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Radiation and chemical reaction effects on MHD flow past a linearly accelerated isothermal vertical plate with variable mass diffusion

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ABSTRACT

An analytical study is performed to study the effects of thermal radiation and chemical reaction on unsteady free convection and mass transfer of a viscous incompressible fluid past an accelerated infinite isothermal vertical plate in the presence of magnetic field. The fluid considered here is a gray, absorbing/ emitting radiation but a non-scattering medium. It is assumed that the effect of viscous dissipation is negligible in the energy equation and there is a first order chemical reaction between the diffusing species and the fluid. The dimensionless governing coupled linear partial differential equations are solved using the Laplace transform technique. The influence of the various parameters, entering into the problem, on the velocity field and temperature field is extensively discussed with the help of graphs.

Introduction

Natural convection induced by the simultaneous action of buoyancy forces from thermal and mass diffusion is of considerable interest in many industrial applications such as geophysics, oceanography, drying processes and solidification of binary alloy. The effect of magnetic field on free convection flows is important in liquid metals, electrolytes and ionized gases. The thermal physics of MHD problems with mass transfer is of interest in power engineering and metallurgy. When free convection flows occur at high temperature, radiation effects on the flow become significant. Many processes in engineering areas occur at high temperatures and knowledge of radiative heat transfer becomes very important for the design of the pertinent equipment. Nuclear power plants, gas turbines and the various propulsion devices for aircraft, missiles and space vehicles are examples of such engineering areas.

Free convection flows occur not only due to temperature difference, but also due to concentration difference or the combination of these two. The study of combined heat and mass transfer play an important role in the design of chemical reaction processing equipment, nuclear reactors formation and dispersion of fog etc. The effect of presence of foreign mass on the free convection flow past a semi infinite vertical plate was studied by Gebhart and Pera[1].Soundalgekar[2] has studied mass transfer effects on flow past an impulsively started infinite isothermal vertical plate. Das et al[3] considered the mass transfer effects on flow past an impulsively started infinite isothermal vertical plate with constant heat flux.

Gupta et al [4] studied free convection flow past a linearly accelerated vertical plate in the presence of viscous dissipative heat using perturbation method. Kafousis and Raptis[5] extended this problem to include mass transfer effects subjected to variable suction or injection. Mass transfer effects on flow past an accelerated vertical plate was studied by Soundalgekar[6]. Again, Mass transfer effects on flow past an accelerated vertical plate with uniform heat flux, was analyzed by the Singh and Singh [7]. Basant Kumar Jha and Ravindra Prasad [8] analyzed mass thransfer effects on the flow past an accelerated infinite vertical plate with heat sources.

The present trend in the field of chemical reaction analysis is to give a mathematical model for the system to predict the reactor performance. A large amount of research work has been reported in this field. In particular, the study of heat and mass transfer with chemical reaction is of considerable importance in chemical and hydrometallurgical industries. Mass diffusion rates can be changed tremendously with chemical reactions. The chemical reaction effects depend whether the reaction is homogeneous or heterogeneous. This depends on whether they occur at an interface or as a single phase volume reaction. In well-mixed systems, the reaction is heterogeneous, if it takes place at an interface and homogeneous, if it takes place in solution. In majority cases, a chemical reaction depends on the concentration of the species itself. A reaction is said to be first order, if the rate of reaction is directly proportional to the concentration itself. A few representative areas of interest in which heat and mass transfer combined along with chemical reaction play an important role in chemical industries like in food processing and polymer production. Chambre and Young [9] have analysed a first order chemical reaction in the neighbourhood of a horizontal plate. Das et al[10] have studied the effect of homogeneous first order chemical reaction on the flow past an impulsively started vertical plate with uniform heat flux and mass transfer. Again, mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction

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studied by Das et al[11]. The dimensionless governing equations were solved by the usual Laplace Transform technique.

Radiative heat and mass transfer play an important role in manufacturing industries for the design of reliable equipment. Nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering applications. If the temperature of the surrounding fluid is rather high, radiation effects play an important role and this situation does exist in space technology. England and Emery [12] have studied the thermal radiation effects of an optically thin gas bounded by a stationary vertical plate. Soundalgekar and Takhar[13]have considered the radiative free convective flow of an optically thin gray gas past a semi-infinite vertical plate. Radiation effects on mixed convection along an isothermal vertical plate were studied by Hossian and Takhar[14]. Raptis and Perdikis[15]studied the effects of thermal radiation and free convection flow past a moving vertical plate. The governing equations were solved by analytically. Dass et al[16]have analyzed radiation effects on flow past an impulsively started infinite isothermal vertical plate. The governing equations were solved by the Laplace transform technique. Rajesh and varma[17]studied Radiation and mass transfer effects on MHD free convection flow past an exponentially accelerated vertical plate with variable temperature.

In this paper, an investigation is carried out to study the effects of radiation on unsteady MHD free convective flow past an linearly accelerated isothermal vertical plate with variable mass diffusion in the presence of a first order homogeneous chemical reaction and applied transverse magnetic field. The dimensionless governing equations are solved by using Laplace transform technique and the solutions are derived in terms of exponential and complementary error functions.

