Other applications of MHD heat transfer include MHD generators, plasma propulsion in astronautics, nuclear reactor thermal dynamics and ionized-geothermal energy systems.

Pop and Soundalgekar [1] have investigated the free convection flow past an accelerated infinite plate. An excellent summary of applications can be found in Hughes and Young [2]. Takar Samria et al. [3] studied the hydromagnetic free convection laminar flow of an elasto-viscous fluid past an infinite plate.

The studies of convective heat transfer in porous media have been more concerned in the past, with steady state conditions (Nield, D.A. and Bejan, A., [4]). Meanwhile, recent engineering developments have led also to an increasing interest in accurate investigations of the transient processes in these media. A detailed review of the subject including exhaustive list of references can be found in the papers by Bradean et.al. [5]. Chaundhary et.al. [6] analyzed free convection effects on flow past a moving vertical plate embedded in porous medium by Laplace – transform technique.

In all these investigations, the viscous dissipation is neglected. The viscous dissipation heat in the natural convective flow is important, when the flow field is of extreme size or at low temperature or in high gravitational field. Such effects are also important in geophysical flows and also in certain industrial operations and are usually characterized by the Eckert number. Whenever the temperature of surrounding fluid is high, the radiation effects play an important role and this situation does exist in space technology. In such cases one has to take into account the effects of radiation and free convection. A number of authors have considered viscous heating effects on Newtonian flows. Israel-Cookey et al. [7] investigated the influence of viscous dissipation and radiation on unsteady MHD free convection flow past an infinite heated vertical plate in a porous medium with time dependent suction. Zueco Jordan [8] used network simulation method (NSM) to study the effects of viscous dissipation and radiation on unsteady MHD free convection flow past a vertical porous plate. Suneetha et al. [9] have analyzed the effects of viscous dissipation and thermal radiation on hydromagnetic free convection flow past an impulsively started vertical plate. Hitesh Kumar [10] has studied the boundary layer steady flow and radiative heat transfer of a viscous incompressible fluid due to a stretching plate with viscous dissipation effect in the presence of a transverse magnetic field. The study of heat and mass transfer with

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chemical reaction is of great practical importance to engineers and scientists because of its almost universal occurrence in many branches of science and engineering. Possible applications of this type of flow can be found in many industries like power industry and chemical process industries.

Chamkha [11] obtained analytical solutions for heat and mass transfer by laminar flow of a Newtonian, viscous, electrically conducting and heat generating/absorbing fluid on a continuously moving vertical permeable surface in the presence of a magnetic field and first order chemical reaction. Kandaswamy et al. [12] presented an approximate numerical solution of chemical reaction, heat and mass transfer on MHD flow over a vertical stretching surface with heat source and thermal stratification effects. Sharma et al. [13] have investigated the influence of chemical reaction and radiation on an unsteady magnetohydrodynamic free convective flow and mass transfer through viscous incompressible fluid past a heated vertical porous plate immersed in porous medium in the presence of uniform transverse magnetic field, oscillating free stream and heat source when viscous dissipation effect is also taken into account. Anand Rao and Shivaiah [14] have analyzed the effect of chemical reaction on an unsteady MHD free convective flow past an infinite vertical porous plate in the presence of constant suction and heat source.

The objective of the present work is to study the influence of chemical reaction on transient free convection flow of an incompressible viscous fluid past an exponentially accelerated vertical plate embedded in a porous medium by taking into account viscous dissipative heat, under the influence of a uniform transverse magnetic field and thermal radiation in the presence of variable surface temperature and concentration. We have extended the problem of Muthucumaraswamy et al. [15].

Mathematical Analysis

The transient radiative MHD free convection flow of an electrically conducting, viscous dissipative incompressible fluid past an exponentially accelerated vertical infinite plate embedded in a porous medium with chemical reaction of first order has been presented. The present flow configuration is shown in Figure 1.

