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Radiation absorption effect on MHD, free convection, chemically reacting visco-elastic fluid past an oscillatory vertical porous plate in slip flow regime

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Abstract

In this paper an analysis presented to investigate the influence of radiation absorption, chemical reaction and heat source effects on hydro magnetic free convection heat and mass transfer flow of visco-elastic fluid through porous medium bounded by an oscillating porous plate in the slip flow regime with constant suction and temperature dependent heat source. A uniform magnetic field of strength B_0 is applied at an angle α with the field flow direction. Analytical solutions for velocity, temperature and concentration are obtained. Skin friction, rate of heat and mass transfer coefficients are also derived. The results have been analyzed and presented graphically for various values of the flow parameters. It is observed that velocity increases with an increase in porosity parameter, radiation absorption, Grashof number, modified Grashof number and it decreases with an increase in magnetic parameter, Schmidt number, chemical reaction parameter, Prandtl number.

Keywords: Radiation absorption, Visco-elastic fluid, MHD, Free convection, Oscillatory flow, Chemical reaction, Slip flow regime, Porous plate

1. Introduction

In recent years, requirements of modern technology have stimulated in fluid flow, which involve the interaction of several phenomena. The process of heat and mass transfer phenomena is encountered in aeronautic, fluid fuel nuclear reactor. Chemical process Industries many engineering applications in which fluid is the working medium. The problems of laminar flow control through a porous media have accomplished considerable significant in aeronautical engineering in view of its application to reduce drag and thus the technical power requirement by a substantial amount. The convection problem in a porous medium has important applications in geothermal reservoirs and geothermal extractions (Sharma et al [1]) Staya sagar saxen et al. [2] studied the Chemical reaction and heat generation on moving Isothermal vertical surface through porous medium with uniform mass flux and transposition .Rajesh [3]discussed the Chemical Reaction and radiation effects on the transient MHD free convection flow of dissipative fluid past an infinite vertical porous plate with Ramped wall Temperature. Raj put et al [4] considered Transient free convection MHD flow between two long vertical parallel plates with variable temperature and uniform mass diffusion in a porous medium. Soudalgekar et al [5] investigation Transient free convection flow between two vertical parallel plates. Sreenadh et al [6] considered the Transient free convection flow between long vertical plates with constant heat flux at one boundary. .Gireesh Kumar et al [7] discussed the Effects of Chemical Reaction and Mass Transfer on Radiation and MHD free convection flow of Kuvshiski fluid through a porous medium. Thakar [8] investigated the Natural convection in unsteady MHD couette flow heat and mass transfer. Raju et al. [10] studied the Unsteady MHD radiative and chemically reactive free convection flow near a moving vertical plate in porous medium. Gireesh Kumar et al. [11] considered the Effects of Chemical Reaction and Mass Transfer on Radiation and MHD free convection flow of Kuvshiski fluid through a porous medium. Raju et al. [12] investigated t Unsteady MHD free convection Oscillating couette flow through a porous medium with periodic wall temperature in presence of chemical reaction and thermal radiation. Raju et al. [13] considered the Chemical Reaction and radiation effects on unsteady MHD free convection flow near a moving vertical. Raju et al. [14] presented the Unsteady MHD free convection Oscillating couette flow through a porous medium with periodic wall temperature in presence of chemical reaction and thermal radiation. Ananda Reddy et al [15] discussed the unsteady free convective MHD Non-Newtonian flow through a porous medium bounded by an Infinite inclined porous plate. The Influence of magnetic field on viscous Incompressible flow of electrically conducting fluid has its importance in many applications such as extrusion of plastic in the manufacture of Rayon and Nylon, purification of crude oil, pulp, paper Industry, Textile Industry and in different geographical cases etc., also, the transposition coding is considered to be very effective process to protect certain structural elements such as combustion chamber wall, exhaust nozzle walls or gas turbine blades of turbo jets and rockets engines, from the Influence of hot gases. In many process industries the coding of threads or sheets of some polymer materials in of importance of production line .The rate of cooling can be controlled effectively to achieve final products of desired characteristics drawing by threads, etc., in the presence of an magnetic field. Siva Raj et al. [14] investigated the Rushi Kumar Chemical Reaction Dusty Viscous elastic fluid flow in an irregular channel with convective boundary. Dwivedi et al. [16] considered the Effects of Thermal diffusion and chemical reaction on MHD flow of dusty visco-elastic (Walter's liquid model-B) fluid. Vajravelu et al. [17] examined the Heat Transfer in MHD visco -elastic boundary layer flow over a stretching sheet with thermal radiation and non-uniform heat –source /sink. Abo-Dahab et al. [18] studied the Influence of chemical reaction and thermal radiation on the heat and mass transfer in a porous medium with heat transfer in MHD micro polar flow over a vertical moving porous plate in a porous medium with heat generation. Mahdy [19] studied the Effect of chemical reaction and heat generation or absorption on double-diffusive convection from a vertical truncated cone in porous media with variable viscosity. Ibrahim et al. [20] examined the Influence of chemical reaction on heat and mass transfer of non-Newtonian fluid with yield stress by free convection from vertical surface in porous medium considering soret effect. Rusi Kumar et al. [21] considered the. Influence of chemical reaction on unsteady MHD mixed convective flow over a moving vertical porous plate. Raptis et al. [22] investigated the Oscillating flow through a porous medium by the presence of free convective flow. Talakdar et al. [23] Buoyancy and chemical reaction effects on MHD mixed convection heat mass transfer in a porous. Mondal, [24] examined the Effects of Soret Dufour, chemical reaction and thermal radiation on MHD non-Darcy unsteady mixed convective heat and mass transfer over a stretching sheet.

