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SLIP EFFECTS ON CHEMICALLY REACTING MHD FREE CONVECTIVE FLOW PAST AN INCLINED POROUS PLATE WITH RADIATION ABSORPTION EFFECTS AND VARIABLE SUCTION

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ABSTRACT :
In this paper, we have analysed the radiation absorption effects of chemically reacting MHD flow of electrically conducting fluid bounded by an oscillating inclined porous plate in the presence of heat source under slip boundary conditions. The plate is assumed to absorb the fluid with variable suction velocity. The coupled non linear partial differential equations for velocity, concentration and temperature are solved using perturbation techniques. The behaviour of velocity, temperature and concentration profiles has been plotted for different physical parameters entered into the problem. Also the skin friction, Nusselt number and Schmidt numbers are discussed through the tables

KEYWORDS : *MHD, radiation absorption, chemical reaction, slip flow, suction.*

1. INTRODUCTION

MHD free convection flow has been investigated by many scholars due to their wide range of applications in the field of fluid engineering such as MHD flow meters, pumps, nuclear reactors, plasma studies, drying of porous solids, geothermal reservoirs etc. Many problems are modelled on MHD convective heat and mass transfer of electrically conducting, viscous and incompressible flow through a porous medium. Hossain and Mandal (1985) derived the results for mass transfer of unsteady hydromagnetic free convection flow around infinite accelerated porous plate. Jha (1991) analysed the heat and mass transfer effects on electrically conducting fluid through porous medium with uniform temperature in the presence of magnetic field. Hayat et al. (2001) studied the rotating flow of MHD third grade fluid past an oscillating porous plate. The heat transfer due to thermal radiation plays important role in many industrial and environment processes. The knowledge of heat transfer due to radiation enables the designing of equipments which operates at higher temperature such as nuclear reactors, heat storage beds, aircrafts, underground disposal of nuclear waste, gas turbines etc. England and Emery (1969) investigated the heat transfer effects due to thermal radiation on a laminar boundary layer flow of an absorbing gas. Further Soudalegkar and Takhar (1993) and Hakeem and Sathiyanathan (2009) also contributed to the study of the radiation effects past an infinite porous plate. Makinde and Mohne (2005) studied the radiative heat transfer of MHD flow through channel with porous medium having non uniform temperature in the presence of magnetic field. Hossain and Takhar (1996) investigated the radiation effects on mixed convection flow past vertical surface with uniform temperature. Muthuraj and Sirinivas (2010) studied effects of radiation parameter, geometric parameters and heat transferred characteristics through wavy asymmetrical channel.

In several physical situations the heat generation or absorption effects are of great interest such as fire and combustion modelling, fluids involving exothermic and endothermic chemical reactions, nuclear energy systems etc. Chamkha (2004) studied the MHD flow past an infinite vertical permeable plate with heat absorption and Hady et al. (2006) studied the same problem along vertical wavy surface. Shankar et al. (2010) studied the heat generation /absorption effects along with radiation effects on unsteady MHD free convective flow past an infinite porous plate. In the recent years, the chemical reaction effects has also been studied on heat and mass transfer problems of MHD flows due to its existence in many chemical engineering process such as glass or ceramics production, food processing, polymer manufacturing etc. Also there exists many transport processes which take place due to buoyancy forces coming from thermal and mass diffusion in the presence of chemical reaction effects. Chamkha (2003) gave the numerical interpretation of chemical reaction effects on MHD flow past a uniformly stretched surface in the presence of heat source/sink. Ibrahim et al. (2008) investigated the combined effects of chemical reaction and radiation absorption on electrically conducting fluids past an infinite vertical plate moving with constant velocity having constant suction in the presence of heat source. Balamurugan et al. (2014) studied flow features of Kuvshinski fluid past a moving porous plate under thermal radiation, radiation absorption, chemical reaction and heat generation effects. Recently Ramaiah et al. (2016) has presented his studies on MHD flow of viscoelastic fluid past an oscillating porous plate under the influence of chemical reaction, radiation absorption and heat generation/absorption effects. All these studies have not considered the slip flow effect of particle adjacent to boundary surface. There exist many practical problems in fluid engineering where particle adjacent to solid surface does not acquire the velocity of surface and slips. Mehmood and Ali (2007) studied the unsteady MHD oscillatory flow of viscous fluid in planner channel with slip conditions and observed the slip effect on velocity profiles. Further Hayat et al. (2008) studied the slip effects of second grade fluid past a stretching sheet in porous medium. Recently Garg et al. (2014) studied the heat radiation effect on viscoelastic MHD oscillatory forced flow in vertical channel under slip boundary conditions.

Our present investigation is aimed on MHD free convection flow passing an inclined porous plate having variable suction under the influence of chemical reaction, heat source and radiation effects with slip conditions at boundary.

2. MATHEMATICAL FORMULATION

A two dimensional unsteady flow of an incompressible, viscous and electrically conducting fluid past an infinite oscillating porous plate with variable suction is considered. The plate is assumed to be inclined at an angle α to the vertical and x' - axis is taken along the plate and y' - axis normal to it. Also a uniform magnetic field of strength B_0 is applied along y' - axis and fluid assumed to be gray, absorbing - emitting and non scattering. No external voltage is applied so that there is no electric field and Reynolds number is too small to neglect the induced magnetic field. Ohmic heating and viscous dissipation effects are neglected. Further the flow is assumed under the presence of chemical reaction, radiation absorption and heat source with slip boundary conditions. As the plate in x' - direction is of infinite length so all physical variables except pressure are functions of y' and t' only. Under above stated assumptions the governing equations for the investigation are:

$$\frac{\partial v'}{\partial y'} = 0 \Rightarrow v' = -v'^{0}\left(1 + \epsilon A e^{i\omega' t'}\right) \tag{1}$$

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \nu\frac{\partial^2 u'}{\partial y^2} + g\beta(T' - T_\infty)\cos(\alpha) + g\beta'(C' - C_\infty)\cos(\alpha) - \frac{\sigma B_0^2 u'}{\rho} - \frac{\nu}{K'}u' \tag{2}$$

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{Q_0}{\rho C_p}(T' - T_\infty) + Q'(C' - C_\infty) \tag{3}$$

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - K_1(C' - C_\infty) \tag{4}$$

along with slip boundary conditions as

$$u' = 0,\ v' = 0,\ T' = T_\infty,\ C' = C_\infty\ \ for\ t' \le 0\ and\ any\ y$$
$$u' = U_0\left(1+\epsilon e^{i\omega' t'}\right) + L_1\frac{\partial u'}{\partial y'},\ T' = T_w + \epsilon(T_w - T_\infty)e^{i\omega' t'},\ C' = C_w + \epsilon(C_w - C_\infty)e^{i\omega' t'}\quad at\ y' = 0$$
$$and\ \ u' \to 0,\ T' \to \infty,\ C' \to \infty\quad as\ y' \to \infty\ \ for\ t' > 0 \tag{5}$$