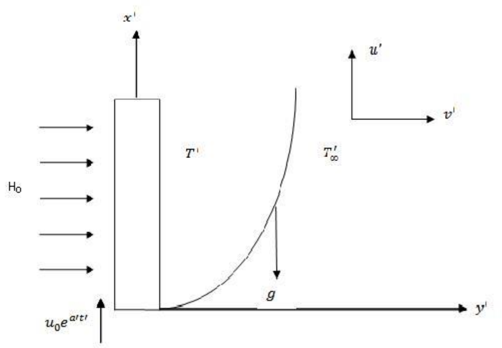

Figure (1): Flow configuration and coordinate system

The x'- axis is taken along the plate in the vertically upward direction and the y'– axis is taken normal to the plate. Since the plate is considered infinite in x'- direction, all flow quantities become self-similar away from the leading edge. Therefore, all the physical variables become functions of t' and y' only. At time $t' \le 0$, the plate and fluid are at the same temperature T'_∞ and concentration C'_∞ lower than the constant wall temperature T'_w and concentration C'_w respectively. At $t' > 0$, the plate is exponentially accelerated with a velocity $u' = u_0 \exp(a't')$ in its own plane and the plate temperature and concentration are raised linearly with time t' Also, it is assumed that there is a homogeneous non-thermic (neither exothermic nor endothermic) chemical reaction of first order with rate constant k_l between the diffusing species and the fluid. The reaction is assumed to take place entirely in the stream. A uniform magnetic field of intensity H_0 is applied in the y' – direction. Therefore the velocity and the magnetic field are given by $\bar{q} = (u, v)$ and $\bar{H} = (0, H_0)$.The fluid being electrically conducting the magnetic Reynolds number is much less than unity and hence the induced magnetic field can be neglected in comparison with the applied magnetic field in the absence of any input electric field. Viscous and Darcy resistance term is taken into account with the constant permeability of porous medium. The heat due to viscous dissipation is taken into an account. Under the above assumptions as well as Boussinesq's approximation, the equations of conservation of mass, momentum, energy and species governing the free convection boundary layer flow past an exponentially accelerated vertical plate can be expressed as:

$$\frac{\partial v'}{\partial y'} = 0 \quad (1)$$

$$\frac{\partial u'}{\partial t'} = g\beta(T' - T'_\infty) + g\beta^*(C' - C'_\infty) + \upsilon \frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma \mu_e^2 H_0^2}{\rho} u' - \frac{\upsilon u'}{k'} \quad (2)$$

$$\rho C_p \frac{\partial T'}{\partial t'} = k \frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q_r}{\partial y'} + \mu \left(\frac{\partial u'}{\partial y'} \right)^2 \quad (3)$$

$$\frac{\partial C'}{\partial t'} = D \frac{\partial^2 C'}{\partial y'^2} - K_l (C' - C'_\infty) \quad (4)$$

with the following initial and boundary conditions:

$$u' = 0,\ T' = T'_\infty,\ C' = C'_\infty; \quad for\ all \quad y', t' \le 0$$

$$t' > 0:\ u' = u_0 \exp(a't'),\ T' = T'_\infty + (T'_w - T'_\infty)At',$$

$$C' = C'_\infty + (C'_w - C'_\infty)At', \qquad at \quad y' = 0$$

$$u' \to 0, \quad T' \to T'_\infty, \quad C' \to C'_\infty, \quad as \quad y' \to \infty$$

Where $A = \frac{u_0^2}{\upsilon}$, T'_w and C'_w are constants not wall values

(5)

Thermal radiation is assumed to be present in the form of a unidirectional flux in the y-direction i.e., q_r (Transverse to the vertical surface). By using the Rosseland approximation [16] the radiative heat flux q_r is given by:

$$q_r = -\frac{4\sigma_s}{3k_e} \frac{\partial T'^4}{\partial y'} \quad (6)$$

It should be noted that by using the Rosseland approximation, the present analysis is limited to optically thick fluids. If temperature differences within the flow are sufficiently small, then equation (5) can be linearized by expanding T'^4 in Taylor series about T'_∞ which after neglecting higher order terms takes the form:

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

In view of equations (6) and (7), equation (3) reduces to:

$$\rho C_p \frac{\partial T'}{\partial t'} = k\frac{\partial^2 T'}{\partial y'^2} + \frac{16\sigma_s}{3k_e}T_\infty'^3 \frac{\partial^2 T'}{\partial y'^2} + \mu\left(\frac{\partial u'}{\partial y'}\right)^2 \tag{8}$$

On introducing the following non-dimensional quantities:

$$u = \frac{u'}{u_0},\quad t = \frac{t'u_0^2}{\upsilon},\quad y = \frac{y'u_0}{\upsilon},\quad \theta = \frac{T'-T'_\infty}{T'_w - T'_\infty},$$

$$M = \frac{\sigma\mu_e^2 H_0^2 \upsilon}{\rho u_0^2},\quad K_1 = \frac{u_0^2 k'}{\upsilon^2}$$

$$Gr = \frac{g\beta\upsilon\left(T'_w - T'_\infty\right)}{u_0^3},\quad \Pr = \frac{\mu C_p}{k}, \tag{9}$$

$$E = \frac{u_0^2}{C_p\left(T'_w - T'_\infty\right)},\quad a = \frac{a'\upsilon}{u_0^2}$$

$$Gc = \frac{g\beta^*\upsilon\left(C'_w - C'_\infty\right)}{u_0^3},\quad C = \frac{C'-C'_\infty}{C'_w - C'_\infty},$$

$$K = \frac{\upsilon K_l}{u_0^2},\quad Sc = \frac{\upsilon}{D},\quad N = \frac{k_e k}{4\sigma_s T_\infty'^3}$$

in equations (1) to (6), lead to

$$\frac{\partial u}{\partial t} = Gr\theta + GcC + \frac{\partial^2 u}{\partial y^2} - (M + \frac{1}{K_1})u \tag{10}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\left[1 + \frac{4}{3N}\right]\frac{\partial^2\theta}{\partial y^2} + E\left(\frac{\partial u}{\partial y}\right)^2 \tag{11}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - KC \tag{12}$$

The initial and boundary conditions in non-dimensional quantities are

$$u = 0,\quad \theta = 0,\quad C = 0 \quad \text{for all} \quad y, t \le 0$$
$$t > 0:\ u = \exp(at),\quad \theta = t,\quad C = t \quad \text{at} \quad y = 0 \tag{13}$$
$$u \to 0,\quad \theta \to 0,\quad C \to 0 \quad \text{as} \quad y \to \infty$$