Mathematical formulation

In this problem, we consider the unsteady hydromagnetic radiative flow of viscous incompressible fluid past a linearly accelerated infinite isothermal vertical plate with variable mass diffusion in the presence of chemical reaction of first order and applied transverse magnetic field. Initially, the plate and the fluid are at the same temperature T_∞' in the stationary condition with concentration level C_∞' at all the points. At time t'>0, the plate is accelerated with a velocity $u=\frac{u_0{}^3}{v}t'$, in its own plane and at the same time the temperature of the fluid near the plate is raised linearly with time t and species concentration level near the plate is also increased linearly with time t . All the physical properties of the fluid are considered to be constant except the influence of the body-force term. A transverse magnetic field of uniform strength B_0 is assumed to be applied normal to the plate. Then under Boussinesq's approximation, the unsteady flow is governed by the following set of equations:

$$\frac{\partial u}{\partial t'}=g\beta(T-T_\infty)+gB^*(c'-c_\infty')+\nu\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0^2 u}{\rho}\ldots\ldots\ldots\ldots(1)$$

$$\rho C_p\frac{\partial T}{\partial t'}=k\frac{\partial^2 T}{\partial y^2}-\frac{\partial q_r}{\partial y}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$\frac{\partial c'}{\partial t'}=D\frac{\partial^2 c'}{\partial y^2}-K_1(c'-c_\infty')\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

With the following initial and boundary conditions

u=0, $T=T_\infty$, $C'=C_\infty'$ for all y, $t'\leq 0$

$$u=\frac{u_0^3}{v}t', T=T_w,\ C'=C'_\infty+(C'_w-C'_\infty)At', \text{ at } y=0\ldots\ldots\ldots(4)$$

$$u\to 0, T\to T_\infty, c'\to c'_\infty\ as\ y\to\infty$$

The local radiant for the case of an optically thin gray gas is expressed by

$$\frac{\partial q_r}{\partial y'}=-4a^*\sigma(T_\infty^4-T^4)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

It is assumed that the temperature differences within the flow are sufficiently small such that T^4 may be expressed as a linear function of the temperature. This is accomplished by expanding T^4 in a Taylor series about T_∞ and neglecting higher-order terms, thus

$$T^4=4T_\infty^3T-3T_\infty^4\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

By using equations (5) and (6), equation (2) reduces to

$$\rho C_p\frac{\partial T}{\partial t'}=K\frac{\partial^2 T}{\partial y^2}+16a^*\sigma T_\infty^3(T_\infty-T)\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

On introducing the following non-dimensional quantities:

$$U=\frac{u}{u_0}, t=\frac{t'u_0^2}{v}, Y=\frac{yu_0}{v}, \theta=\frac{T-T_\infty}{T_w-T_\infty}, Gr=\frac{g\nu\beta(T_w-T_\infty)}{u_0^3},$$

$$C=\frac{C'-C'_\infty}{C'_w-C'_\infty}, K=\frac{K_1 v}{u_0^2}, Sc=\frac{v}{D}, R=\frac{16a^*\sigma T_\infty^3}{k}\left(\frac{v}{u_0^2}\right)\ldots\ldots\ldots\ldots(8)$$

$$Gc=\frac{g\nu\beta^*(C'_w-C'_\infty)}{u_0^3}, M=\frac{\sigma B_0^2 v}{\rho u_0^2}, \Pr=\frac{\mu C_p}{k}, A=\frac{u_0^2}{v}$$

In equations (1) to (4), leads to

$$\frac{\partial U}{\partial t}=Gr\,\theta+Gc\,C+\frac{\partial^2 U}{\partial Y^2}-MU\ldots\ldots\ldots\ldots(9)$$

$$\frac{\partial\theta}{\partial t}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial Y^2}-\frac{R}{\Pr}\theta\ldots\ldots\ldots\ldots(10)$$

$$\frac{\partial C}{\partial t}=\frac{1}{Sc}\frac{\partial^2 C}{\partial Y^2}-KC\ldots\ldots\ldots\ldots(11)$$

The initial and boundary conditions in non-dimensional quantities are

$$U=0,\theta=0,C=0\ for\ all\ Y, t\leq 0$$

$$t>0: U=t,\theta=1,C=t, at\ Y=0\ldots\ldots\ldots\ldots(12)$$

$$U\to 0,\theta\to 0,C\to 0\ as\ Y\to\infty$$

Solution Procedure

The solutions are in terms of exponential and complementary error function. The relation connecting error function and its complementary error function is as follows:

erfc(x) = 1- erf(x)