Here $U_0, v'^0, g, \beta, \beta', \nu, K, \sigma, \kappa, \rho, C_p, \mu, Q_0, Q', \omega'\ T',\ T_w, T_\infty,\ C', C_w,\ C_\infty,\ D,\ K_1\ and\ \ L_1$

respectively are plate velocity, constant suction velocity, acceleration due to gravity, volumetric coefficient of thermal expansion, volumetric coefficient of expansion of concentration, kinematic coefficient of viscosity, permeability of medium, electrical conductivity, thermal conductivity, fluid density, specific heat at constant pressure, viscosity of fluid, heat source/sink coefficient, radiation absorption coefficient, oscillation frequency, temperature of the fluid near plate, wall temperature, free stream temperature, species concentration, wall concentration, free stream species concentration, chemical molecular diffusivity, chemical reaction constant and mean free path. Also ϵ and A are small positive constants such that $\epsilon A \le 1$.

On introducing following non dimensional quantities and parameters as

$$y = \frac{y' U_0}{\nu},\ \ u = \frac{u'}{U_0},\ \ t = \frac{t' U_0{}^2}{\nu},\ \ \omega = \frac{\omega' \nu}{U_0{}^2},\ \ v^0 = \frac{v'^0}{U_0},\ \ T = \frac{T' - T_\infty}{T_w - T_\infty},\ \ C = \frac{C' - C_\infty}{C_w - C_\infty},\ \ M = \frac{\sigma B_0^2\,\nu}{\rho U_0{}^2},$$

$$K = \frac{K' U_0{}^2}{\nu^2},\ \ Gr = \frac{g\beta\nu\,(T_w - T_\infty)}{U_0{}^3},\ \ Gm = \frac{g\beta'\nu\,(C_w - C_\infty)}{U_0{}^3},\ \ Pr = \frac{\mu C_p}{\kappa},\ \ S = \frac{Q_0\nu^2}{\kappa U_0{}^2},$$

$$R_1 = \frac{Q'\nu^2(C_w - C_\infty)}{\kappa U_0{}^2(T_w - T_\infty)},\ \ Sc = \frac{\nu}{D}, h = \frac{L_1 U_0}{\nu},\ \ k_1 = \frac{K_1\nu^2}{D U_0{}^2} \tag{6}$$

Equations (2) – (4) along with using (1) reduces to

$$\frac{\partial^2 u}{\partial y^2} + v^0\left(1+\epsilon A e^{i\omega t}\right)\frac{\partial u}{\partial y} - \frac{\partial u}{\partial t} - \left(M + \frac{1}{K}\right)u + GrT + GmC = 0 \tag{7}$$

$$\frac{\partial^2 T}{\partial y^2} + Prv^0\left(1+\epsilon A e^{i\omega t}\right)\frac{\partial T}{\partial y} - Pr\frac{\partial T}{\partial t} - ST + \ R_1\, C = 0 \tag{8}$$

$$\frac{\partial^2 C}{\partial y^2} + Scv^0\left(1+\epsilon A e^{i\omega t}\right)\frac{\partial C}{\partial y} - Sc\frac{\partial C}{\partial t} - Sck_1 C = 0 \tag{9}$$

with corresponding boundary conditions as

$$u = 0,\ \ T = 0,\ \ C = 0\ \ for\ t \le 0\ and\ any\ y$$

$$u = \left(1+\varepsilon e^{i\omega t}\right) + h\frac{\partial u}{\partial y},\ \ T = 1 + \epsilon e^{i\omega t},\ C = 1 + \epsilon e^{i\omega t}\ \ at\ \ y = 0$$

$$u \to 0,\ T \to 0,\ C \to 0\ \ at\ \ y \to \infty\ for\ t > 0 \tag{10}$$

M is the magnetic number, K is the permeability parameter, Gr is the thermal Grashof number, Gm is the mass Grashof number, Pr is the Prandtl number, S is the heat absorption parameter R_1 is the radiation absorption parameter, k_1 is the chemical reaction parameter, Sc is the Schmidt number and h is slip flow parameter.

3. SOLUTION OF THE PROBLEM

In order to reduce the above system of partial differential equations to a system of ordinary differential equations in dimensionless form, we assume the solutions for velocity, temperature and concentration as

$$u(y,t) = u_0(y) + \varepsilon u_1(y)e^{i\omega t} + O(\varepsilon^2)$$
$$T(y,t) = T_0(y) + \varepsilon T_1(y)e^{i\omega t} + O(\varepsilon^2)$$
$$C(y,t) = C_0(y) + \varepsilon C_1(y)e^{i\omega t} + O(\varepsilon^2) \qquad (11)$$

On using Eqs. (11) in Eqs. (7) - (10) and comparing the harmonic and non harmonic terms with neglecting higher order terms $O(\varepsilon^2)$, we get

$$\frac{\partial^2 u_0}{\partial y^2} + v^0 \frac{\partial u_0}{\partial y} - \left(M + \frac{1}{K}\right) u_0 = -Grcos(\alpha)T_0 - Gmcos(\alpha)C_0 \qquad (12)$$

$$\frac{\partial^2 T_0}{\partial y^2} + Pr\, v^0 \frac{\partial T_0}{\partial y} - ST_0 = -R_1 C_0 \qquad (13)$$

$$\frac{\partial^2 C_0}{\partial y^2} + Scv^0 \frac{\partial C_0}{\partial y} - Sck_1 C_0 = 0 \qquad (14)$$

and

$$\frac{\partial^2 u_1}{\partial y^2} + v^0 \frac{\partial u_1}{\partial y} - \left(M + \frac{1}{K} + i\omega\right) u_1 = -Grcos(\alpha)T_1 - Gmcos(\alpha)C_1 - v^0 A \frac{\partial u_0}{\partial y} \qquad (15)$$

$$\frac{\partial^2 T_1}{\partial y^2} + Prv^0 \frac{\partial T_1}{\partial y} - (S + i\omega \mathrm{Pr})T_1 = -\ R_1 C_1 - Prv^0 A \frac{\partial T_0}{\partial y} \qquad (16)$$

$$\frac{\partial^2 C_1}{\partial y^2} + Scv^0 \frac{\partial C_1}{\partial y} - Sc(k_1 + i\omega)C_1 = -Scv^0 A \frac{\partial C_0}{\partial y} \qquad (17)$$

with boundary conditions as

$$u_0 = 0,\ u_1 = 0,\ T_0 = 0,\ T_1 = 0,\ C_0 = 0,\ C_1 = 0\ for\ t \le 0\ and\ any\ y$$
$$u_0 = 1 + h\frac{\partial u_0}{\partial y},\ u_1 = 1 + h\frac{\partial u_1}{\partial y},\ T_0 = 1,\ T_1 = 1,\ C_0 = 1,\ C_1 = 1\ at\ y = 0$$
$$u_0 \to 0,\ u_1 \to 0,\ T_0 \to 0,\ T_1 \to 0,\ C_0 \to 0,\ C_1 \to 0\ at\ y \to \infty\ \ for\ t > 0 \qquad (18)$$