The skin-friction, Nusselt number and Sherwood number are the important physical parameters for this type of boundary layer flow, which in non-dimensional form respectively are given by:

$$\tau = -\left(\frac{\partial u}{\partial y}\right)_{y=0} \tag{14}$$

$$Nu = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} \tag{15}$$

$$Sh = -\left(\frac{\partial C}{\partial y}\right)_{y=0} \tag{16}$$

NUMERICAL TECHNIQUE

In order to solve the unsteady, non-linear coupled equations (10) - (12) under the initial and boundary conditions (13), an implicit finite difference scheme of Crank-Nicolson's type has been employed. The finite difference equation corresponding to equations (10) - (12) are as follows:

$$\frac{u_{i,j+1} - u_{i,j}}{\Delta t} = \frac{Gr}{2}\left(\theta_{i,j+1} + \theta_{i,j}\right) + \frac{Gc}{2}\left(C_{i,j+1} + C_{i,j}\right) + \left(\frac{u_{i-1,j+1} - 2u_{i,j+1} + u_{i+1,j+1} + u_{i-1,j} - 2u_{i,j} + u_{i+1,j}}{2(\Delta y)^2}\right) - \frac{1}{2}(M + \frac{1}{K_1})(u_{i,j+1} + u_{i,j}) \tag{17}$$

$$\frac{\theta_{i,j+1} - \theta_{i,j}}{\Delta t} = \frac{1}{\Pr}\left[1 + \frac{4}{3N}\right]\left(\frac{\theta_{i-1,j+1} - 2\theta_{i,j+1} + \theta_{i+1,j+1} + \theta_{i-1,j} - 2\theta_{i,j} + \theta_{i+1,j}}{2(\Delta y)^2}\right) + E\left(\frac{u_{i+1,j} - u_{i,j}}{\Delta y}\right)^2 \tag{18}$$

$$\frac{C_{i,j+1} - C_{i,j}}{\Delta t} = \frac{1}{Sc}\left(\frac{C_{i-1,j+1} - 2C_{i,j+1} + C_{i+1,j+1} + C_{i-1,j} - 2C_{i,j} + C_{i+1,j}}{2(\Delta y)^2}\right) - \frac{K}{2}\left(C_{i,j+1} + C_{i,j}\right) \tag{19}$$

Initial and boundary conditions take the following forms

$$u_{i,0} = 0,\quad \theta_{i,0} = 0,\quad C_{i,0} = 0 \quad \text{for all} \quad i \ne 0$$
$$u_{0,j} = \exp(a.j.\Delta t),\ \theta_{0,j} = j.\Delta t,\ C_{0,j} = j.\Delta t$$
$$u_{L,j} = 0,\quad \theta_{L,j} = 0,\quad C_{L,j} = 0 \tag{20}$$

Where L corresponds to ∞.

Here the suffix 'i' corresponds to 'y' and 'j' corresponds to 't'. Also $\Delta t = t_{j+1} - t_j$ and $\Delta y = y_{i+1} - y_i$.

Here we consider a rectangular grid with grid lines parallel to the coordinate axes with spacing Δy and Δt in space and time directions respectively. The grid points are given by y_i = i Δy, i = 1,2,3,---,L-1 and t_j = j Δt, j = 1,2,3 …, P. The spatial nodes on the j[th] time grid constitute the j[th] layer or level. The maximum value of y was chosen as 10 after some preliminary investigations, so that the boundary conditions of equation (20) are satisfied. After experimenting with few sets of mesh sizes, they have been fixed at the level $\Delta y = 0.05$ and the time step $\Delta t = 0.01$, in this case, special mesh size is reduced by 50% and the results are compared. It is observed that when mesh size is reduced by 50% in y – direction, the result differ only in the fifth decimal place.

The complete solution of the discrete equations (17) to (19) proceeds as follows:

(1) Knowing the values of C, θ and u at a time t=j, calculate C and θ at time t=j+1 using equations (19) and (18) and solving the tri diagonal linear system of equations by using Thomas algorithm as discussed in Sastry [17].

(2) Knowing C and θ at times t = j and t = j+1 and u at time t = j, solve equation (17) (via tri diagonal matrix inversion), to obtain u at time t = j+1.

We can repeat steps 1 and 2 to proceed from t = 0 to the desired time value.

The implicit Crank-Nicolson method is a second order method ($O(\Delta t^2)$) in time and has no restrictions on space- and time-steps Δy and Δt, i.e., the method is unconditionally stable (Jain et al, [18]. The derivatives involved in equations (14), (15) and (16) are evaluated using five point approximation formula.

The accuracy of the present model has been verified by comparing with the theoretical solution of Muthucumaraswamy et al. [15] through Figure 2 and the agreement between the results is excellent. This has established confidence in the numerical results reported in this paper.