The dimensionless governing equations (9) to (11), subject to the initial and boundary conditions (12), are solved by the usual Laplace transform technique and the solutions are derived as follows:

$$C=\frac{t}{2}\left[\exp(2\eta\sqrt{kt})erfc(\eta\sqrt{Sc}+\sqrt{kt})+\exp(-2\eta\sqrt{kt})erfc(\eta\sqrt{Sc}-\sqrt{kt})\right]$$

$$-\frac{\eta\sqrt{Sc}\sqrt{t}}{2\sqrt{k}}\left[\exp(-2\eta\sqrt{kt})erfc(\eta\sqrt{Sc}-\sqrt{kt})-\exp(2\eta\sqrt{kt})erfc(\eta\sqrt{Sc}+\sqrt{kt})\right]$$

$$\theta=\frac{1}{2}\left[\exp(2\eta\sqrt{\Pr ta})erfc(\eta\sqrt{\Pr}+\sqrt{at})+\exp(-2\eta\sqrt{\Pr ta})erfc(\eta\sqrt{\Pr}-\sqrt{at})\right]$$

The Sherwood number is given by,

$$Sh=-\left(\frac{\partial C(y,t)}{\partial y}\right)_{y=0}=-\frac{1}{2\sqrt{t}}\left(\frac{\partial C(y,t)}{\partial\eta}\right)_{\eta=0}$$

$$Sh=-\frac{\sqrt{t}}{2}\left\{\frac{t}{2}\left[2\sqrt{Kt}(1-erf(\sqrt{Kt})-\frac{1}{\sqrt{\pi}}e^{-Kt}\sqrt{Sc}-2\sqrt{Kt}(1+erf(\sqrt{Kt})\right]-\sqrt{KtSc}erf(\sqrt{Kt})\right\}$$

$$U=\left(\frac{t}{2}+d+e+tce\right)\left[\exp(2\eta\sqrt{Mt})erfc(\eta+\sqrt{Mt})+\exp(-2\eta\sqrt{Mt})erfc(\eta-\sqrt{Mt})\right]$$
$$-(1+2ce)\frac{\eta\sqrt{t}}{2\sqrt{M}}\left[\exp(-2\eta\sqrt{Mt})erfc(\eta-\sqrt{Mt})-\exp(2\eta\sqrt{Mt})erfc(\eta+\sqrt{Mt})\right]$$
$$-d\exp(bt)\left[\exp(2\eta\sqrt{(M+b)t})erfc(\eta+\sqrt{(M+b)t})+\exp(-2\eta\sqrt{(M+b)t})erfc(\eta-\sqrt{(M+b)t})\right]$$
$$-e\exp(ct)\left[\exp(2\eta\sqrt{(M+c)t})erfc(\eta+\sqrt{(M+c)t})+\exp(-2\eta\sqrt{(M+c)t})erfc(\eta-\sqrt{(M+c)t})\right]$$
$$-d\left[\exp(2\eta\sqrt{\Pr ta})erfc(\eta\sqrt{\Pr}+\sqrt{at})+\exp(-2\eta\sqrt{\Pr ta})erfc(\eta\sqrt{\Pr}-\sqrt{at})\right]$$
$$+d\exp(bt)\left[\exp(2\eta\sqrt{\Pr(a+b)t})erfc(\eta\sqrt{\Pr}+\sqrt{(a+b)t})+\exp(-2\eta\sqrt{\Pr(a+b)t})erfc(\eta\sqrt{\Pr}-\sqrt{(a+b)t})\right]$$
$$-e(1+tc)\left[\exp(2\eta\sqrt{KtSc})erfc(\eta\sqrt{Sc}+\sqrt{Kt})+\exp(-2\eta\sqrt{KtSc})erfc(\eta\sqrt{Sc}-\sqrt{Kt})\right]$$
$$+e\exp(ct)\left[\exp(2\eta\sqrt{Sc(K+c)t})erfc(\eta\sqrt{Sc}+\sqrt{(K+c)t})+\exp(-2\eta\sqrt{Sc(K+c)t})erfc(\eta\sqrt{Sc}-\sqrt{(K+c)t})\right]$$
$$+\frac{c\eta\sqrt{Sct}}{\sqrt{K}}\left[\exp(-2\eta\sqrt{KtSc})erfc(\eta\sqrt{Sc}-\sqrt{Kt})-\exp(2\eta\sqrt{KtSc})erfc(\eta\sqrt{Sc}+\sqrt{Kt})\right]$$

Where a = R / Pr, b = (R – M) /(1 – Pr), c = (KSc – M)/ (1 – Sc),
d = Gr / 2b(1 – Pr), e = Gc / $2c^2$ (1 – Sc) and η = y / 2 √t

The Nusselt number is given by,

$$Nu=-\left(\frac{\partial\theta(y,t)}{\partial y}\right)_{y=0}=-\frac{1}{2\sqrt{t}}\left(\frac{\partial\theta(y,t)}{\partial\eta}\right)_{\eta=0}$$

$$Nu=-\frac{\sqrt{t}}{2}\left\{\sqrt{\Pr ta}(1-erf(\sqrt{at})-\frac{2}{\sqrt{\pi}}\exp(-at)\sqrt{\Pr}-\sqrt{\Pr ta}(1+erf(\sqrt{at})\right\}$$