2. Formulation of the Problem

An unsteady convective heat and mass transfer flow of a viscous electrically conducting viscoelastic fluid (Walter's Liquid Model B) through a porous medium bounded by an oscillating porous plate in the slip-flow regime is considered. The x^*-axis taken along the vertical plate in the upward direction and y^*-axis is taken normal to it. Let u and v be the components of velocity in and y directions respectively. A uniform magnetic field of strength B_0 is applied normal to the fluid flow direction. The effects of first order chemical reaction, radiation absorption and heat generation/absorption sources are (taken into account) considered. The flow is assumed that

(i) The surface is maintained at constant temperature and concentration.
(ii) As the plates are long enough, all the physical variables are functions of y and t only
(iii) Magnetic Reynolds number is very small so that the induced magnetic field is neglected
(iv) Applied electric field is also neglected
(v) Dissipation effects are neglected
(vi) Pressure in flow field is assumed to be a constant

Under the above assumptions and the constitutive equation for the rheological equation of stat for visco -elastic fluid are characterized by Walter's Liquid Model B). The governing boundary layer equations of the flow field are given by

Continuity equation

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

Momentum equation:

$$\frac{\partial u*}{\partial t*} + v^* \frac{\partial u^*}{\partial y^*} = \vartheta \frac{\partial^2 u^*}{\partial y^{*2}} - \frac{K^*_1}{\rho} \frac{\partial^3 u^*}{\partial y^{*2} \partial t^*} + g\beta(T^* - T^*_\infty) + g\beta^*(C^* - C^*_\infty) - \frac{\sigma B_0^2}{\rho} u^* - \frac{\vartheta}{k} u^* \tag{2}$$

Energy equation:

$$\rho C_p \left(\frac{\partial T^*}{\partial t^*} + v^* \frac{\partial^2 T}{\partial y^{*2}}^* \right) = \kappa \frac{\partial^2 T^*}{\partial y^{*2}} - S_1\left(T^* - T^*_\infty\right) + R_1\left(C^* - C^*_\infty\right) \tag{3}$$

Diffusion equation:

$$\frac{\partial C^*}{\partial t^*} + v \frac{\partial C^*}{\partial y^*} = D \frac{\partial^2 C^*}{\partial y^{*2}} - K_1\left(C^* - C^*_\infty\right) \tag{4}$$

Boundary Conditions are

$$u^* = e^{i\omega^* t^*} + R\frac{\partial u^*}{\partial y^*},\ T^* = T_w^* + \left(T_w^* - T_\infty^*\right)e^{i\omega t} \quad C^* = C_w^* + \left(C_w^* - C_\infty^*\right)e^{i\omega t} \quad at \ \ y^* = 0$$
$$u^* \to 0,\ T^* \to 0,\ C^* \to 0,\ \ as\ \ y^* \to \infty \tag{5}$$

The equation of continuity (1) gives $v^* = -v_0$ (6) where v_0 is the constant suction to the velocity normal to the plate.