Results and Discussion

It is very difficult to study the influence of all governing parameters involved in the present problem "the effects of viscous dissipation, heat and mass transfer on the transient MHD free convection flow in the presence of chemical reaction of first order". Therefore, this study is focused on the effects of governing parameters on the transient velocity, temperature as well as on the concentration profiles. To have a physical feel of the problem we, exhibit results to show how the material parameters of the problem affect the velocity, temperature and concentration profiles. Here we restricted our discussion to the aiding of favourable case only, for fluids with Prandtl number Pr = 0.71 which represent air at 20^0 C at 1 atmosphere. The value of thermal Grashof number *Gr* is taken to be both positive and negative, which corresponds to the cooling of the plate and heating of the plate respectively. The diffusing chemical species of most common interest in air has Schmidt number (*Sc*) and is taken for Hydrogen (*Sc* = 0.22), Oxygen (Sc = 0.66), and Carbon dioxide (*Sc* = 0.94).

Extensive computations were performed. Default values of the thermo physical parameters are specified as follows:

Magnetic parameter *M* = 2, thermal Grashof number *Gr* = 5, mass Grashof number *Gc* = 5, Permeability of porous medium K_1 = 0.5, Radiation parameter *N* = 3, Prandtl number *Pr* = 0.71(air), Eckert number *E* = 0.5, Schmidt number *Sc* = 0.22 (hydrogen), chemical reaction parameter K= 1 and time *t* = 0.6. All graphs therefore correspond to these values unless otherwise indicated.

The effects of governing parameters like magnetic field, thermal Grashof number as well as mass Grashof number, acceleration parameter, permeability parameter, radiation parameter, viscous dissipation, Prandtl number, Schmidt number, time and chemical reaction, on the transient velocity have been presented in the respective Figures 3 to 11 for both the cases of cooling and heating of the plate and in presence of foreign species *'Sc = 0.22'*.

Figure (3) illustrate the influences of *'M'* in cases of cooling and heating of the plate. It is found that the velocity decreases with increasing magnetic parameter for air (*Pr = 0.71*) in presence of Hydrogen. The presence of transverse magnetic field produces a resistive force on the fluid flow. This force is called the Lorentz force, which leads to slow down the motion of electrically conducting fluid. Also it is interesting to see that increase in *'M'* leads to decrease the flow velocity in the interval $0 \le y < 1$, while this behaviour is reversed for $y \ge 1$ in case of heating of the plate (*Gr < 0*).

Figs. (4) and (5) reveal the velocity variations with *Gr* and *Gc* in cases of cooling and heating of the surface respectively. It is observed that greater cooling of surface (an increase in *Gr*) and increase in *Gc* results in an increase in the velocity for air. It is due to the fact increase in the values of thermal Grashof number and mass Grashof number has the tendency to increase the thermal and mass buoyancy effect. This gives rise to an increase in the induced flow. The reverse effect is observed in case of heating of the plate (*Gr* < 0).

The effect of acceleration parameter (*a*) in cases of cooling and heating of the plate on the transient velocity (*u*) is plotted in Figure (6). It is noticed that an increase in acceleration parameter leads to increase in *u*.

Fig (7) reveals the effects of, K_1 on the velocity profile. The presence of a porous medium increases the resistance to flow resulting in decrease in the flow velocity. This behavior is depicted by the decrease in the velocity as *'K_1'* decreases. Also it is interesting to see that increase in *'K_1'* leads to decrease the flow velocity in the interval $0 \le y < 0.7$, while this behaviour is reversed for $y \ge 0.7$ in case of heating of the plate (*Gr < 0*).

Fig.(8) display the effects *'E'* on the velocity field for the cases Gr > 0, Gc > 0 and Gr < 0, Gc < 0 respectively. Eckert number is the ratio of the kinetic energy of the flow to the boundary layer enthalpy difference. The effect of viscous dissipation on flow field is to increase the energy, yielding a greater fluid temperature and as a consequence greater buoyancy force. The increase in the buoyancy force due to an increase in the dissipation parameter enhances the velocity in cooling of the plate. Also the reverse effect is noticed in the case of heating of the plate.

The effect of Prandtl number *'Pr'* on the velocity variations is depicted in Fig (9) for both the cases of heating and cooling of the plate. The velocity for Pr=0.71 is higher than that of Pr=7. Physically, it is possible because fluids with high Prandtl number have high viscosity and hence move slowly. The reverse effect is observed in case of heating of the plate (Gr < 0).

Fig (10) represents the velocity profiles due to the variations in *Sc* in cases of heating and cooling of the plate. It is evident from the figure that the velocity decreases owing to an increase in the value of *'Sc'* when the plate is cool. The reverse effect is observed for the heating of the plate.

It is seen from Fig (11) that under the influence of chemical reaction K, the flow velocity reduces in air for cooling of the plate (*Gr>0*). The hydrodynamics boundary layer becomes thin as the chemical reaction parameter increases. The reverse effect is noticed in the case of heating of the plate (*Gr<0*).

The effect of time *'t'* on the velocity in cooling and heating of the plate is shown in Fig. (12). It is obvious from the figure that the velocity increases with the increase of time *'t'* in cooling of the plate. Also the reverse effect is notice in the case of heating of the plate.