The non-dimensional form of Skin friction is given by,

$$\tau=-\left(\frac{\partial U(y,t)}{\partial y}\right)_{y=0}=-\frac{1}{2\sqrt{t}}\left(\frac{\partial U(y,t)}{\partial\eta}\right)_{\eta=0}$$

$$\tau=-\frac{\sqrt{t}}{2}\left\{\begin{array}{l}
\frac{t}{2}\left[2G_2-\frac{1}{\sqrt{\pi}}\exp(-Mt)-2G_1\right]-\frac{\sqrt{t}}{M}erf(\sqrt{Mt})+ \\
\frac{Gr}{2b(1-\Pr)}\left[\begin{array}{l}2G_2-\frac{1}{\sqrt{\pi}}\exp(-Mt)-2G_1- \\ \exp(bt)\left[\begin{array}{l}2\sqrt{(M+b)t}(1-erf(\sqrt{(M+b)t})-\frac{1}{\sqrt{\pi}}\exp(-(M+b)t)\\ -2\sqrt{(M+b)t}(1+erf(\sqrt{(M+b)t})\end{array}\right]\end{array}\right] \\
+\frac{Gc}{2c^2(1-Sc)}\left[\begin{array}{l}2G_2-\frac{1}{\sqrt{\pi}}\exp(-Mt)-2G_1+ct(2G_2-\frac{1}{\sqrt{\pi}}\exp(-Mt)-2G_1)\\ -c\sqrt{\frac{t}{M}}erf(\sqrt{Mt})-\exp(ct)\left[\begin{array}{l}2\sqrt{(M+c)t}(1-erf(\sqrt{(M+c)t}-\\ \frac{1}{\sqrt{\pi}}\exp(-(M+c)t)\\ -2\sqrt{(M+c)t}(1+erf(\sqrt{(M+c)t}))\end{array}\right]\end{array}\right]\\
+\frac{Gr}{2b(1-\Pr)}\left[\begin{array}{l}-2\sqrt{\Pr ta}(1-erf(\sqrt{at})+\frac{1}{\sqrt{\pi}}\exp(-at)\sqrt{\Pr}\\ +2\sqrt{\Pr ta}(1+erf(\sqrt{at})\\ +\exp(bt)\left[\begin{array}{l}2\sqrt{\Pr(a+b)t}(1-erf(\sqrt{(a+b)t}))\\ -\frac{1}{\sqrt{\pi}}\exp(-(a+b)t)\sqrt{\Pr}\\ -2\sqrt{\Pr(a+b)t}(1+erf(\sqrt{(a+b)t}))\end{array}\right]\end{array}\right]\\
-\frac{Gc}{2c^2(1-Sc)}\left[\begin{array}{l}2\sqrt{ScKt}(1-erf(\sqrt{Kt}))-\frac{1}{\sqrt{\pi}}\exp(-Kt)\sqrt{Sc}\\ -2\sqrt{ScKt}(1+erf(\sqrt{Kt}))\\ -\exp(ct)\left[\begin{array}{l}2\sqrt{Sc(K+c)t}(1-erf(\sqrt{(K+c)t})\\ -\frac{1}{\sqrt{\pi}}\exp(-(K+c)t)\sqrt{Sc}\\ -2\sqrt{Sc(K+c)t}(1+erf(\sqrt{(K+c)t})\end{array}\right]\\ +ct\left[\begin{array}{l}2\sqrt{ScKt}(1-erf(\sqrt{Kt})-\frac{1}{\sqrt{\pi}}\exp(-Kt)\sqrt{Sc}\\ -2\sqrt{ScKt}(1+erf(\sqrt{Kt})-c\sqrt{\frac{Sct}{K}}erf(\sqrt{Kt})\end{array}\right]\end{array}\right]
\end{array}\right\}$$

$$where\,G_1=\sqrt{Mt}(1+erf(\sqrt{Mt})),G_2=\sqrt{Mt}(1-erf(\sqrt{Mt}))$$

Where a = R / Pr, b = (R – M) /(1 – Pr), c = (KSc – M)/ (1 – Sc),
d = Gr / 2b(1 – Pr), e = Gc / $2c^2$ (1 – Sc) and η = y / 2 √t

Results and Discussion

In order to get physical insight into the problem, we have velocity profiles for different values of the physical parameter M (Magnetic field parameter), R (Radiation parameter), Gr (Thermal Grashof parameter) , Gc(Mass Grashof parameter), Pr(Prandtl number), Sc(Schmidt number) and t(time) for the cases of cooling (Gr>0, Gc>0) and heating (Gr<0, Gc<0) of the plate. The heating and cooling take place by setting up free convection current due to concentration gradient and temperature gradient.

Fig.1 & Fig.2 illustrate the influences of M(Magnetic field parameter) on the velocity field in cases of cooling and heating of the plate at time t = 0.2 & t = 0.4 respectively. It is found that with the increase of magnetic field parameter the velocity decreases for cooling of the plate but a reverse effect is noticed in the case of heating of the plate. Magnetic field lines act as a string to retard the motion of the fluid are free convection flow as the consequence the rate of heat transfer increases.