On solving Eqs. (12) - (17) along with boundary conditions (18), we get

$$u_0 = A_9 e^{-a_5 y} + A_7 e^{-a_1 y} - A_8 e^{-a_3 y} \qquad (19)$$

$$T_0 = (1 + A_2)e^{-a_3 y} - A_2 e^{-a_1 y} \qquad (20)$$

$$C_0 = e^{-a_1 y} \qquad (21)$$

$$u_1 = A_{15} e^{-a_6 y} + A_{14} e^{-a_5 y} - A_{13} e^{-a_4 y} - A_{12} e^{-a_3 y} + A_{11} e^{-a_2 y} + A_{10} e^{-a_1 y} \qquad (22)$$

$$T_1 = A_6 e^{-a_4 y} + A_5 e^{-a_3 y} - A_4 e^{-a_2 y} - A_3 e^{-a_1 y} \qquad (23)$$

$$C_1 = (1 - A_1)e^{-a_2 y} + A_1 e^{-a_1 y} \qquad (24)$$

Thus the compiled solutions for velocity, temperature and concentration can be written as

$$u(y,t) = A_9 e^{-a_5 y} + A_7 e^{-a_1 y} - A_8 e^{-a_3 y} + \varepsilon e^{i\omega t}(A_{15} e^{-a_6 y} + A_{14} e^{-a_5 y} - A_{13} e^{-a_4 y}$$
$$-A_{12} e^{-a_3 y} + A_{11} e^{-a_2 y} + A_{10} e^{-a_1 y}) \quad (25)$$

$$T(y,t) = (1 + A_2)e^{-a_3 y} - A_2 e^{-a_1 y} + \varepsilon e^{i\omega t}(A_6 e^{-a_4 y} + A_5 e^{-a_3 y} - A_4 e^{-a_2 y} - A_3 e^{-a_1 y}) \quad (26)$$

$$C(y,t) = e^{-a_1 y} + \varepsilon e^{i\omega t}((1 - A_1)e^{-a_2 y} + A_1 e^{-a_1 y}) \quad (27)$$

Skin friction

The skin friction at the plate derived from velocity field (25) is given by

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0}$$
$$= -a_5 A_9 - a_1 A_7 + a_3 A_8 + \varepsilon e^{i\omega t}(-a_6 A_{15} - a_5 A_{14} + a_4 A_{13} + a_3 A_{12} - a_2 A_{11} - a_1 A_{10})$$
$$= -a_5 A_9 - a_1 A_7 + a_3 A_8 + \varepsilon |U| \cos(\omega t + \varphi_1) \quad (28)$$

Where $|U| = \sqrt{U_r^2 + U_i^2}$ is the amplitude of Skin friction and $\varphi_1 = \tan^{-1}\frac{U_i}{U_r}$ is the phase angle such that $U_r + iU_i = (-a_6 A_{15} - a_5 A_{14} + a_4 A_{13} + a_3 A_{12} + A_{11} e^{-a_2 y} - a_1 A_{10})$

Nusselt Number

The Nusselt number representing the measure of rate of heat transfer is derived from temperature field (26) as

$$Nu = -\left(\frac{\partial T}{\partial y}\right)_{y=0}$$
$$= a_3(1 + A_2) - a_1 A_2 + \varepsilon e^{i\omega t}(a_4 A_6 + a_3 A_5 - a_2 A_4 - a_1 A_3)$$
$$= a_3(1 + A_2) - a_1 A_2 + \varepsilon |V| \cos(\omega t + \varphi_2) \quad (29)$$

Where $|V| = \sqrt{V_r^2 + V_i^2}$ is the amplitude of Nusselt number and $\varphi_2 = \tan^{-1}\frac{V_i}{V_r}$ is the phase angle such that

$$V_r + iV_i = a_4 A_6 + a_3 A_5 - a_2 A_4 - a_1 A_3$$

Sherwood Number

The Sherwood number representing the measure of rate of mass transfer at the plate is derived from concentration field (27) as

$$Sh = -\left(\frac{\partial C}{\partial y}\right)_{y=0} = a_1 + \varepsilon e^{i\omega t}(a_2(1 - A_1) + a_1 A_1)$$

$$= a_1 + \varepsilon |W| \cos(\omega t + \varphi_3) \quad (30)$$

Where $|W| = \sqrt{W_r^2 + W_i^2}$ is the amplitude and $\varphi_2 = \tan^{-1}\frac{W_i}{W_r}$ is the phase angle of Sherwood number such that $W_r + iW_i = a_2(1 - A_1) + a_1 A_1$

4. RESULTS AND DISCUSSIONS

In this section the study of different parametric effects on velocity, temperature and concentration profiles have been carried out through the graphs. For the realistic approach, fluid considered is ionized air (Pr = 0.71), gaseous ammonia (Pr = 1.38) and water (Pr = 7). Also during studying the one parametric effect other parameters are kept constant.

The behaviour of velocity profiles with different parameters is shown on Figs. 1-12. It is observed from the Figs. 1-4 that velocity shows increasing behaviour with increase in the values of Gr, Gm, K and R_1. Also the velocity is seen higher near the plate and it goes on decreasing as we move away from the plate. However the Figs 5-8, convey that velocity profiles have decreasing behaviour with the increment in values of M, Pr, Sc and S. This indicates that the presence of magnetic field and heat source causes reduction in the velocity of fluid near the plate. Also the effects of time, chemical reaction parameter, slip flow parameter and inclination on velocity behaviour are studied through the Figs. 9-12. It is observed that with the increase in time (t), inclination (α) and chemical reaction parameter (k_1), there is decrease in velocity profiles whereas the slip flow parameter has adverse effect on velocity profiles. Also the behaviour of velocity profiles with variation in t and h is prominent near the plate and on moving away from plate it is not appreciable.

The various parametric effects on temperature profiles has been investigated through the Figs 13-18.In the Figs 13-15, it is concluded that the temperature profiles are decreasing with the increase in the values of suction parameter (A) and Prandtl number (Pr) but they show increasing behaviour with increase in radiation parameter values. Also the temperature rises firstly near the plate with radiation absorption effect and then it starts decreasing on moving away from the plate and attains the stationary stage. The temperature falls very rapidly near the plate in case of water as compared to other considered fluids. The variation in temperature profiles with heat source parameter, Schmidt number and time is concluded in the Figs. 16-18. The temperature profiles shows decreasing patterns with the increase in S, Sc and t. The concentration behaviour patterns with the different values of Sc, k_1, A and t is demonstrated through the Figs.19-21. It is observed that the concentration profiles are decreased with the increase in the values of Sc, k_1, A and t. However the effect of A on concentration profiles is not prominent but chemical reaction and mass diffusion shows remarkable fall in concentration profiles.

