International Journal of Fluids Engineering.
ISSN 0974-3138 Volume 6, Number 1 (2014), pp. 39-51

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Chemical Reaction on a Transient MHD Flow Past an Impulsively Started Vertical Plate with Ramped Temperature and Concentration with Viscous Dissipation

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Abstract

A numerical study based on finite difference scheme to investigate the effect of first order chemical reaction on a transient MHD free convective mass transfer flow of an incompressible viscous electrically conducting, Newtonian fluid past a suddenly started infinite vertical plate with ramped wall temperature and concentration in presence of appreciable radiation heat transfer with viscous dissipation and Joulian heat and uniform transverse magnetic field is presented. The fluid is assumed to be optically thin and the Magnetic Reynolds number considered small enough to neglect the induced hydro magnetic effects. The equations governing the flow are solved by an iterative technique based on finite difference scheme. Effects of various flow governing parameters on the fluid velocity, temperature, concentration, skin friction , heat transfer rate and Sherwood number at the plate are presented graphically and in tabular form. The results are physically interpreted. It is observed that the fluid motion is retarded due to the effect of chemical reaction irrespective of the plate temperature being ramped or isothermal.

Keywords-MHD, thermal diffusion, thermal radiation, ramped temperature, chemical reaction, viscous dissipation.

INTRODUCTION

MHD is concerned with the study of the interaction of magnetic fields and electrically conducting fluids in motion. There are numerous examples of applications of MHD principles including MHD generators, MHD pumps and MHD flow meters etc. Convection problems of electrically conducting fluid in presence of transverse magnetic field have got much importance because of its wide applications in

Geophysics, Astrophysics, Plasma Physics, Missile technology etc. MHD principles find its applications in Medicine and Biology also. The present form of MHD is due to the pioneer contributions of several notable authors like Cowling[1], Shercliff[2], Ferraro and Plumpton[3] and Crammer and Pai[4].

The natural flow arises in fluid when the temperature change causes density variation leading to buoyancy forces acting on the fluid. Free convection is a process of heat transfer in natural flow. The heating of rooms and buildings by use of radiator is an example of heat transfer by free convection. Radiation is another process of heat transfer through electromagnetic waves. Radiative convective flows are encountered in countless industrial and environment processes like heating and cooling chambers, evaporation from large open water reservoirs, astrophysical flows and solar power technology. Due to importance of the above physical aspects, several authors have carried out model studies on the problems of free convective flows of incompressible viscous fluid under different flow geometries taking into account of the thermal radiation. Some of them are Mansor[5], Raptis and Perdikis[6], Ganesan and Logonathan[7], Mbeledogue et al. [8], Makinde[9] and Sattar and Kalim[10]. Investigation of problems on natural convective radiating flow of electrically conducting fluid past an infinite plate becomes very interesting and fruitful when a magnetic field is applied normal to the plate. Comprehensive literature on various aspects of free convective radiative MHD flows and its applications can be found in Sattar and Maleque[11], Samad and Rahman[12], Prasad et al. [13], Takhar et al. [14], Ahmed and Sarmah[15] and Ahmed[16]. The effect of rotation on unsteady hydromagnetic natural convection flow of a viscous incompressible electrically conducting fluid past an impulsively moving vertical plate with ramped wall temperature has been investigated recently by Seth et al.[17].

In many times, it has been observed that the foreign mass reacts with the fluid and in such a situation chemical reaction plays an important role in chemical industry. The study of effect of chemical reaction on heat and mass transfer in a flow is of great practical importance to the Engineers and Scientists because of its almost universal occurrence in many branches of Science and technology. In processes such as drying, distribution of temperature and moisture over agricultural fields, energy transfer in a wet cooling tower and flow in a cooler heat and mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries. Many investigators have studied the effect of chemical reaction in different convective heat and mass transfer flows of whom Apelblat[18] and Anderson et.al [19] are worth mentioning. Chambre and Young[20] have presented a first order chemical reaction in the neighbourhood of a horizontal plate. Muthucumaraswamy[21] presented heat and mass transfer effects on a continuously moving isothermal vertical surface with uniform suction by taking in to account the homogeneous chemical reaction of first order. Muthucumaraswamy and Meenakshisundaram[22] investigated theoretical study of chemical reaction effects on vertical oscillating plate with variable temperature and mass diffusion. Ahmed and Sinha[23] studied the effect of chemical reaction on a transient MHD flow past an impulsively started vertical plate with ramped temperature and concentration. Solutions are obtained using Laplace transformation neglecting viscous dissipation and Joule heatinf.