Fig.1 Velocity profiles for different values of M at t=0.2

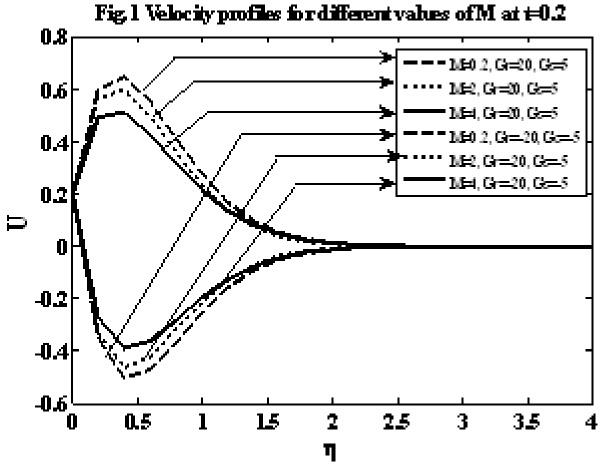
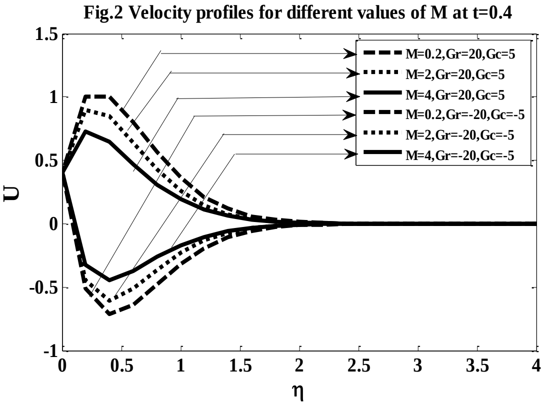


Fig.2 Velocity profiles for different values of M at t=0.4



From Fig.3, it is observed that with increase of Pr, the velocity decreases in the cooling of the plate but a reverse effect is noticed in the case of heating of the plate. Physically, it meets the logic that the fluids with high prandtl number have high viscosity and hence move slowly.

From Fig.4 & Fig.5, it is observed that with increase of R, the velocity decreases in the case of cooling of the plate but a reverse effect is noticed in the case of heating of the plate.

From Fig.6, it is observed that the increase of Sc, the velocity decreases in the case of the cooling of the plate but a reverse effect is noticed in the case of the heating of the plate.

Fig 3 Velocity profiles for different values of Pr at t=0.2

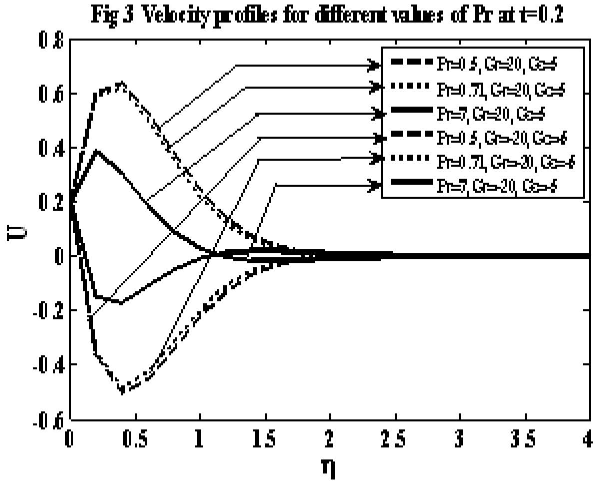


Fig.4 Velocity profiles for different values of R at t=0.2

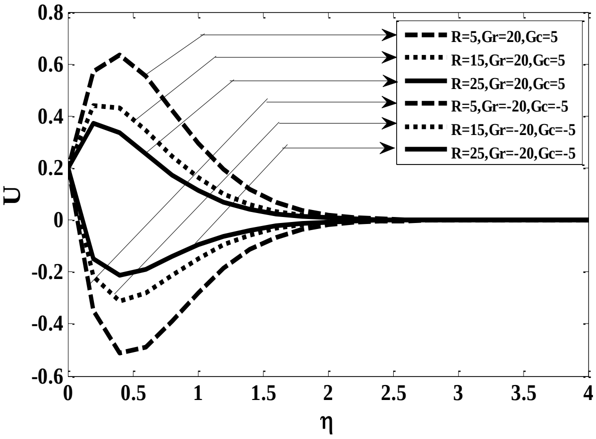


Fig 5 Velocity profiles for different values of R at t=0.4

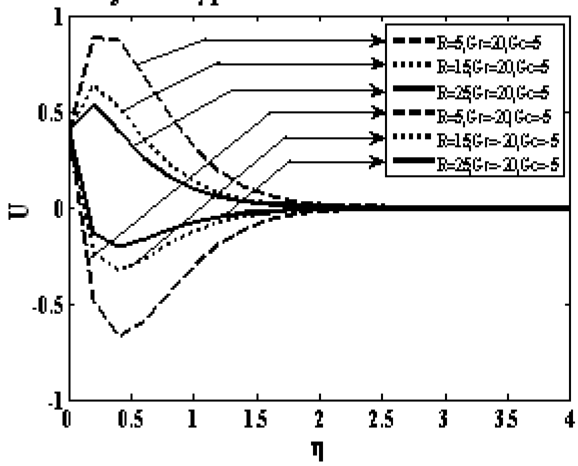


Fig.7 represents the velocity profiles for different values of t(time) in cases of cooling and heating of the surface. It is found that the velocity increases as time t increases in the case of cooling of the plate and an opposite phenomenon is observed in the case of heating of the plate.