Figure (13) reveals the transient temperature profiles against y (distance from the plate). The magnitude of temperature is maximum at the plate and then decays to zero asymptotically. The magnitude of temperature for air (*Pr*=0.71) is greater than that of water (*Pr*=7). This is due to the fact that thermal conductivity of fluid decreases with increasing '*Pr*', resulting a decrease in thermal boundary layer thickness. Also the temperature increases with an increase in the time *'t'* for both air and water.

The effect of radiation parameter '*N*' on the temperature variations is depicted in fig. (14). The radiation parameter *N* (i.e., Stark number) defines the relative contribution of conduction heat transfer to thermal radiation transfer. As *'N'* increases, considerable reduction is observed in temperature profiles from the peak value at the plate (y=0) across the boundary layer regime to free stream $(y \to \infty)$, at which the temperature is negligible for any value of '*N*'.

It is marked from Fig. (15) that the increasing value of the viscous dissipation parameter enhancing the flow temperature for the cases of air and water. However, significantly, it is observed that the temperature decreases with increasing Pr.

Figures 16 and 17 illustrate the dimensionless concentration profiles (*C*) for Schmidt number and chemical reaction (*K*). A decrease in concentration with increasing *'Sc'* as well as *'K'* is observed from these figures. Also, it is noted that the concentration boundary layer becomes thin as the Schmidt number as well as chemical reaction parameter increases.

The effects of magnetic field, porous medium, thermal Grashof number and mass Grashof number on the skin-friction against time *t* are presented in the figure 18. It is noticed that the skin friction increases with an increase in magnetic field and decrease in the permeability of porous medium while it decreases with an increase in thermal Grashof number and mass Grashof number for air.

Figure 19 depicts the Nusselt number against time't' for various values of parameters *'Pr, N* and *E'*. Nusselt number for *Pr*=7 is higher than that of *Pr*=0.71. The reason is that smaller values of *Pr* are equivalent to increasing thermal conductivities and therefore heat is able to diffuse away from the plate more rapidly than higher values of Prandtl number. Hence, the rate of heat transfer is enhanced. It is found that the rate of heat transfer falls with increasing *E*. Also Nusselt number increases as radiation parameter *'N'* increases.

It is marked from Fig. (20) that the rate of concentration transfer increases with increasing values of chemical reaction parameter *'K'* and Schmidt number *'Sc'*.

Conclusions

In this paper effects of chemical reaction and viscous dissipation on MHD free convection flow past an exponentially accelerated vertical plate with variable surface temperature and concentration have been studied numerically. Implicit finite difference method is employed to solve the equations governing the flow.

From the present numerical investigation, following conclusions have been drawn:

- It is found that the velocity decreases with increasing magnetic parameter (M). Also it is interesting to see that increase in *'M'* leads to decrease the flow velocity in the vincinity of the plate while this behaviour is reversed for away from the plate in case of heating of the plate (*Gr < 0*).
- An increase in the dissipation parameter enhances the velocity in cooling of the plate. Also the reverse effect is noticed in the case of heating of the plate.
- The velocity for Pr=0.71 is higher than that of Pr=7.
- Under the influence of chemical reaction, the flow velocity reduces while the velocity increases with the increase of time *'t'* in air for cooling of the plate (*Gr>0*). Also the reverse effect is notice in the case of heating of the plate (*Gr<0*).
- The increasing value of the viscous dissipation parameter enhancing the flow temperature as well as temperature increases with an increase in the time *'t'* for both air and water. However, significantly, it is observed that the temperature decreases with increasing Pr.
- A decrease in concentration with increasing Schmidt number as well as chemical reaction parameter is observed.
- Skin friction increases with an increase in magnetic field, acceleration parameter, Schmidt number and chemical reaction while it decrease with an increase in thermal Grashof number, mass Grashof number, Eckert number for both air and water. The magnitude of the Skin-friction for water is greater than air.
- It is found that the rate of heat transfer falls with increasing magnetic field, acceleration parameter and Eckert number while it increases with an increase in thermal Grashof number.

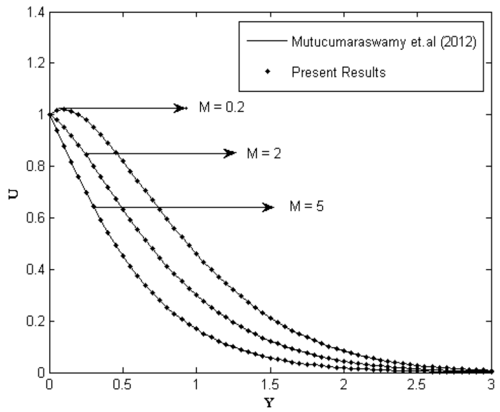

Fig. (2): Comparison of velocity profiles for different values of 'm'

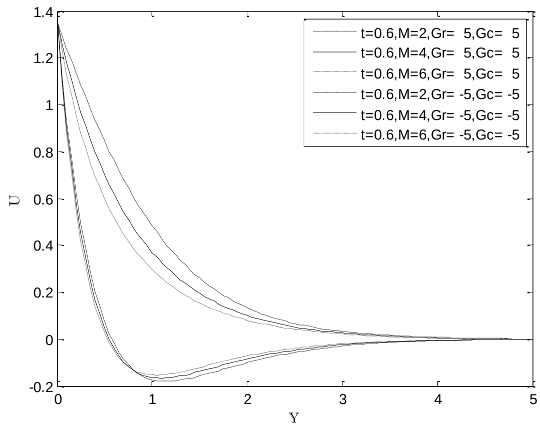

Fig. (3): Velocity profile for different values of 'm'