In view of the practical importance of the above fields, an attempt has been made in the present work to study the problem discussed by Ahmed and Sinha[23] for a transient MHD free convective flow of an incompressible viscous electrically conducting chemically reacting, thermal radiating and optically thin fluid past a suddenly started infinite vertical plate with ramped wall temperature and concentration together with viscous dissipation and Joule heating effect. Here our main objective is to solve the governing boundary value problem in non-linear partial differential equations using finite difference scheme by employing an iterative method and to find the effects of the parameters on velocity, temperature, concentration, wall shear stress, rate of heat transfer and rate of mass transfer. The effects of all the physical parameters are investigated. It is seen that effects are quite significant.

MATHEMATICAL FORMULATION OF THE PROBLEM

The equations governing the motion of an incompressible, viscous, electrically conducting radiating fluid past a solid surface in presence of a magnetic field are

Continuity equation: $\vec{\nabla}.\vec{q} = 0$ (1)

Magnetic field continuity equation: $\vec{\nabla}.\vec{B} = 0$ (2)

Ohm's law for moving conductor: $\vec{J} = \sigma\left(\vec{E} + \vec{q} \times \vec{B}\right)$ (3)

Momentum equation: $\rho\left[\frac{\partial \vec{q}}{\partial t'} + \left(\vec{q}.\vec{\nabla}\right)\vec{q}\right] = -\vec{\nabla}p + \vec{J} \times \vec{B} + \rho\vec{g} + \mu\nabla^2\vec{q}$ (4)

Energy equation: $\rho C_p\left[\frac{\partial T'}{\partial t'} + \left(\vec{q}.\vec{\nabla}\right)T'\right] = K_T\nabla^2 T' + \varphi + \frac{\vec{J}^2}{\sigma} - \frac{\partial q_r}{\partial n'}$ (5)

Species Concentration equation: $\left(\vec{q}.\vec{\nabla}\right)C' = D_M\nabla^2 C' + D_T\nabla^2 T'$ (6)

All the physical quantities are defined in the Nomenclature.

Our investigation is restricted to the following assumptions:

1. All the fluid properties are considered constants except the influence of the variation in density in the buoyancy force term.
2. The magnetic Reynolds number is so small for that the induced magnetic field can be neglected in comparison to the applied magnetic field.
3. The plate is electrically non-conducting.
4. The radiation heat flux in the direction of the plate velocity is considered negligible in comparison to that in the normal direction.
5. No external electric field is applied for which the polarization voltage is negligible leading to $\vec{E} = \vec{0}$

Initially the plate and the surrounding fluid were at rest at the same temperature T'_∞ and concentration C'_∞. At time $t' > 0$, the plate is suddenly moved in its own plane with a constant velocity U_0 and the temperature and concentration of the wall is raised to $T'_\infty + \left(T'_w - T'_\infty\right)\dfrac{t'}{t_0}$ and $C'_\infty + \left(C'_w - C'_\infty\right)\dfrac{t'}{t_0}$ for $0 < t' \le t_0$ and the constant temperature $T'_w\left(T'_w > T'_\infty\right)$ and concentration $C'_w\left(C'_w > C'_\infty\right)$ is maintained at $t' > t_0$.

We now introduce a coordinate system $\left(x', y', z'\right)$ with $\bar{X}$ -axis along the plate in the upward vertical direction, $\bar{Y}$ -axis normal to the plate directed into the fluid region and $\bar{Z}$-axis along the width of plate. Let $\vec{q} = \left(u', o, o\right)$ denote the fluid velocity and $\vec{B} = \left(0, B_0, 0\right)$ be the applied magnetic field at the point $\left(x', y', z', t'\right)$ in the fluid.