Now we introduce the following non-dimensional variables and parameters:

$$u = \frac{u^*}{V_0}, y = \frac{y^*}{\vartheta}, t = \frac{t^* V_0^2}{\vartheta}, T = \frac{T^* - T_\infty^*}{T_w^* - T_\infty^*}, C = \frac{C^* - C_\infty}{C_w^* - C_\infty^*}, M = \sqrt{\frac{\sigma\vartheta}{\rho}}\frac{B_0}{V_0}, K_1 = \frac{V_0^2 K_1^*}{\vartheta^2\rho}, R = \frac{V_0 R_1}{\vartheta}$$
$$Gr = \frac{g\beta\vartheta\left(T_w - T_\infty\right)}{V_0^3}, Gm = \frac{g\beta^*\vartheta\left(C_w - C_\infty\right)}{V_0^3}, K_p = \frac{KV_0^2}{v^2}, \Pr = \frac{\mu C_p}{k}, Kr = \frac{K_1\vartheta}{V_0^2}, Sc = \frac{\vartheta}{D} \tag{7}$$

In view of the above non-dimensional form

$$\frac{\partial u}{\partial t} - \frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + GrT + GmC - \left(M + \frac{1}{K_p}\right)u - K_1\frac{\partial^3 u}{\partial y^2 \partial t} \tag{8}$$

$$\Pr\frac{\partial T}{\partial t} - \Pr\frac{\partial T}{\partial y} = \frac{\partial^2 T}{\partial y^2} - ST + R_1 C \tag{9}$$

$$Sc\frac{\partial C}{\partial t} - Sc\frac{\partial C}{\partial y} = \frac{\partial^2 C}{\partial y^2} - ScKrC \tag{10}$$

Where $M_1 = M + \frac{1}{K_p}$, K_p is the Porosity parameter, M is the magnetic parameter, K_1 is the visco-elastic parameter, $R_1$is the radiation absorption parameter, Kr is the chemical reaction parameter, Pr is the Prandtl number, Gr is the modified Grashof number, Sc is the Schmidt number.

Corresponding boundary conditions in dimensionless form are:

$$u = e^{i\omega t} + R\frac{\partial u}{\partial t}, T = 1 + e^{i\omega t}, C = 1 + e^{i\omega t} \ \ at \ y = 0$$
$$u \to 0, T \to 0, C \to 0, \ \ as \ \ y \to \infty \tag{11}$$

3. Method of Solution:

For solving the equations (8)-(10) subject to the boundary conditions (11), we assume the following expressions for the velocity, temperature and concentration distributions of the flow field

$$u = u_0\left(y\right) + u_1\left(y\right)e^{i\omega t}, T = T_0\left(y\right) + T_1\left(y\right)e^{i\omega t}, C = C_0\left(y\right) + C_1\left(y\right)e^{i\omega t} \tag{12}$$

Using the equations (12) in (8)-(10) and equating the harmonic and non-harmonic terms we obtain the following set of equations.

$$u_0^{11} + u_0^1 - M_1 u_0 = -GrT_0 - GmC_0 \tag{13}$$

$$b_1 u_1^{11} + u_1^1 - b_2 u_1 = -GrT_1 - GmC_1 \tag{14}$$

$$T_0^{11} + \Pr T_0^1 - ST_0 = -R_1 C_0 \tag{15}$$

$$T_1^{11} \Pr T_1^1 - (S + i\Pr\omega)T_1 = -R_1 C_1 \tag{16}$$

$$C_0^{11} + ScC_0^1 - ScKrC_0 = 0 \tag{17}$$

$$C_1^{11} + ScC_1^1 - Sc(Kr + i\omega)C_1 = 0 \tag{18}$$

The corresponding boundary conditions are

$$\begin{aligned} &u_0 = R\frac{\partial u_0}{\partial y},\ u_1 = 1 + R\frac{\partial u_1}{\partial y}, T_0 = 1, T_1 = 0, C_0 = 1, C_1 = 0 \quad at \quad y = 0 \\ &u_0 \to 0, u_1 \to 0, T_0 \to 0, T_1 \to 0, C_0 \to 0, C_1 \to 0 \quad as \quad y \to \infty \end{aligned} \tag{19}$$