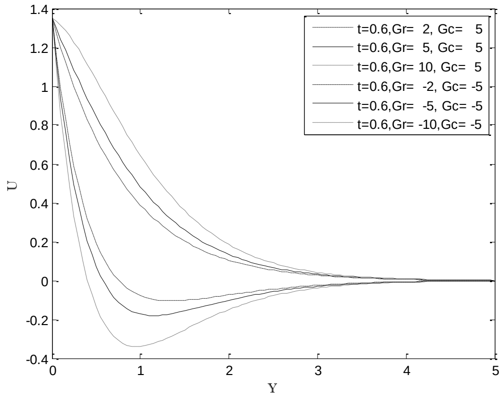

Fig. (4): Velocity profile for different values of 'gr'

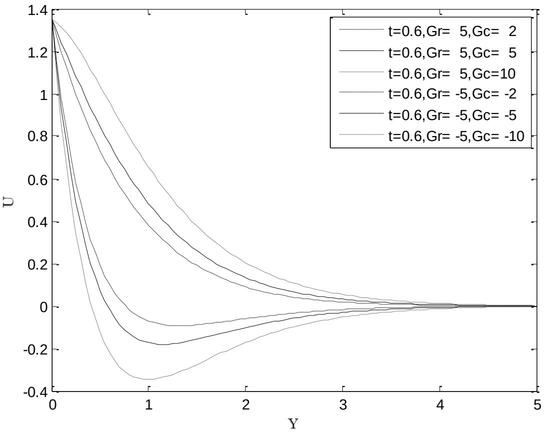

Fig. (5): Velocity profile for different values of 'gc'

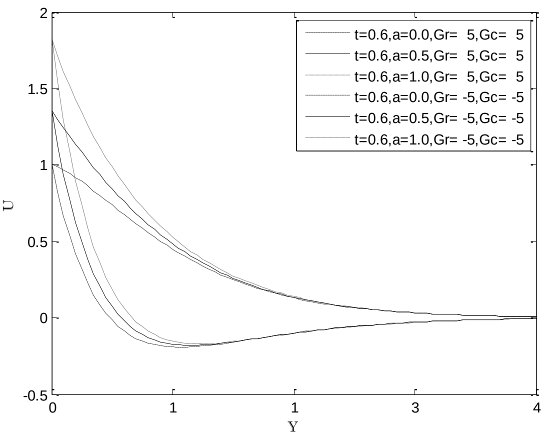

Fig. (6): Velocity profile for different values of 'a'

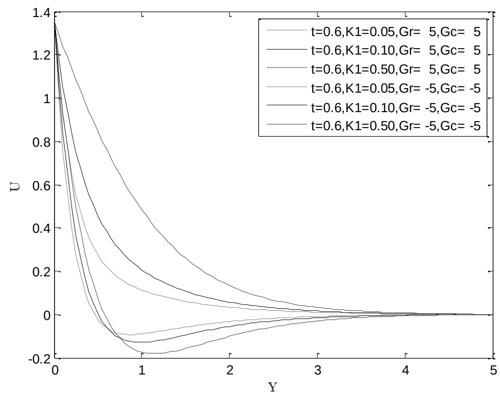

Fig. (7): Velocity profile for different values of 'k_1'

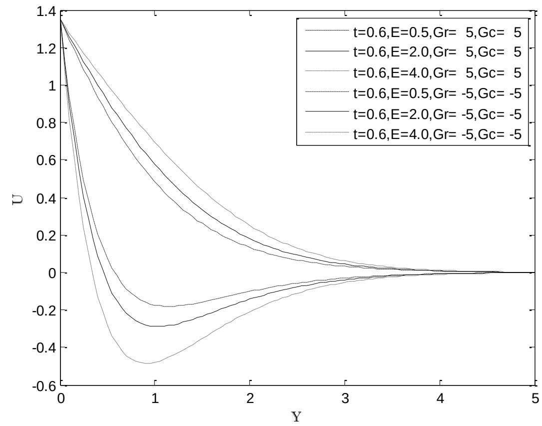

Fig. (8): Velocity profile for different values of 'e'

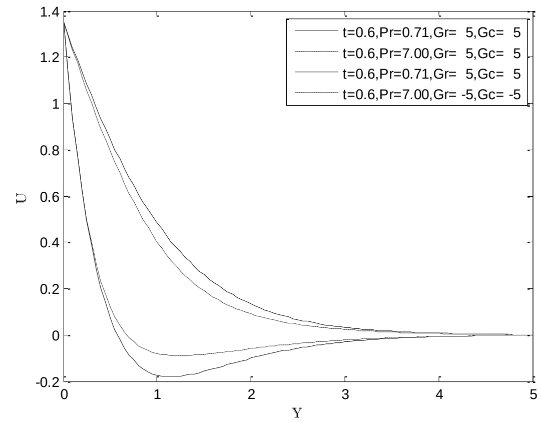

Fig. (9): Velocity profile for different values of 'pr'