Numerical values of the skin friction τ, Nusselt number (Nu) and Sherwood number (Sh) along with their phase and amplitude calculated from Eqs. (28) - (30) for different parameter values has been entered in the Tables 1 and 2. A close observation from the Table 1 reveals that the amplitude $|U|$ of skin friction increases with the increase in Pr, M, A, Gr and R_1 but it decreases with increase in K, Gm, S, Sc, h and ω. Also it is observed that the phase of skin friction is decreasing with the increase in M, Sc, A, k_1, h and w. However the increase in phase of skin friction is observed with the increase in K, Gm, Gr, S and R_1. Phase of gaseous ammonia (Pr = 1.38) is greater than water (Pr = 7) and ionized air (Pr = 0.71). Numerical values of skin friction presented in Table 1 have interesting behaviour. It is observed that the skin friction is reduced with the increase in Pr i.e. in case of water skin friction is lowest as compared to other considered fluid. Also the skin friction is lowered at the plate with the increase in M, S, h, Sc, k_1 and $\boldsymbol{\alpha}$ and increased with the increase in K, Gm, Gr, R_1, ω. Variations in Nusselt number and Sherwood number with different parameters are put in the Table 2. It is noticed that the amplitude of Nusselt number increases with Pr, S, Sc, A, $k_1$and ω whereas it decrease with R_1.But the phase of Nusselt number has adverse effects in comparison with amplitude. Also the Nusselt number calculated from Eq. (29) shows interesting observations in the Table 2. It decreases with increase in R_1 and ω but increases with the increase in Pr, A, S, Sc and k_1. It is noticed that amplitude of Sherwood number increases with increase in Sc, A, ω and k_1 whereas the phase shows decreasing behaviour with Sc, A, and k_1 but it increases with ω. However the Sherwood number values calculated from Eq. (30) represents that it increases with increase in Schmidt number, chemical reaction parameter and suction constant but decreases with ω.