With the foregoing assumptions and under the usual boundary layer and Boussinesq approximations, the equations (1), (4), (5) and (6) reduce to

$$\frac{\partial u'}{\partial x'} = 0\text{, which yields } u' = u'\left(y', t'\right) \tag{7}$$

$$\frac{\partial u'}{\partial t'} = \upsilon\frac{\partial^2 u'}{\partial y'^2} + g\beta\left(T' - T_\infty'\right) + g\beta^*\left(C' - C_\infty'\right) - \frac{\sigma B_0^{\,2}}{\rho}u' \tag{8}$$

$$\rho C_p\frac{\partial T'}{\partial t'} = K_T\frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q_r}{\partial y'} + \mu\left(\frac{\partial u'}{\partial y'}\right)^2 + \frac{J^2}{\sigma} \tag{9}$$

$$\frac{\partial C'}{\partial t'} = D_M\frac{\partial^2 C'}{\partial y'^2} + D_T\frac{\partial^2 T'}{\partial y'^2} + K'\left(C'_\infty - C'\right) \tag{10}$$

The appropriate initial and boundary conditions are

$$u' = 0,\ T' = T'_\infty, C' = C'_\infty\ \ \forall y',\ t' \le 0 \tag{11}$$

$$u' = U_0, T' = T'_\infty + \frac{T'_w - T'_\infty}{t_0}t', C' = C'_\infty + \frac{C'_w - C'_\infty}{t_0}t' \text{ at } y' = 0,\ 0 < t' \le t_0 \tag{12}$$

$$u' = U_0,\ T' = T'_w\ C' = C'_w \text{ at } y' = 0,\ t' > t_0 \tag{13}$$

$$u' \to 0,\ T' \to T'_\infty\ C' \to C'_\infty \text{ at } y' \to \infty,\ t' > 0 \tag{14}$$

It is emphasized by Cogley et al. [24] that the rate of rediative flux in optically thin limit is given by

$$\frac{\partial q_r}{\partial y'} = 4I\left(T' - T'_\infty\right) \tag{15}$$

where, $I = \int_0^\infty k_w\left(\frac{\partial e_{b\lambda}}{\partial T'}\right)_w d\lambda$

On use of (15), (9) reduces to

$$\rho C_p\frac{\partial T'}{\partial t'} = K_T\frac{\partial^2 T'}{\partial y'^2} - 4I\left(T' - T'_\infty\right) + \mu\left(\frac{\partial u'}{\partial y'}\right)^2 + \frac{J^2}{\sigma} \tag{16}$$

Proceeding with the analysis, we introduce the following non-dimensional variables and similarity parameters to normalize the flow model:

$$u = \frac{u'}{U_0},\ y = \frac{y'}{U_0 t_0},\ t = \frac{t'}{t_0},$$

$$Gr = \frac{\upsilon g \beta \left(T'_w - T'_\infty\right)}{U_0^2}, Gm = \frac{\upsilon g \beta^* \left(C'_w - C'_\infty\right)}{U_0^2},\ \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty}$$

$$\phi = \frac{C' - C'_\infty}{C'_w - C'_\infty}, Pr = \frac{\mu C_p}{K_T}, Q = \frac{4 I \upsilon}{\rho C_p U_0^2}, M = \frac{\sigma B_0^2 \upsilon}{\rho U_0^2},$$

$$Re = \frac{U_0^2 t_0}{\upsilon}, Sr = \frac{D_T \left(T'_w - T'_\infty\right)}{\upsilon \left(C'_w - C'_\infty\right)}, Sc = \frac{\upsilon}{D_M}, K = K' t_0$$

$$Ec = \frac{U_0^2}{C_p\,(T'_w - T'_\infty)}\ . \tag{17}$$

All the physical quantities are defined in the Nomenclature.