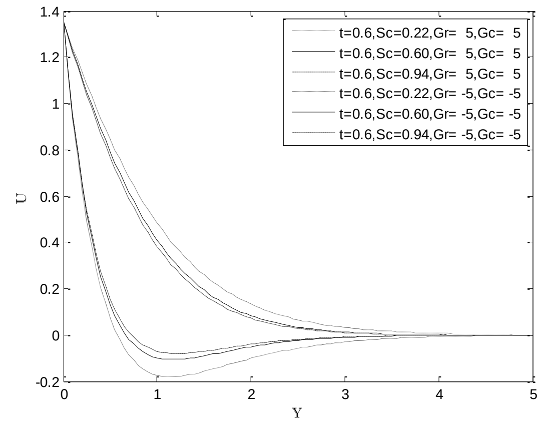

Fig. (10): Velocity profile for different values of 'sc'

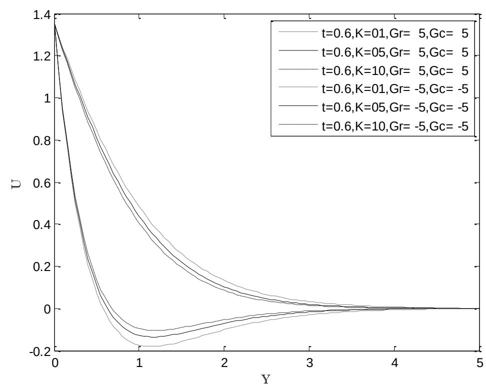

Fig. (11): Velocity profile for different values of 'k'

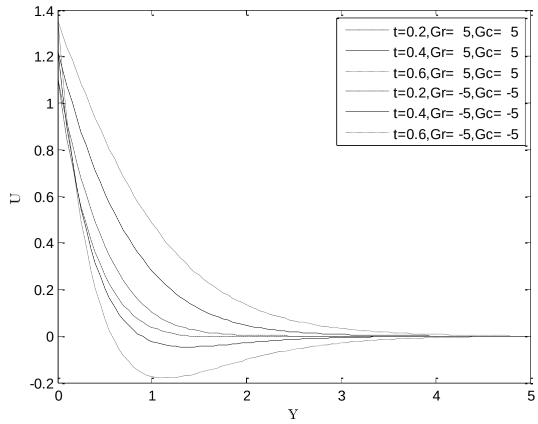

Fig. (12): Velocity profile for different values of 't'

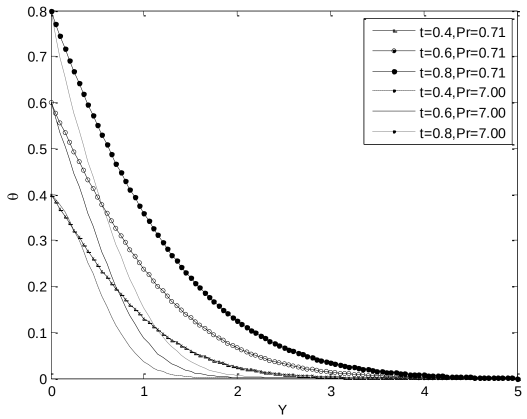

Fig.(13): Temperature profile for different values of 't & pr'

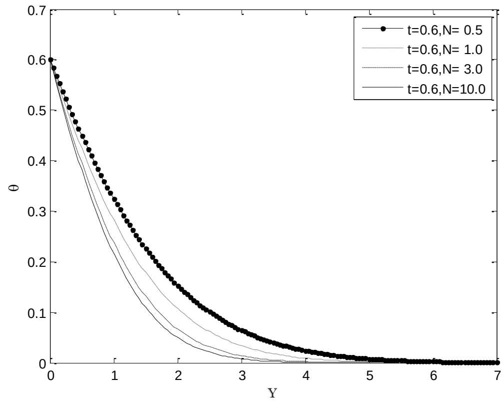

Fig.(14) : Temperature profile for different values of 'n'

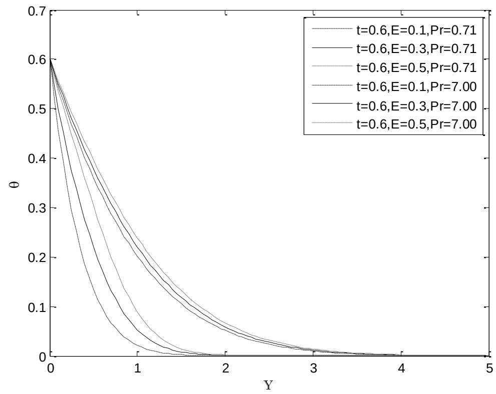

Fig.(15) : Temperature profile for different values of 'e'