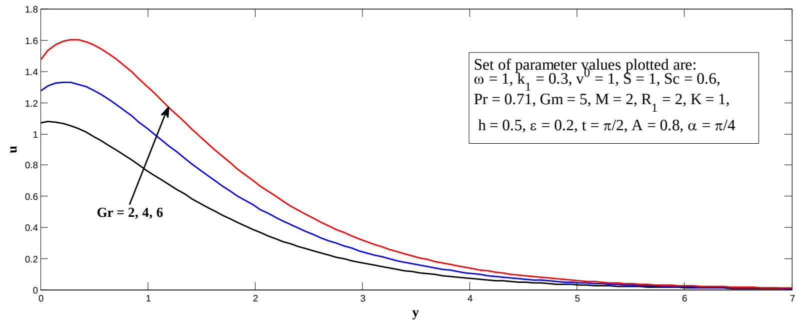

Fig.1. Effect of thermal Grashoff number (Gr) on velocity profiles

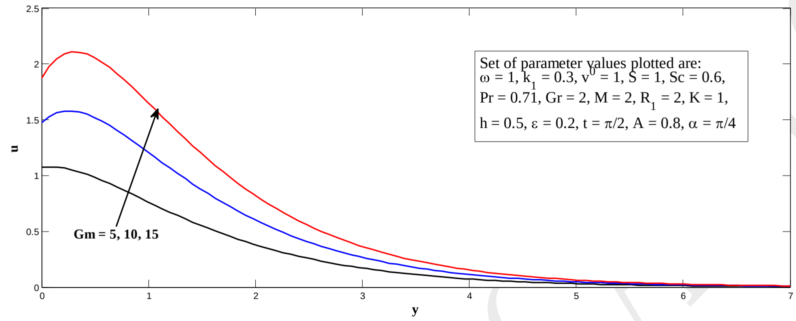

Fig.2. Effect of mass Grashoff number (Gr) on velocity profiles

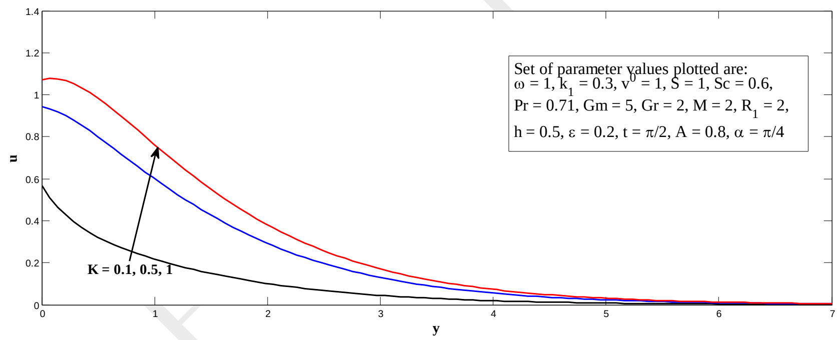

Fig.3. Effect of permeability parameter (K) on velocity profiles

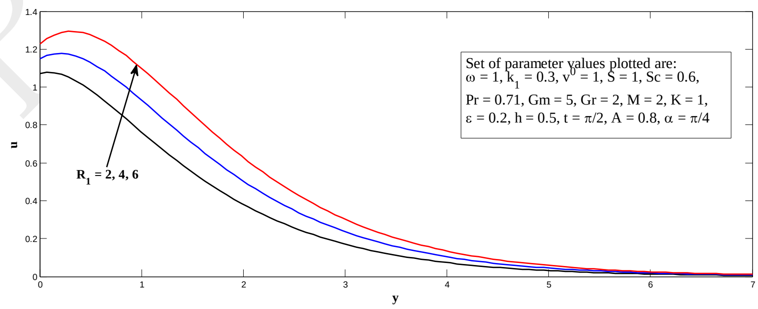

Fig. 4.Effect of radiation absorption parameter (R_1) on velocity profiles

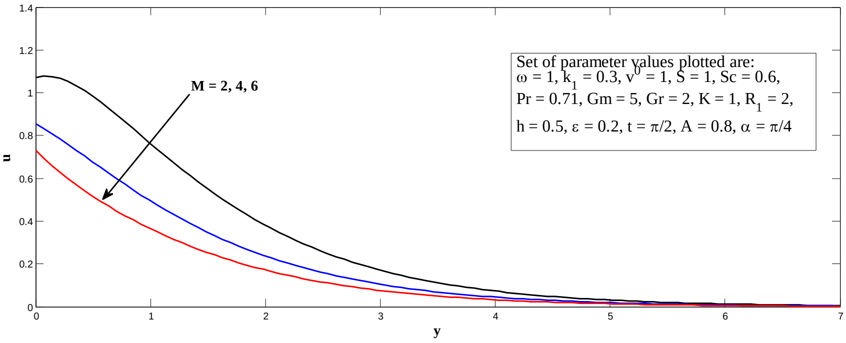

Fig.5. Effect of magnetic number (M) on velocity profiles

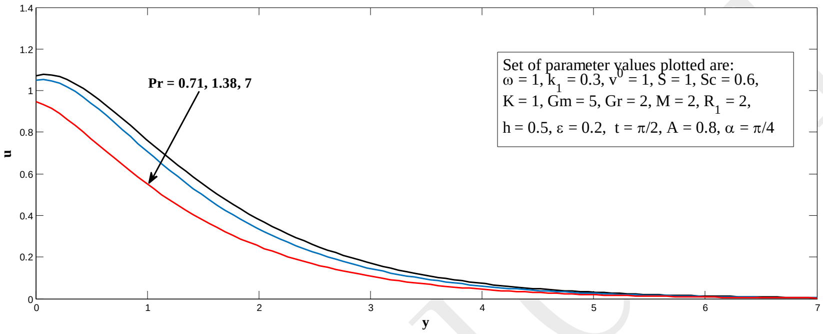

Fig. 6.Effect of Prandtl number (Pr) on velocity profiles

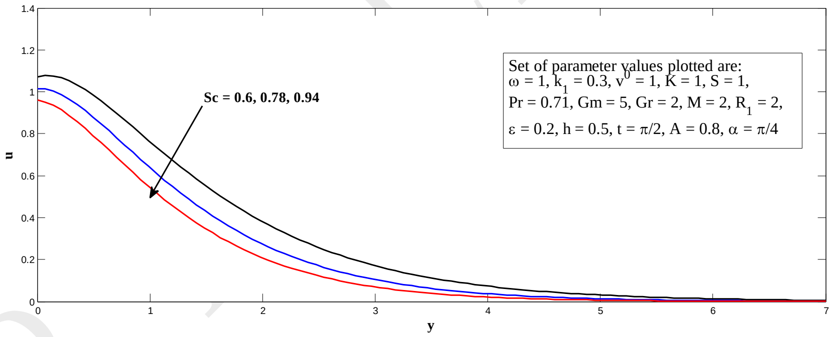

Fig.7. Effect of Schmidt number (Sc) on velocity profiles

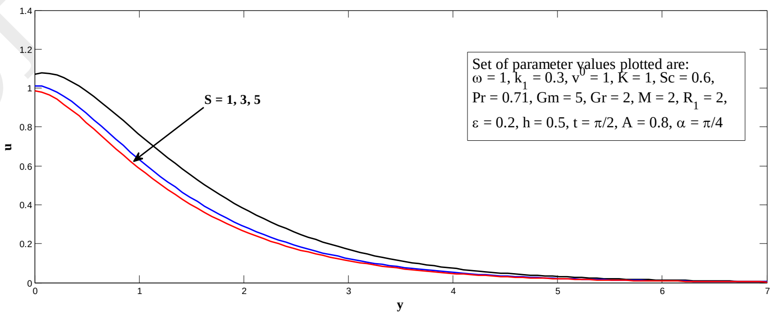

Fig.8. Effect of heat source parameter (S) on velocity profiles

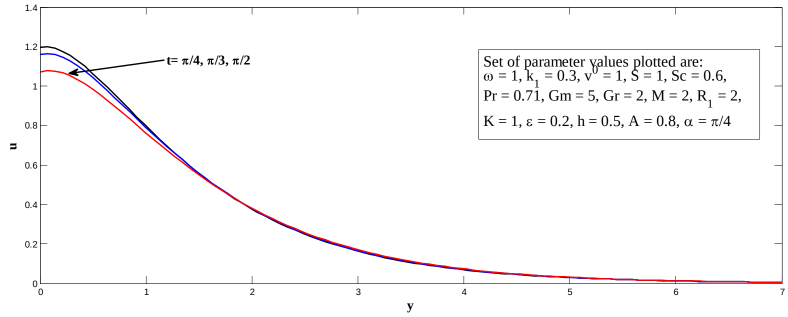

Fig.9. Effect of time (t) on velocity profiles

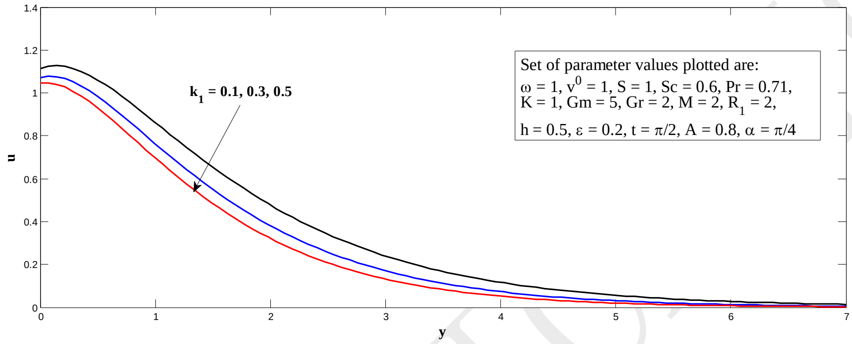

Fig.10.Effect of chemical reaction parameter (k_1) on velocity profiles