Solving the equations (15) to (18) subject to the boundary conditions (19) we obtain

$$u_0 = l_8 e^{-m_9 y} - l_5 e^{-m_5 y} + (l_6 - l_7)e^{-m_1 y} \tag{20}$$

$$u_1 = l_{13} e^{-m_{11} y} - l_9 e^{-m_7 y} + l_{14} e^{-m_3 y} \tag{21}$$

$$T_0 = l_2 e^{-m_5 y} - l_1 e^{-m_1 y} \tag{22}$$

$$T_1 = l_4 e^{-m_7 y} - l_3 e^{-m_3 y} \tag{23}$$

$$C_0 = e^{-m_1 y} \tag{24}$$

$$C_1 = e^{-m_3 y} \tag{25}$$

Using the above expressions (21) to (23) in equations (12) to (14) we obtain the velocity, temperature and concentration fields as

$$u(y,t) = \left(l_8 e^{-m_9 y} - l_5 e^{-m_5 y} + (l_6 - l_7)e^{-m_1 y}\right) + e^{i\omega t}\left(l_{13} e^{-m_{11} y} - l_9 e^{-m_7 y} + l_{14} e^{-m_3 y}\right) \tag{26}$$

$$T(y,t) = \left(l_2 e^{-m_5 y} - l_1 e^{-m_1 y}\right) + e^{i\omega t}\left(l_4 e^{-m_7 y} - l_3 e^{-m_3 y}\right) \tag{27}$$

$$C(y,t) = e^{-m_1 y} + e^{i\omega t} e^{-m_3 y} \tag{28}$$

Skin Friction: the skin friction at the wall is given by

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = \left(-l_8 m_9 + l_5 m_5 - m_1(l_6 - l_7)\right) + e^{i\omega t}\left(-l_{13} m_{11} + l_9 m_7 - m_3 l_{14}\right) \tag{29}$$

Heat Flux: The rate of heat transfer on the wall in terms of Nusselt number is given by

$$N_u = -\left(\frac{\partial T}{\partial y}\right)_{y=0} = \left(-l_2 m_5 + l_1 m_1\right) + e^{i\omega t}\left(-l_4 m_7 + l_3 m_3\right) \tag{30}$$

Sherwood number: The rate of mass transfer on the wall in terms of Sherwood number is given by

$$Sh = -\left(\frac{\partial C}{\partial y}\right)_{y=0} = \left(-m_1\right) + e^{i\omega t}\left(-m_3\right) \tag{31}$$

$$m_1 = \frac{Sc + \sqrt{Sc^2 + 4ScKr}}{2}, m_3 = \frac{Sc + \sqrt{Sc^2 + 4Sc(Kr + i\omega)}}{2}, m_5 = \frac{\Pr + \sqrt{\Pr^2 + 4S}}{2}, b_1 = 1 - k_1 i\omega, b_2 = M_1 + i\omega,,$$

$$m_7 = \frac{\Pr + \sqrt{\Pr^2 + 4(S + i\omega \Pr)}}{2}, m_9 = \frac{1 + \sqrt{1 + 4M_1}}{2}, m_{11} = \frac{1 + \sqrt{1 + 4b_1 b_2}}{2}, l_1 = \frac{R_1}{m_1^2 - \Pr m_1 - Sc}$$

$$l_2 = 1 + l_1, l_3 = \frac{R_1}{m_3^2 - \Pr m_3 - (S + i\omega \Pr)}, l_4 = 1 + l_3, l_5 = \frac{Grl_2}{m_5^2 - m_5 - M_1}, l_6 = \frac{Grl_1}{m_1^2 - m_1 - M_1},$$