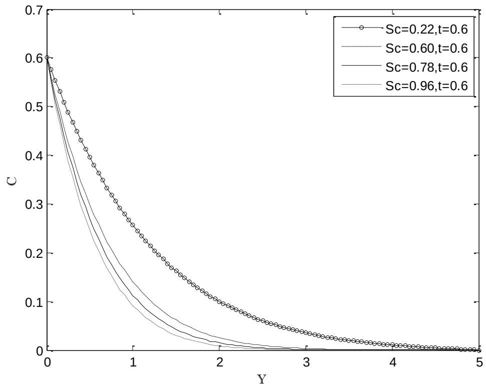

Fig.(16) : Concentration profile for different values of 'sc'

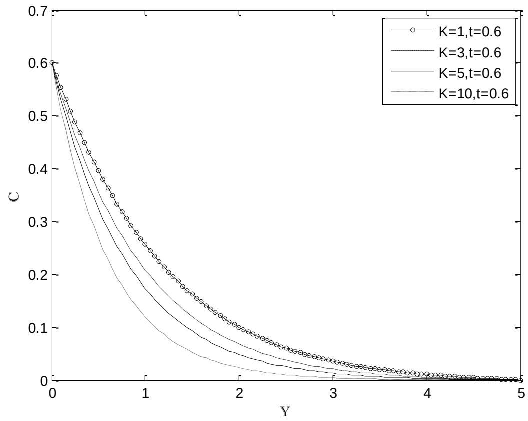

Fig.(17) : Concentration profile for different values of 'k'

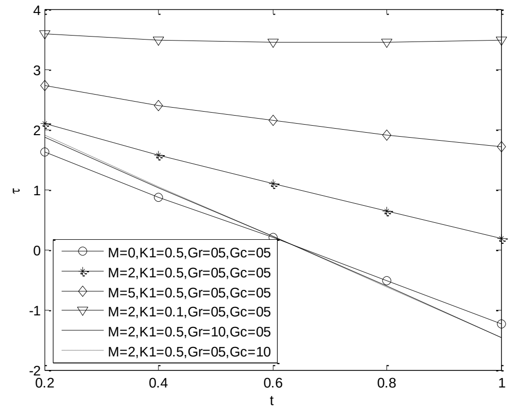

Fig.(18) : Skin friction profile for different values of 'm,k_1,gr & gc'

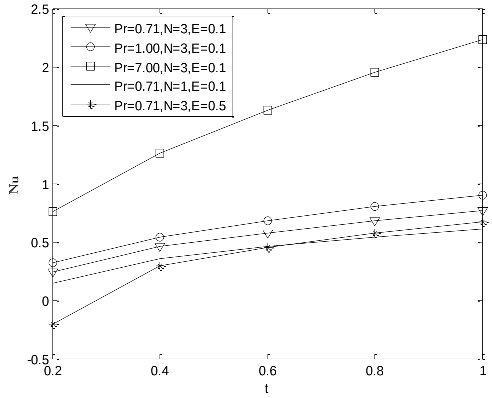

Fig.(19) : Nusselt number profile for different values of 'pr, n & e'

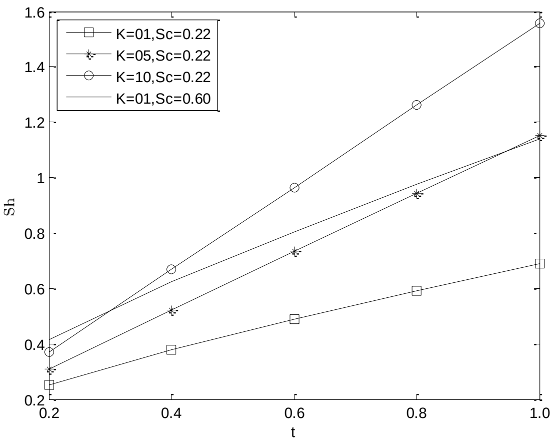

Fig.(20) : Sherwood number profile for different values of 'k & sc'

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Nomenclature

A, a', a	Constants
C_p	Specific heat at constant pressure
C'	Species concentration
C	Dimensionless concentration
D	Mass Diffusion coefficient
E	Eckert number
Gr	Thermal Grash of number
Gc	Mass Grash of number
g	Acceleration due to gravity
H_0	Magnetic field intensity
k	Thermal conductivity
k'	permeability of the porous medium
k_e	mean absorption coefficient
K_l	Chemical reaction coefficient
K	Dimensionless chemical reaction parameter
K_1	permeability parameter
M	Magnetic parameter
Nu	Nusselt Number
Pr	Prandtl number
q_r	the radiation heat flux.
Sc	Schmidt number
T'	Temperature of the fluid near the plate
T	Dimensionless temperature of the fluid near the plate
t'	Time
t	Dimensionless time
u'	Velocity of the fluid in the x' - direction

u_0 Velocity of the plate
u Dimensionless velocity
y' Coordinate axis normal to the plate
y Dimensionless coordinate axis normal to the plate

Greek symbols

β Volumetric coefficient of thermal expansion
$\beta*$ Volumetric coefficient of thermal expansion with concentration
θ Dimensionless temperature
μ Coefficient of viscosity
μ_e Magnetic permeability
υ Kinematic viscosity
ρ Density of the fluid
σ Electrical conductivity of the fluid
σ_s Stefan – Boltzmann Constant
τ Dimensionless shear stress

Subscripts

w Conditions at the wall
∞ Conditions in the free stream