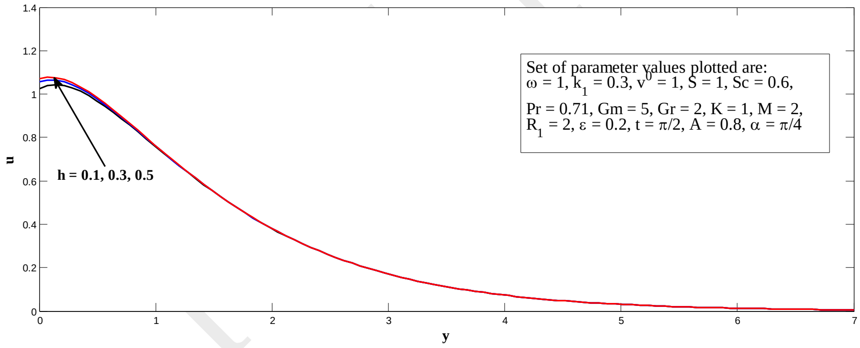

Fig.11. Effect of slip flow parameter (h) on velocity profiles

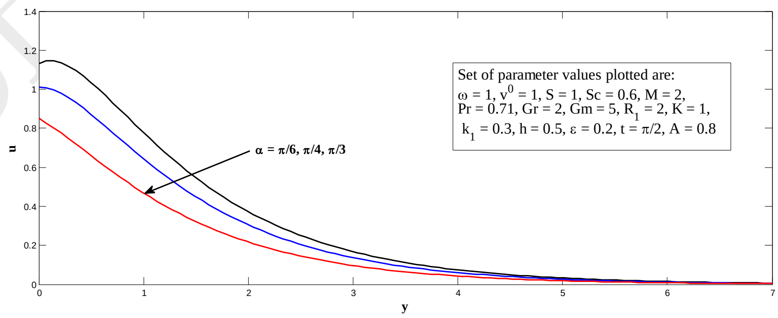

Fig.12. Effect of angle of inclination (α) on velocity profiles

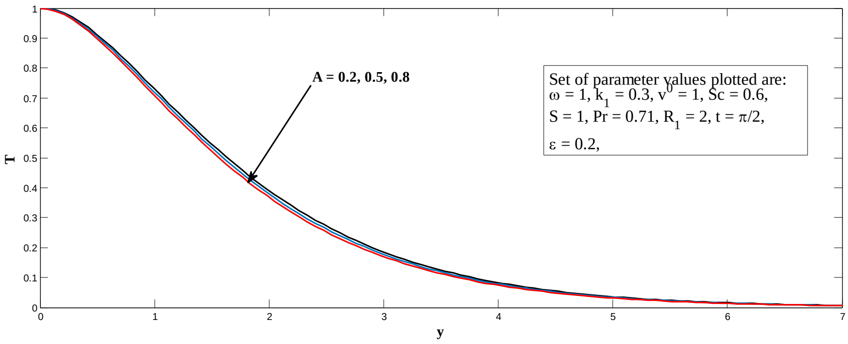

Fig.13.Effect of suction parameter (A) on temperature profiles.

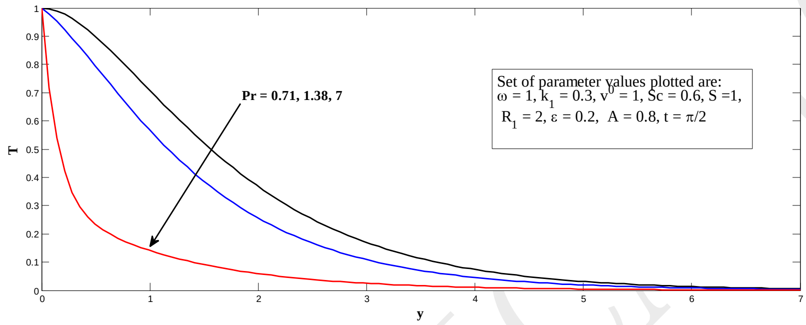

Fig.14. Effect of Prandtl number (Pr) on temperature profiles.

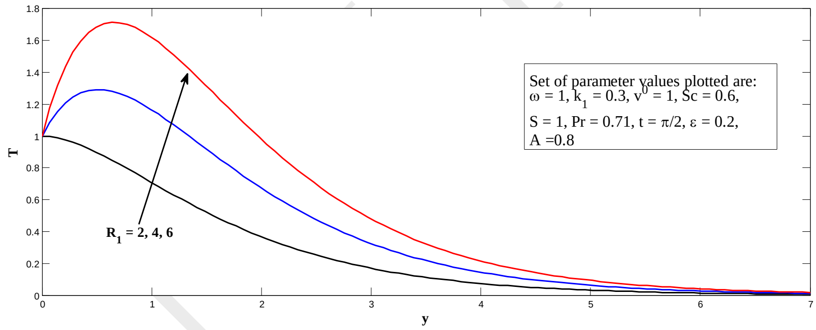

Fig.15. Effect of radiation absorption parameter (R_1) on temperature profiles.

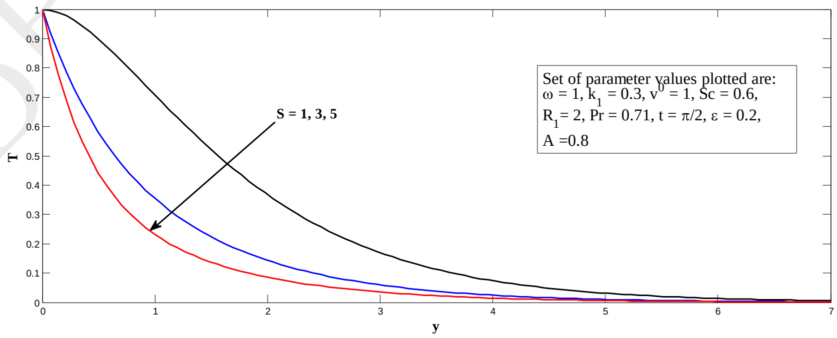

Fig.16.Effect of heat source parameter (S) on temperature profiles

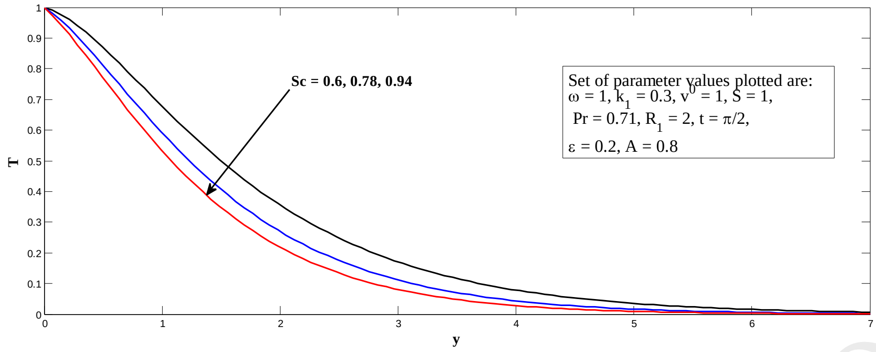

Fig.17. Effect of Schmidt number (Sc) on temperature profiles

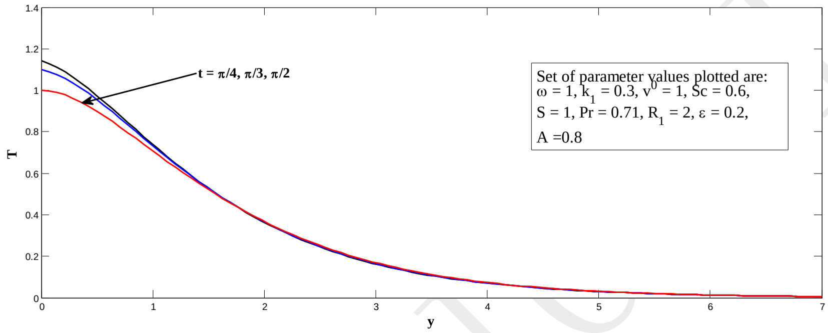

Fig.18. Effect of time (t) on temperature profiles

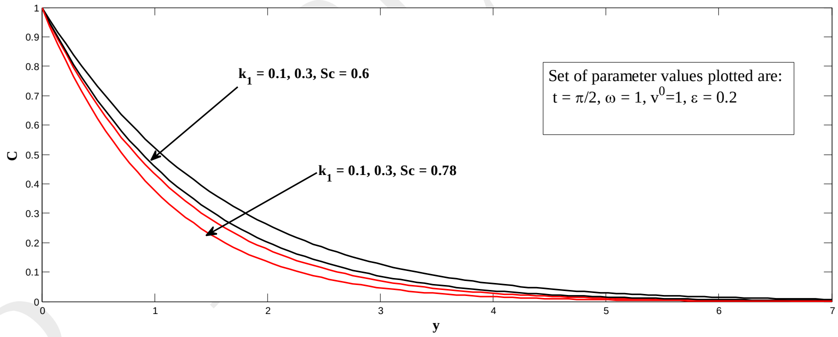

Fig.19. Effect of chemical reaction parameter and Schmidt number on concentration profiles