$$l_7 = \frac{Gm}{m_1^2 - m_1 - M_1}, l_8 = \frac{l_5(1 + m_5) - (1 + m_1)(l_6 - l_7)}{1 + Rm_9}, l_9 = \frac{Grl_4}{b_1 m_7^2 - m_7 - b_2}, l_{10} = \frac{Grl_3}{b_1 m_3^2 - m_3 - b_2},$$

$$l_{11} = \frac{Gm}{b_1 m_3^2 - m_3 - b_2}, l_{12} = l_{10} - l_{11}, l_{13} = \frac{l_9\left(1 + Rm_7\right) - l_{10} + l_{11} - Rl_{12} m_3 + 1}{1 + Rm_{11}}, l_{14} = l_{10} - l_{11},$$

4. **Result and discussion:**

In order to look in to the physical insight of the problem, the expressions obtained in previous section are studied with help of graphs from figures 1-14. The effects of various physical parameters viz., the Schmidt number (Sc), the thermal Grashof number (Gr), the mass Grashof number (Gm), the magnetic parameter (M), the slip parameter (R), the radiation absorption (R_1) The chemical reaction (Kr), Non-Newtonian (k_1), the source parameter (S), Prandtl number (Pr), Porosity parameter (K_p), time (t) are studied numerically by choosing arbitrary values.