By virtue of transformations cum definitions (17), the equations (8), (9) and (10) in normalized form become

$$\frac{\partial u}{\partial t} = \frac{1}{Re}\frac{\partial^2 u}{\partial y^2} + Re\ Gr\ \theta + Re\ Gm\ \phi - M Re u \tag{18}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{Pr Re}\frac{\partial^2 \theta}{\partial y^2} - Q Re\ \theta + \frac{Ec}{Re}\left(\frac{\partial \theta}{\partial y}\right)^2 + M\ Re\ u^2 \tag{19}$$

$$\frac{\partial \phi}{\partial t} = \frac{1}{Sc Re}\frac{\partial^2 \phi}{\partial y^2} + \frac{Sr}{Re}\frac{\partial^2 \theta}{\partial y^2} - K\phi \tag{20}$$

Subject to relevant initial and boundary conditions:

$$u = 0,\ \theta = 0, \phi = 0\ \forall\, y \ge 0\ \text{ and }\ t \le 0 \tag{21}$$

$$u = 1,\ \theta = t,\ \phi = t\ \text{ at }\ y = 0,\ 0 < t \le 1 \tag{22}$$

$$u = 1,\ \theta = 1,\ \phi = 1\ \text{ at }\ y = 0,\ t > 1 \tag{23}$$

$$u = 0,\ \theta = 0,\ \phi = 0\ \text{ as }\ y \to \infty,\ t > 0 \tag{24}$$

METHOD OF SOLUTION

The boundary value problem (18)-(24) is reduced to a system of difference equations using the following finite difference scheme. The scheme for an independent variable f is given by,

$$\frac{\partial f}{\partial T} = \frac{f_{i+1,j} - f_{i,j}}{\Delta T}$$

$$\frac{\partial^2 f}{\partial \eta^2} = \frac{1}{(\Delta\eta)^2}\,(f_{i,\,j+1} - 2f_{ij} + f_{i,\,j-1})$$

The system of difference equations are then solved numerically by an iterative scheme.

The physical quantities of interest in this problem are the skin –friction coefficient c_f, Nusselt number Nu and Sherwood number S_h which indicate physically wall shear stress, rate of heat transfer and rate of mass transfer respectively.

COEFFICIENT OF SKIN FRICTION

The viscous drag at the plate per unit area in the direction of the plate velocity is given by the Newton's law of viscosity in the form:

$$\tau' = -\mu \frac{\partial u'}{\partial y'}\bigg]_{y'=0} = -\frac{\mu}{t_0}\frac{\partial u}{\partial y}\bigg]_{y=0} \tag{25}$$

The coefficient of skin friction at the plate is given by

The skin –friction coefficient c_f can be defined as

$$c_f = -\frac{2}{t_o \rho U_o{}^2}\left[(\mu)\ \frac{\partial u}{\partial y}\right]_{y=0} = -2\ \mathrm{Re}\left[\frac{\partial u}{\partial y}\right]_{y=0} \tag{26}$$

COEFFICIENT OF RATE OF HEAT TRANSFER

The heat flux q^* from the plate to the fluid is given by the Fourier law of conduction in the form

$$q^* = -K_T \frac{\partial T'}{\partial y'}\bigg]_{y'=0} = -\frac{K_T}{U_0 t_0}\left(T'_w - T'_\infty\right)\frac{\partial \theta}{\partial y}\bigg]_{y=0} \tag{27}$$

The co-efficient of the rate of heat transfer from the plate to the fluid in terms of Nusselt number is given by

$$\mathrm{Nu} = \frac{q^* U_0 t_0}{K_T\left(T'_w - T'_\infty\right)} = -\frac{\partial \theta}{\partial y}\bigg]_{y=0} \tag{28}$$

COEFFICIENT OF RATE OF MASS TRANSFER

The mass flux at the wall is given by

$$M_w = -D\left[\frac{\partial C}{\partial y}\right]_{y=0}$$

Sherwood number is given by-

$$S_h = \frac{M_w U_0}{D(C_w - C_\infty)\alpha} = -\left[\frac{\partial C}{\partial y}\right]_{y=0} \ \ldots \tag{29}$$

RESULTS AND DISCUSSION

Numerical solutions are obtained by solving the finite difference equations using an iterative scheme for the velocity field, temperature field , concentration field, the coefficient of skin friction, rate of heat transfer in terms of Nusselt number and the rate of mass transfer in terms of Sherwood number have been carried out by assigning some arbitrarily chosen specific values to the physical parameters involved in the problem. Our investigation is carried out in general for Ec=.1, Gr=5, Re=1.5, Gm=5, Pr=.71, Q=1, M=1, Sc=.22, Sr=1 and K=1 unless otherwise stated. The results computed from the numerical method of the problem have been displayed in figure 2-10.