The effect of concentration profiles for different values of K (chemical reaction parameter) at time t=0.2 are represented in fig.8. It is observed that the concentration increases with decreasing chemical reaction parameter.

Fig.9 demonstrates the effect of Sc (Schmidt number) on the concentration field at time t=0.2. It is found that the concentration decreases with an increase in Sc.

Fig.6 Velocity profiles for different values of Sc at t=0.2

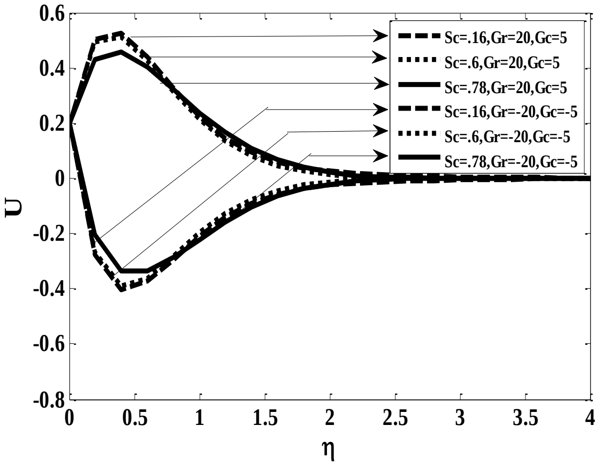


Fig.7 Velocity profiles for different values of t

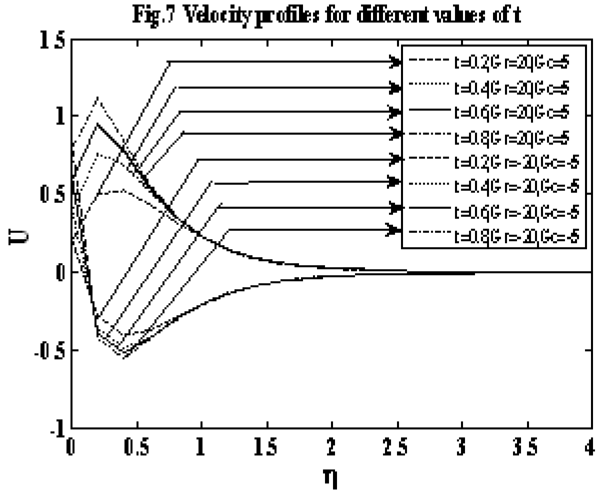


Fig.8 Concentration profiles for different values of K at t=0.2

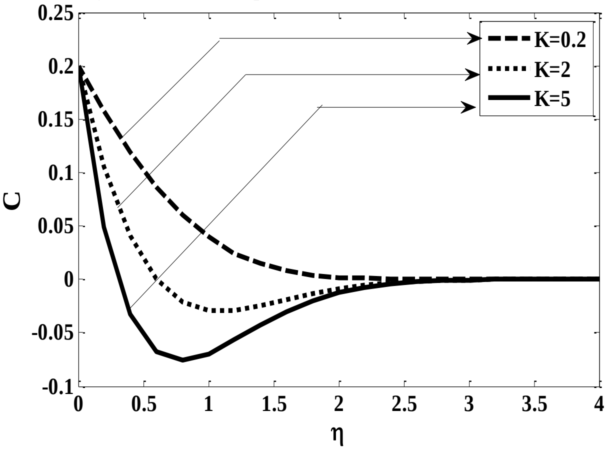


Fig.9 Concentration profiles for different values of Sc at t=0.2

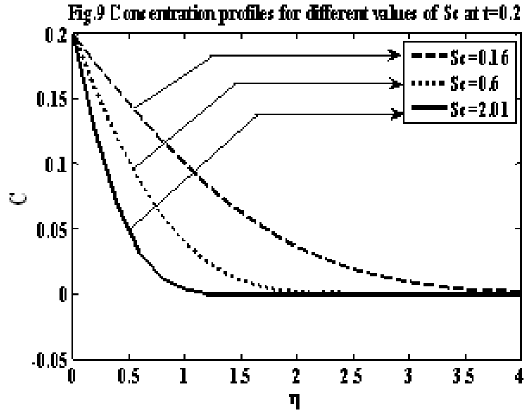


Fig.10 Temperature profiles for different values of R

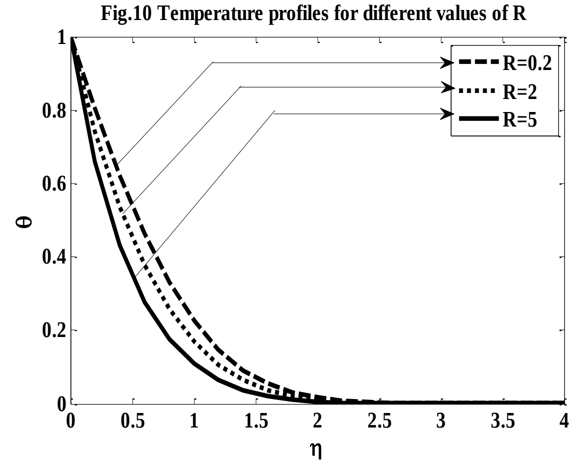


Fig.11 Concentration profiles for different values of t

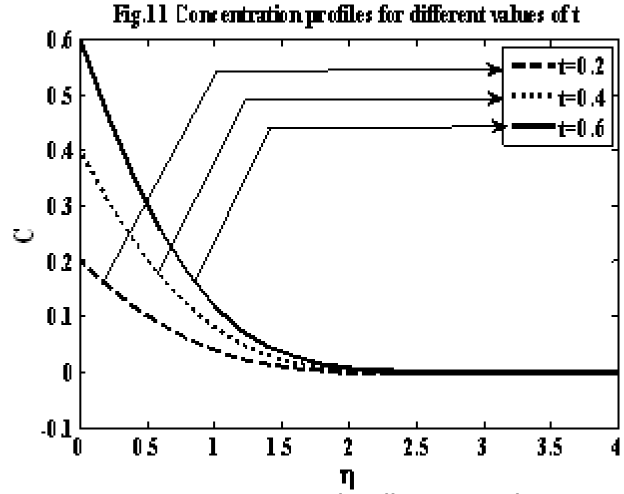


Fig.12 Sherwood number for different values of K