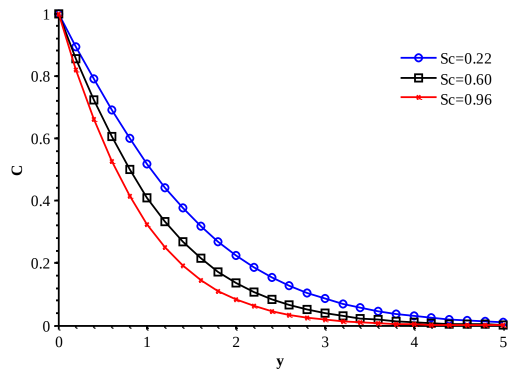

Fig.1. Effect of Schmidt number on Concentration

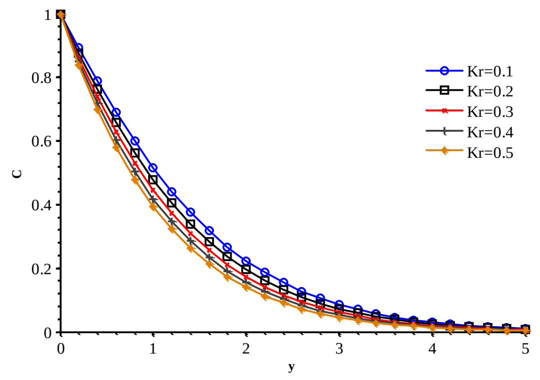

Fig.2. Effect of Chemical reaction parameter on Concentration

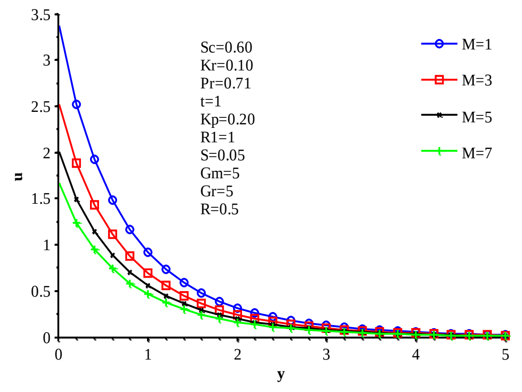

Fig.3. Effect of magnetic parameter on velocity

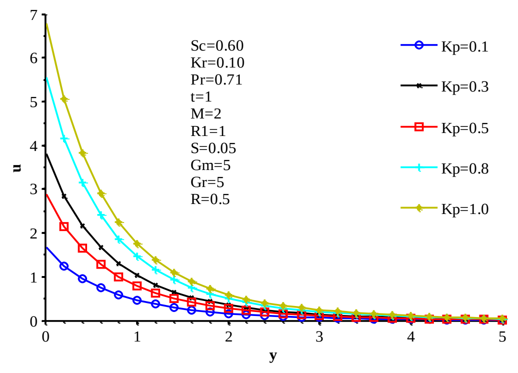

Fig.4. Effect porosity parameter on velocity

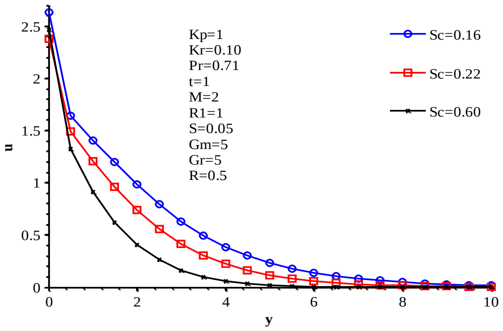

Fig.5. Effect of Schmidt number on velocity

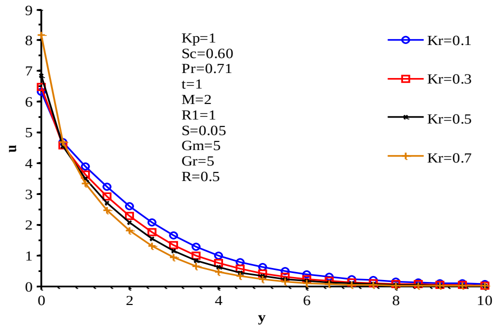

Fig.6. Effect of chemical reaction parameter on velocity

Fig 1. Depicts the variations in concentration profiles for different values Schmidt number, from this figure it is noticed that concentration decreases as Schmidt number increases. Physically it is true because Schmidt number is a dimensionless number defined as the ratio of momentum diffusivity (viscosity) and mass diffusivity, and is used to characterize fluid flows in which there are simultaneous momentum and mass diffusion convection processes as in the present problem. Near the vicinity of the plate concentration appears to be very high, whereas it reaches to the stationary position for away from the plate. This result is very similar to the result of Raju et al. [10]. In fig 2 effect of chemical reaction parameter (Kr) on concentration is presented. As Kr increases concentration decreases. Raju et al. [11] also showed that chemical reaction process condenses the concentration boundary layer. Therefore our result is in good agreement with that result. Effect of magnetic parameter on velocity distribution is shown in fig 3. From this figure it is noticed that as the magnetic parameter increases the velocity is decreases. This is due to the fact that the application of transverse magnetic field, that acts as a drag force, which is termed as Lorentz force. This force has the normal tendency of decreasing the velocity. The influence of this force is very significant near the plate compared to for away from the plate, where velocity is in stationary condition. This effect also has been studied by many authors [1, 4, 11, 12, 16, and 17] who have concluded the same result. Raju et al. [26] showed that velocity increases when the permeability of the porous medium increases. Physically, an increase in the permeability of porous medium leads the rise in the flow of fluid through it. When the holes of the porous medium become large, the resistance of the medium may be neglected. In figure 4 effect of porosity parameter K_p is shown. This figure witnesses that an increase in porosity parameter increases the velocity.

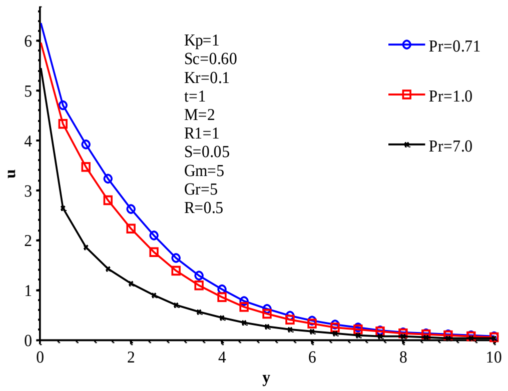

Fig.7. Effect of Prandle number on

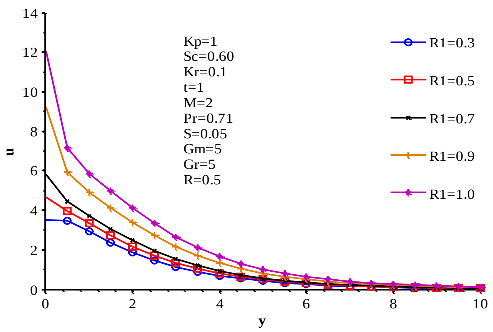

Fig.8. Effect radiation absorption on velocity (u)