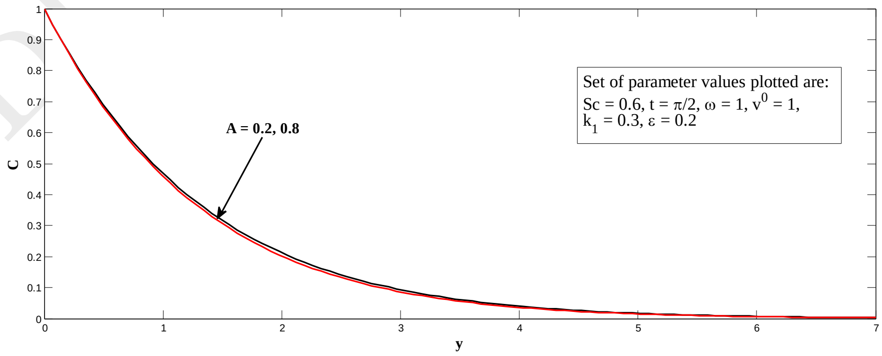

Fig.20. Effect of suction parameter (A) on concentration profiles

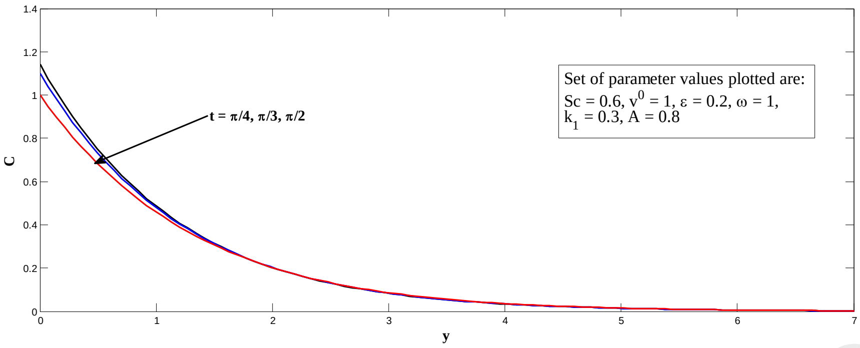

Fig.21. Effect of time (t) on concentration profiles

Table 1. Variation in Skin friction for $\varepsilon = 0.2,\ \omega t = \frac{\pi}{2}$

Pr	M	K	Gm	Gr	S	R_1	Sc	k_1	h	α	ω	A	$\lvert U\rvert$	φ_1	τ
0.71	2	0.1	5	2	1	2	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	1.9954	-3.0429	-1.8154
1.38	2	0.1	5	2	1	2	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	2.0405	-3.0390	-1.8324
7	2	0.1	5	2	1	2	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	2.1800	-3.0609	-1.9722
7	4	0.1	5	2	1	2	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	2.3717	-3.0764	-2.1856
7	6	0.1	5	2	1	2	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	2.5398	-3.0873	-2.3704
7	6	0.5	5	2	1	2	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	1.6898	-2.9968	-1.4099
7	6	1	5	2	1	2	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	1.5339	-2.9644	-1.2241
7	6	1	10	2	1	2	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	0.7566	-2.5841	-0.2675
7	6	1	15	2	1	2	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	0.5764	-1.1684	0.6891
7	6	1	15	4	1	2	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	0.6623	-1.0297	0.9078
7	6	1	15	6	1	2	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	0.7579	-0.9244	1.1266
7	6	1	15	6	3	2	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	0.7488	-0.9219	1.0391
7	6	1	15	6	5	2	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	0.7379	-0.9182	0.9848
7	6	1	15	6	5	4	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	0.8322	-0.9011	1.1673
7	6	1	15	6	5	6	0.6	0.1	0.1	$\frac{\pi}{4}$	1	0.2	0.9267	-0.8875	1.3497
7	6	1	15	6	5	6	0.78	0.1	0.1	$\frac{\pi}{4}$	1	0.2	0.7482	-1.0085	1.0789
7	6	1	15	6	5	6	0.94	0.1	0.1	$\frac{\pi}{4}$	1	0.2	0.6208	-1.1435	0.8745
7	6	1	15	6	5	6	0.94	0.3	0.1	$\frac{\pi}{4}$	1	0.2	0.5575	-1.2235	0.7131
7	6	1	15	6	5	6	0.94	0.5	0.1	$\frac{\pi}{4}$	1	0.2	0.5067	-1.3044	0.5926
7	6	1	15	6	5	6	0.94	0.5	0.3	$\frac{\pi}{4}$	1	0.2	0.3402	-1.3272	0.3995`
7	6	1	15	6	5	6	0.94	0.5	0.5	$\frac{\pi}{4}$	1	0.2	0.2561	-1.3389	0.3013
7	6	1	15	6	5	6	0.94	0.5	0.5	$\frac{\pi}{4}$	3	0.2	0.4823	-1.9498	0.3410
7	6	1	15	6	5	6	0.94	0.5	0.5	$\frac{\pi}{4}$	5	0.2	0.6469	-2.1633	0.3588
7	6	1	15	6	5	6	0.94	0.5	0.5	$\frac{\pi}{3}$	1	0.2	0.3727	-2.6256	-0.1456
7	6	1	15	6	5	6	0.94	0.5	0.5	$\frac{\pi}{2}$	1	0.2	1.2493	-3.1207	-1.2244
7	6	1	15	6	5	6	0.94	0.5	0.5	$\frac{\pi}{2}$	1	0	1.2319	-3.1194	-1.2242

Table 2. Variation in Nusselt number and Sherwood number for $\varepsilon = 0.2,\ \omega t = \frac{\pi}{2}$