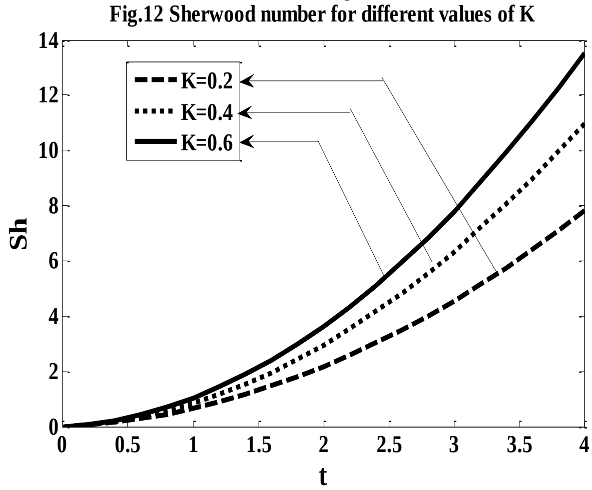
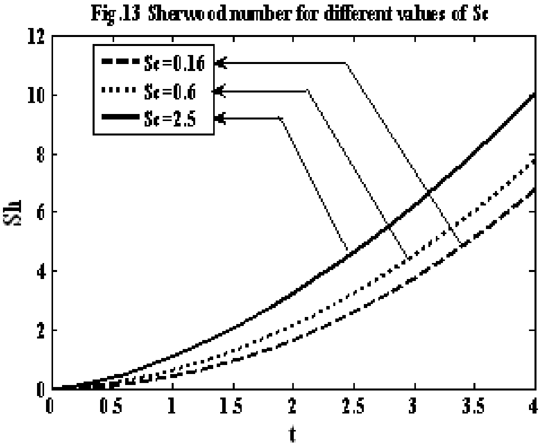


Fig.13 Sherwood number for different values of Sc



The effects of R (Radiation parameter) on the temperature profiles are shown in Fig.10.For large values of R, it is pointed out that the temperature decreases more rapidly with the increase of R. Therefore, using radiation we can control the temperature distribution and flow transport.

From Fig.11 it is seen that the concentration increases with an increase in time t. From Fig.12 &Fig.13, it is seen that Sherwood number decreases as increasing values of K(chemical reaction parameter) but the trend is reversed in case of Sc(Schmidt number).

Fig.14 Nusselt number

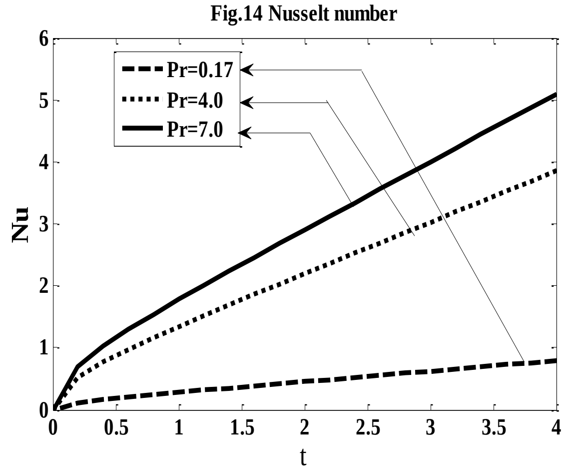
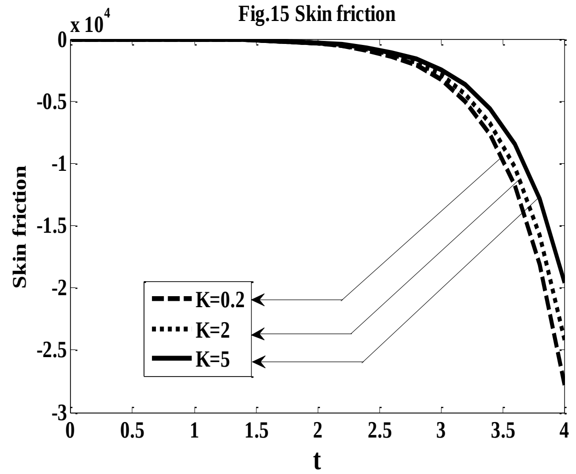


Fig.15 Skin friction



From fig.14, it is observed that Nusselt number increases as increasing values of Pr and fig.15,we concluded that the skin friction decreases with an increasing values of K(chemical reaction parameter).