In fig. 5 effect of Schmidt number on velocity is presented. This shows that velocity decreases as the Schmidt number increases. Physically this is true because of the increase in Schmidt number the viscosity of the fluid increases and hence velocity decreases. A similar effect is noticed in the presence of chemical reaction parameter from figure 6. It is quite interesting to observe the opposite reaction near the plate. Fig. 7 depicts the velocity profiles for different values of Prandtl number. Prandtl number is the ratio of momentum diffusivity to thermal diffusivity. It is known that lower thermal conductivity material has high velocity and higher thermal conductivity material have lower velocity. Figure 7 witnesses that the velocity decreases when the Prandtl number increases

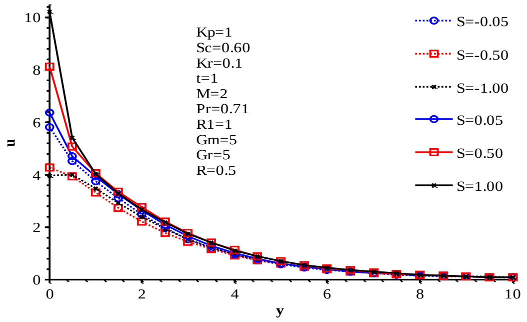

Fig.9. Effect of source parameter on velocity

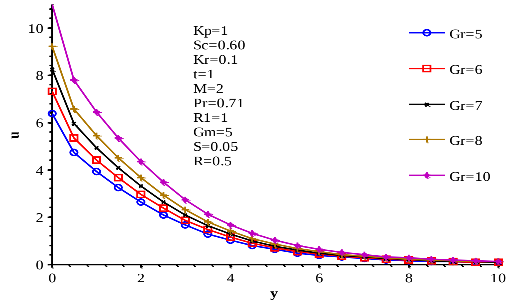

Fig.10. Effect of Grashof number on velocity

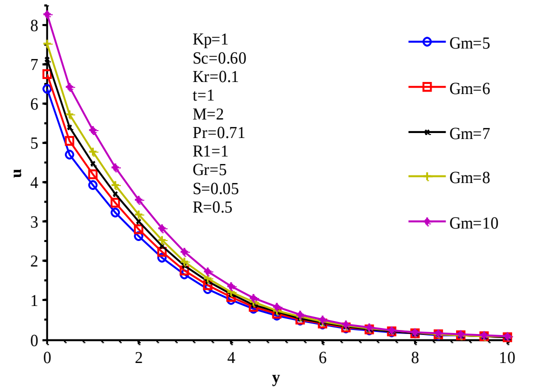

Fig.11. Effect of modified Grashof number on velocity

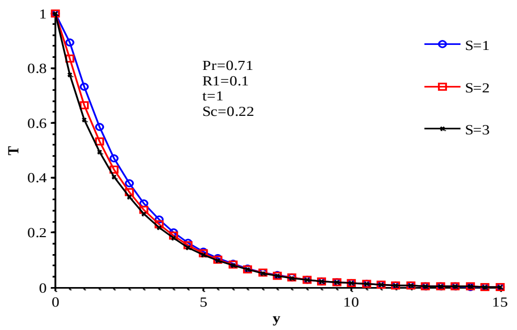

Fig.12.Effect of heat source on Temperature

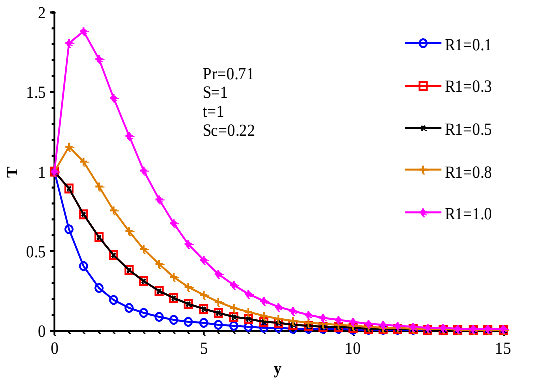

Fig.13. Effect of radiation absorption on Temperature

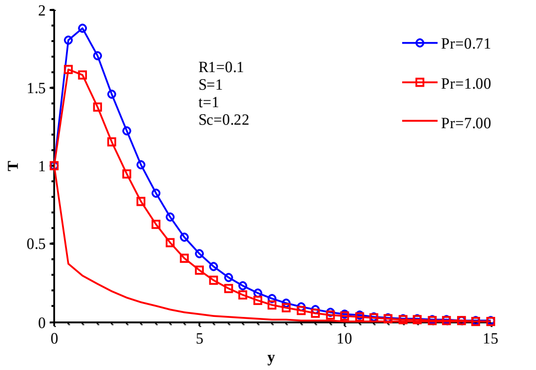

Fig.14. Effect of slip parameter on Temperature

The effects of the chemical reaction and radiation absorption on an unsteady flow of a viscous incompressible electrically conducting fluid past an infinite hot vertical non-conducting porous plate with mass transfer and span wise cosinusoidel surface temperature has been investigated by Satyac narayana and Haribabu [27]. They showed that the translational velocity decreases with an increase of radiation absorption and the magnitude of temperature profile on porous plate decreases. From figure 8 it is clear that an increase in radiation absorption increases the velocity. In figure 9 effect of heat source parameter is shown on velocity, from this figure it is noticed that velocity