Figure 2 simulates the effect of time t on velocity profile versus y. It is observed from this figure that as time progresses the fluid velocity increases near the plate and as we move further away from the plate it decreases asymptotically.

The temperature profiles dissipation parameter Ec versus y are exhibited in figures 3 & 4 for the cases $t > 1$ and $0 < t \le 1$ respectively. These figures indicate that the fluid motion is enhanced on account of viscous dissipation. It is observed that the fluid velocity quickly falls to some thin layer of the fluid adjacent to the plate in case of both ramped and isothermal temperature and then decreases asymptotically towards $u = 0$ as $y \to \infty$. i.e in the free stream effect.

Figures 5 & 6 present the variation of the species concentration ϕ under the influence of chemical reaction. These figures predict that the species concentration decreases to zero as $y \to \infty$. This phenomenon physically states that the consumption of chemical species leads to fall in the species concentration for ramped temperature and isothermal plates. This clearly agrees with the physical laws.

The velocity profiles under the influence of Chemical reaction parameter K and Hartmann number M versus y are exhibited in figures 7-10. Figures 7 & 10 present how the fluid velocity is affected by chemical reaction for the cases $0 < t \leq 1$ and $t > 1$ respectively. These figures indicate that the fluid motion is retarded on account of chemical reaction. It is observed that the fluid velocity quickly increases up to some thin layer of the fluid adjacent to the plate in case of both ramped and isothermal temperature and then decreases asymptotically towards $u = 0$ as $y \to \infty$. i.e in the free stream effect. It is also inferred that the buoyancy effects (due to concentration and temperature difference) are significant near the hot plate.

It is inferred from figure 8 & 9 that, for ramped temperature and isothermal plates, an increase in Magnetic parameter M has an inhibiting effect on the fluid velocity. The fluid velocity is continuously reduced with increasing M. In other words the imposition of the transverse magnetic field tends to retard the fluid flow irrespective of ramped plate temperature or uniform plate temperature. This phenomenon has an excellent agreement with the physical fact that the Lorentz force generated in the present flow model due to interaction of the transverse magnetic field and the fluid velocity acts as a resistive force to the fluid flow which serves to decelerate the flow. It is further revealed from the two figures that the fluid velocity first increases in a thin layer adjacent to the plate and there after it decreases asymptotically as we move away from the plate indicating the fact that the buoyancy force has a significant role on the flow near the plate and its effect is nullified in the free stream.

Tables 1 & 2 demonstrate the effect of the Chemical reaction parameter K and Reynolds number Re on the skin friction, rate of heat transfer and Sherwood number for $0<t<1$ and $t>1$ respectively at the plate in the direction of the plate velocity. Both the tables indicate that the magnitude of shear stress, Nusselt number Nu and Sherwood number Sh at the plate are increased with the increase in K and Re.

The effects of chemical reaction parameter K and Schmidt number Sc on the coefficient of skin friction, rate of heat transfer and on the co-efficient of rate of mass transfer in terms of Sherwood number, have been presented in Tables 3 & 4 for $0<t<1$ and $t>1$ respectively. It is observed from these tables that the mass flux and skin friction are constantly increased while coefficient of heat transfer decreased for increasing values of the chemical reaction parameter K and Schmidt number Sc. This simulates that the high consumption (chemical reaction) or small viscosity leads the substantial rise in the mass transfer rate. It is also seen that the rate of mass flux rises as Schmidt number Sc increases. It may be noted that an increase in Schmidt number Sc means a decrease in mass diffusion. That is the rate of mass transfer falls comprehensively due to mass diffusivity. Both the tables show that the effect of mass diffusion raises the coefficient of rate of mass transfer.