Table.1. represents the values of skin friction. When t and K values are increased, skin friction value decreased.

Table 2. represents the Sherwood number increases with increasing values of t and Sc and table 3 represents the Nusselt number increases with increasing values of t and Pr.

Conclusion:

An exact solution of thermal radiation and hydromagnetic flow past a uniformly accelerated infinite isothermal vertical plate with variable mass diffusion, in the presence of chemical reaction of first order has been studied. The dimensionless governing equations are solved by the usual Laplace-transform technique. The effect of different parameters like thermal Grashof number, mass Grashof number, chemical reaction parameter, radiation parameter, magnetic field parameter and t are studied graphically. The conclusions of the study are as follows:

Table 1. Skin Friction

t	Sc	Pr	Gr	Gc	M	K	τ
0.2	0.16	0.71	5	5	2	2	-0.5215
0.4	0.16	0.71	5	5	2	2	-2.5110
0.6	0.16	0.71	5	5	2	2	-6.9488
0.8	0.16	0.71	5	5	2	2	-15.1779
1.0	0.16	0.71	5	5	2	2	-29.1185
0.2	0.16	0.71	5	5	2	0.2	-0.5208
0.4	0.16	0.71	5	5	2	0.2	-2.5266
0.6	0.16	0.71	5	5	2	0.2	-7.0550
0.8	0.16	0.71	5	5	2	0.2	-15.5548
1.0	0.16	0.71	5	5	2	0.2	-30.1247
0.2	0.16	0.71	5	5	2	5	-0.5216
0.4	0.16	0.71	5	5	2	5	-2.4800
0.6	0.16	0.71	5	5	2	5	-6.7721
0.8	0.16	0.71	5	5	2	5	-14.6014
1.0	0.16	0.71	5	5	2	5	-27.6612

Table 2. Sherwood Number

t	Sc	K	Sh
0.2	0.16	0.2	0.0274
0.4	0.16	0.2	0.0861
0.6	0.16	0.2	0.1737
0.2	0.6	0.2	0.0493
0.4	0.6	0.2	0.1458
0.6	0.6	0.2	0.2797
0.2	2.5	0.2	0.0964
0.4	2.5	0.2	0.2745
0.6	2.5	0.2	0.5079

Table 3. Nusselt Number

t	Pr	Nu
0.2	0.17	0.1082
0.4	0.17	0.1587
0.6	0.17	0.2014
0.2	7.0	0.6941
0.4	7.0	1.0186
0.6	7.0	1.2923
0.2	4.0	0.5247
0.4	4.0	0.7700
0.6	4.0	0.9769

(i). The concentration of the plate increases with decreasing values of the chemical reaction parameter or Schmidt number. But the trend is just reversed with respect to time t.

(ii) The plate temperature decreases with increasing values of the thermal radiation parameter.

(iii) The velocity decreases with increasing values of the magnetic field parameter or Prandtl number or thermal radiation parameter or Schmidt number in the case of the cooling of the plate but the trend is just reversed in the case of the heating of the plate.

(iv) The velocity increases as time t increases in the case of the cooling of the plate, but the trend is reversed in the case of heating of the plate.

(v) Skin friction value decreases, when t and K values are increases.

(vi) Sherwood number increases with increasing values of t and Sc.

(vii) Nusselt number increases with increasing values of t and Pr.

Nomenclature, Greek Symbols

C' Species concentration in the fluid
C Dimensionless concentration
C_w Wall concentration
C_∞ Concentration far away from the plate
C_p Specific heat at constant pressure
D Mass diffusion coefficient
Gc Mass Grashof number
Gr Thermal Grashof number
g Accelerated due to gravity
k Thermal conductivity
K Chemical reaction parameter
M Magnetic field parameter
Pr Prandtl number
R Thermal radiation parameter
Sc Schmidt number
T Temperature of the fluid near the plate
T_W Temperature of the plate
T_∞ Temperature of the fluid far away from 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
X Spatial coordinate along the plate
y' Coordinate axis normal to the plate
Y Dimensionless coordinate axis normal to the plate
β Volumetric coefficient of thermal expansion
β^* Volumetric coefficient of expansion with concentration
μ Coefficient of viscosity
υ Kinematic viscosity
ρ Density of the fluid
τ Dimensionless skin friction
Nu Nusselt number
Sh Sherwood number
θ Dimensionless temperature
η Similarity parameter
erfc Complementary error function

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