Pr	S	R_1	Sc	k_1	A	ω	$\lvert V\rvert$	$\lvert W\rvert$	φ_2	φ_3	Nu	Sh
0.71	1	2	0.6	0.1	0.2	1	0.9119	1.0850	0.9160	0.4297	-0.1638	0.5969
1.38	1	2	0.6	0.1	0.2	1	1.5730	1.0850	0.6909	0.4297	0.0546	0.5969
7	**1**	2	0.6	0.1	0.2	1	7.6895	1.0850	0.1856	0.4297	4.4389	0.5969
7	**3**	2	0.6	0.1	0.2	1	7.9484	1.0850	0.1667	0.4297	5.3106	0.5969
7	**5**	**2**	0.6	0.1	0.2	1	8.1815	1.0850	0.1486	0.4297	5.9192	0.5969
7	5	**4**	0.6	0.1	0.2	1	7.3861	1.0850	0.2352	0.4297	4.3254	0.5969
7	5	**6**	**0.6**	0.1	0.2	1	6.6590	1.0850	0.3416	0.4297	2.7316	0.5969
7	5	6	**0.78**	0.1	0.2	1	6.8190	1.3049	0.2975	0.3914	3.3139	0.7701
7	5	6	**0.94**	**0.1**	0.2	1	6.9460	1.4954	0.2678	0.3627	3.7238	0.9250
7	5	6	0.94	**0.3**	0.2	1	6.9768	1.5595	0.2565	0.3189	4.0250	1.0814
7	5	6	0.94	**0.5**	**0.2**	1	6.9990	1.6251	0.2462	0.2826	4.2423	1.2106
7	5	6	0.94	0.5	**0.5**	1	8.4864	1.7964	0.1402	0.2254	4.3464	1.2209
7	5	6	0.94	0.5	**0.8**	**1**	10.0404	1.9726	0.0663	0.1782	4.4504	1.2313
7	5	6	0.94	0.5	0.8	**3**	10.5198	2.3449	0.1704	0.3824	4.2268	1.1262
7	5	6	0.94	0.5	0.8	**5**	11.0891	2.7223	0.2457	0.4789	4.0440	1.0503
7	**5**	**6**	**0.94**	**0.5**	**0**	**1**	**6.0689**	**2.2463**	**0.3451**	**0.3279**	**4.1729**	**1.1565**

5. CONCLUSION

The findings of unsteady flow of an incompressible, viscous and electrically conducting fluid past an infinite oscillating inclined porous plate with variable suction under slip boundary conditions discussed in earlier section are concluded as

- Both the Prandtl number and Schmidt number shows the retarding effect on the velocity and temperature fields.
- Both the velocity and temperature fields shows rising patterns with the increase in radiation absorption parameter and heat source parameter
- An accelerating behaviour of thermal and mass Grashoff number is seen on the velocity patterns.
- The velocity field is accelerated under slip flow but has adverse effects under the influence of magnetic field and angle of inclination.
- The chemical reaction parameter shows the decreasing behaviour on velocity, temperature and concentration profiles.
- The suction parameter and time has decreasing influence on temperature and concentration profiles.
- The drag at the plate is reduced under the influence of magnetic field, heat source, slip flow, chemical reaction and inclination whereas radiation absorption and oscillation frequency has adverse effects .
- The rate of heat and mass transfer at the plate is accelerated with Schmidt number, suction constant and chemical reaction but reduced with oscillation frequency.

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Appendix

$$a_1 = \frac{Scv^0 + \sqrt{Sc^2{v^0}^2 + 4Sck_1}}{2} \qquad a_2 = \frac{Scv^0 + \sqrt{Sc^2{v^0}^2 + 4Sc(k_1 + i\omega)}}{2}$$

$$a_3 = \frac{Prv^0 + \sqrt{Pr^2{v^0}^2 + 4S}}{2} \qquad a_4 = \frac{Prv^0 + \sqrt{Pr^2{v^0}^2 + 4(S + i\omega Pr)}}{2}$$

$$a_5 = \frac{v^0 + \sqrt{{v^0}^2 + 4\left(M + \frac{1}{K}\right)}}{2} \qquad a_6 = \frac{v^0 + \sqrt{{v^0}^2 + 4\left(M + \frac{1}{K} + i\omega\right)}}{2}$$

$$A_1 = \frac{a_1 Scv^0 A}{{a_1}^2 - Scv^0 a_1 - Sc(k_1 + i\omega)} \qquad A_2 = \frac{R_1}{{a_1}^2 - Prv^0 a_1 - S}$$

$$A_3 = \frac{R_1 A_1 + Prv^0 a_1 A_2 A}{{a_1}^2 - Prv^0 a_1 - (S + i\omega \mathrm{Pr})} \qquad A_4 = \frac{R_1(1 - A_1)}{{a_2}^2 - Prv^0 a_2 - (S + i\omega \mathrm{Pr})}$$

$$A_5 = \frac{a_3(1 + A_2)Pr\, v^0 A}{{a_3}^2 - Prv^0 a_3 - (S + i\omega \mathrm{Pr})} \qquad A_6 = 1 + A_3 + A_4 - A_5$$

$$A_7 = \frac{Gr\cos(\alpha)\, A_2 - Gm\cos(\alpha)}{{a_1}^2 - v^0 a_1 - \left(M + \frac{1}{K}\right)} \qquad A_8 = \frac{Gr\cos(\alpha)(1 + A_2)}{{a_3}^2 - v^0 a_3 - \left(M + \frac{1}{K}\right)}$$

$$A_9 = \frac{1 - (1 + ha_1)A_7 + (1 + ha_3)A_8}{(1 + ha_5)} \qquad A_{10} = \frac{Gr\cos(\alpha)\, A_3 - Gm\cos(\alpha)\, A_1 + v^0 a_1 A_7 A}{{a_1}^2 - v^0 a_1 - \left(M + \frac{1}{K} + i\omega\right)}$$

$$A_{11} = \frac{Gr\cos(\alpha)\, A_4 - Gm\cos(\alpha)\,(1 - A_1)}{{a_2}^2 - v^0 a_2 - \left(M + \frac{1}{K} + i\omega\right)} \qquad A_{12} = \frac{Gr\cos(\alpha)\, A_5 + v^0 A_8 A}{{a_3}^2 - v^0 a_3 - \left(M + \frac{1}{K} + i\omega\right)}$$

$$A_{13} = \frac{Gr\cos(\alpha)\, A_6}{{a_4}^2 - v^0 a_4 - \left(M + \frac{1}{K} + i\omega\right)} \qquad A_{14} = \frac{a_5 v^0 A_9 A}{{a_5}^2 - v^0 a_5 - \left(M + \frac{1}{K} + i\omega\right)}$$

$$A_{15} = \frac{1 - (1 + ha_1)A_{10} - (1 + ha_2)A_{11} + (1 + ha_3)A_{12} + (1 + ha_4)A_{13} - (1 + ha_5)A_{14}}{(1 + ha_6)}$$

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