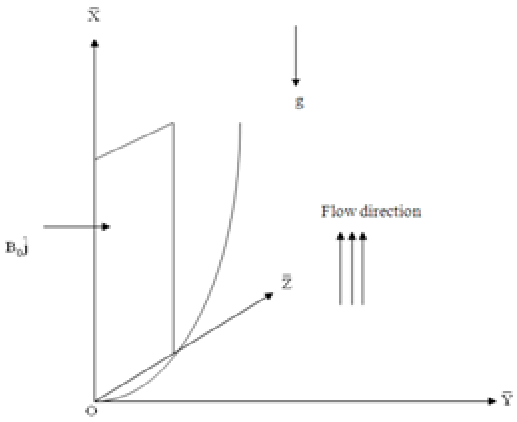

Figure 1: Flow Configuration

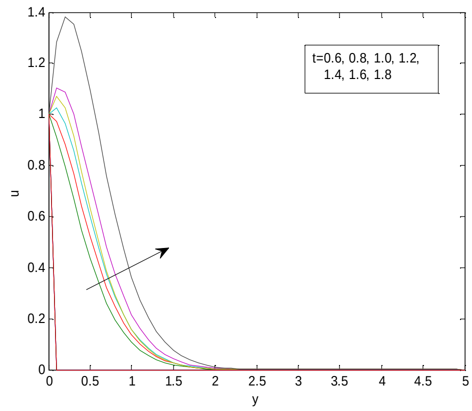

Fig-2 Velocity distribution against time

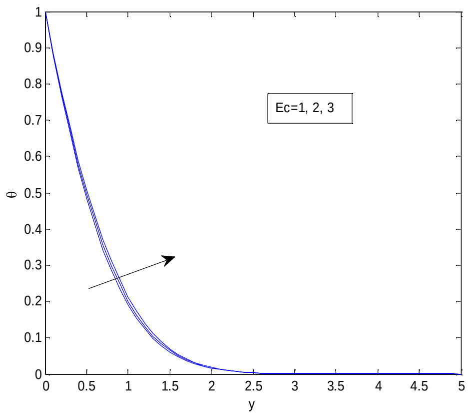

Fig-3 Temperature distribution for different Ec at t= 1.4

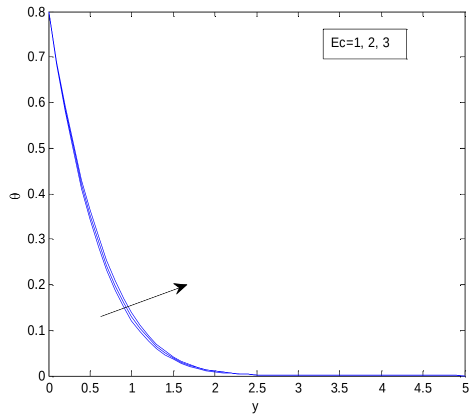

Fig-4 Temperature distribution for different Ec at t= .8

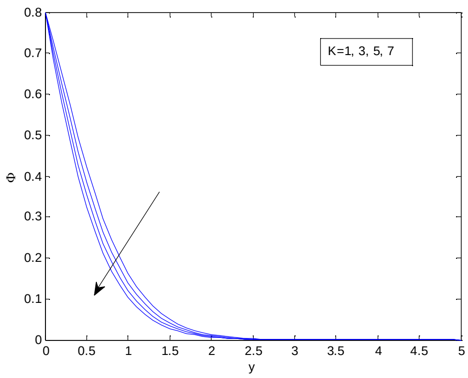

Fig-5 Species concentration for different K at t= .8

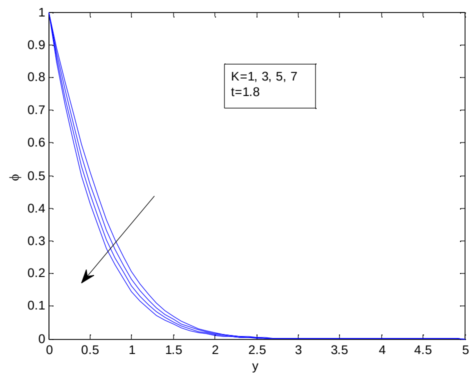

Fig-6 Species concentration for different K at t= 1.8

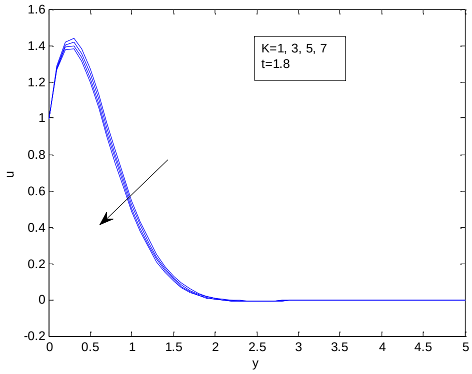

Fig-7 Velocity distribution for different K at t=1.8

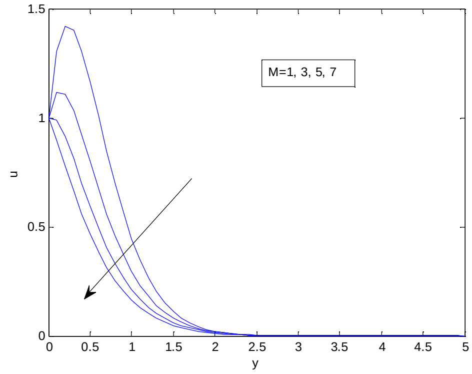

Fig-8 Velocity variation for different M at t=.4

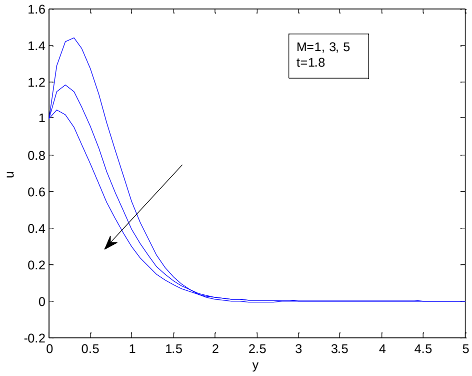

Fig-9 Velocity distribution for different M at t=1.8

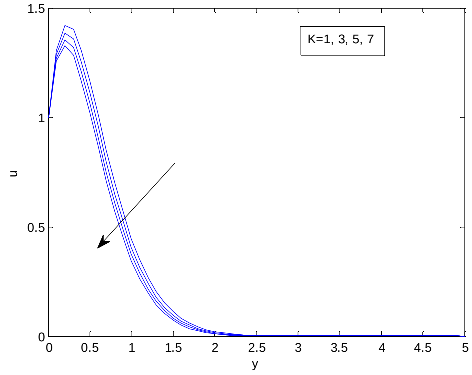

Fig-10 Velocity distribution for different K at t= .4

Table-1

t= .4 K ->	1			3			5			7		
Re	C_f	Nu	Sh	C_f	Nu	Sh	C_f	Nu	Sh	C_f	Nu	Sh
1.00	1.2850	0.7901	0.6855	1.2875	0.7901	0.7100	1.2900	0.7901	0.7340	1.2924	0.7901	0.7575
3.00	-0.5268	1.1929	0.6759	-0.4743	1.1929	0.7464	-0.4250	1.1929	0.8127	-0.3786	1.1929	0.8751
5.00	-1.9013	1.6271	0.6640	-1.7354	1.6270	0.7767	-1.5858	1.6269	0.8788	-1.4502	1.6268	0.9718
7.00	-2.7206	1.9907	0.6717	-2.4211	1.9903	0.8210	-2.1610	1.9900	0.9518	-1.9329	1.9896	1.0677

Table – 2

t=1.4 K ->	1			3			5			7		
Re	C_f	Nu	Sh	C_f	Nu	Sh	C_f	Nu	Sh	C_f	Nu	Sh
1.00	0.4460	1.7482	1.6896	0.4528	1.7482	1.7518	0.4593	1.7482	1.8127	0.4658	1.7482	1.8724
3.00	-7.2067	2.4155	1.5875	-7.0478	2.4158	1.7730	-6.8985	2.4160	1.9472	-6.7579	2.4163	2.1109
5.00	-15.1394	3.4455	1.4048	-14.5745	3.4469	1.7163	-14.0659	3.4480	1.9969	-13.6061	3.4489	2.2513
7.00	-19.9166	4.4645	1.2246	-18.8070	4.4652	1.6634	-17.8507	4.4655	2.0435	-17.0191	4.4655	2.3765

Table – 3

t= .4 K ->	1			3			5			7		
Sc	C_f	Nu	Sh	C_f	Nu	Sh	C_f	Nu	Sh	C_f	Nu	Sh
0.20	0.8852	0.8766	0.6847	0.8926	0.8765	0.7179	0.8998	0.8765	0.7501	0.9068	0.8765	0.7814
0.40	0.8874	0.8766	0.6968	0.9017	0.8765	0.7606	0.9153	0.8765	0.8210	0.9282	0.8765	0.8781
0.60	0.8897	0.8766	0.7090	0.9105	0.8765	0.8012	0.9297	0.8765	0.8861	0.9475	0.8765	0.9647

Table – 4

t=1.4 K ->	1			3			5			7		
Sc	C_f	Nu	Sh	C_f	Nu	Sh	C_f	Nu	Sh	C_f	Nu	Sh
0.20	-0.9901	1.8568	1.6773	-0.9699	1.8568	1.7620	-0.9501	1.8568	1.8443	-0.9310	1.8568	1.9242
0.40	-0.9924	1.8568	1.6727	-0.9523	1.8568	1.8395	-0.9143	1.8569	1.9968	-0.8784	1.8569	2.1456
0.60	-0.9946	1.8568	1.6681	-0.9351	1.8568	1.9143	-0.8803	1.8569	2.1403	-0.8298	1.8569	2.3486

CONCLUSIONS

Our investigation leads to the following conclusions:

1. The fluid motion is retarded under the application of transverse magnetic field as well as chemical reaction.
2. The concentration level of the fluid falls due to increasing chemical reaction. i.e the consumption of chemical species leads to fall in the species concentration field.
3. Magnitude of shear stress and rate of heat transfer at the plate are considerably increased due to the application of chemical reaction.
4. Mass flux increases with the increasing values of chemical reaction and Schmidt number. i.e high consumption (chemical reaction) or small viscosity

leads the substantial rise in the mass transfer rate.

5. Heat transfer rate increase for increase chemical reaction and Reynolds number where as it decreases for increase of Schmidt number for t>1 but remain unchanged for 0<t<1.
6. Dissipation enhances both velocity and fluid temperature

Nomenclature:

Symbol	Description	Symbol	Description
$\vec{B}$	Magnetic induction vector	D_M	Mass diffusivity
B_0	Strength of the applied magnetic field $\left(y-\text{component of } \vec{B}\right)$	D_T	Thermal diffusion ratio
C'	Concentration	$e^{b\lambda}$	Plank function
C_p	Specific heat at constant pressure	$\vec{E}$	Electric Field
C'_w	Concentration at the plate	$\vec{g}$	Acceleration vector
C'_∞	Concentration far away from the plate	g	Acceleration due to gravity
Ec	Eckert Number	t	Non-dimensional time
Gr	Grashof number for heat transfer	t'	Time
Gm	Grashof number for mass transfer	t_0	Characteristic time
$\vec{J}$	Current Density vector	T'	Fluid temperature
k_w	Mean absorption coefficient	T'_w	Reference temperature
K	Chemical Reaction Parameter	T'_∞	Temperature far away from the plate
K_T	Thermal conductivity	u	Non-dimensional velocity profile
M	Hartmann number	u'	X component of $\vec{q}$
Nu	Nusselt number	U_0	Plate velocity
p	Pressure	$\left(x', y', z'\right)$	Cartesian coordinates
Pr	Prandtl number	y	Non-dimensional normal coordinate
$\vec{q}$	Fluid velocity vector	ρ	Fluid density
Q	Radiation parameter	τ	Coefficient of Skin friction
q_r	Radiative flux in magnitude	μ	Co-efficient of viscosity
Re	Reynolds number	λ	Wave length
Sc	Schmidt number	σ	Electrical conductivity

Sh	Sherwood number	φ	Dissipation of energy
Sr	Soret number	β^*	Volumetric co-efficient of expansion with concentration
β	Volumetric co-efficient of thermal expansion	ϕ	Non-dimensional concentration
υ	Kinematic viscosity	Subscript $_w$	Refers to the values of physical quantities at the plate
θ	Non-dimensional temperature	Subscript $_\infty$	Refers to the values of the physical quantities away from the plate

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