increases with an increase in source parameter. In figures 10 and 11 effects of Grashof number and modified Grashof number are shown. From these figures it is evident that velocity increases with the increasing values of these two parameters. In fig.12 -14, effects of source parameter, radiation absorption parameter and slip parameter are shown on temperature respectively. From these figures it is observed that temperature decreases when source parameter increases where as it increases when both radiation absorption parameter and slip parameter increase.

Table 1(a): Variations in Skin friction, Nusselt number and Sherwood number

Sc	Kr	Pr	Gm	Gr	M	**τ**	**Nu**	**Sh**
0.60	0.1	0.71	5	5	1	**15.8373**	**0.2654**	**1.4552**

0.78	0.1	0.71	5	5	1	**106.6246**	**3.2785**	**1.8610**
0.22	0.2	0.71	5	5	1	**19.3718**	**1.9742**	**0.6649**
0.22	0.4	0.1	5	5	1	**21.9263**	**1.9876**	**0.7947**
0.22	0.5	0.71	5	5	1	**23.6577**	**2.0429**	**0.8516**
0.22	0.1	7.1	5	5	1	**5.3954**	**11.8190**	**0.5866**
0.22	0.1	0.71	6	5	1	**18.5002**	**2.0427**	**0.5866**
0.22	0.1	0.71	7	5	1	**18.3248**	**2.0427**	**0.5866**
0.22	0.1	0.71	8	5	1	**18.1495**	**2.0427**	**0.5866**
0.22	0.1	0.71	5	6	1	**22.8849**	**2.0427**	**0.5866**
0.22	0.1	0.71	5	7	1	**27.0942**	**2.0427**	**0.5866**
0.22	0.1	0.71	5	8	1	**31.3035**	**2.0427**	**0.5866**
0.22	0.1	0.71	5	5	2	**20.4536**	**2.0427**	**0.5866**
0.22	0.1	0.71	5	5	3	**14.2163**	**2.0427**	**0.5866**
0.22	0.1	0.71	5	5	4	**10.8822**	**2.0427**	**0.5866**

Effects of Schmidt number, chemical reaction parameter, Prandtl number, Grashof number, modified Grashof number and magnetic parameter on Skin friction, Nusselt number and Sherwood number are shown in table 1. From this table it is noticed that Skin friction increases with an increase in Schmidt number, chemical reaction parameter, Grashof number and it decreases in the case of Prandtl number, modified Grashof number and magnetic parameter. Nusselt number increases with an increase in Schmidt number, chemical reaction parameter, Prandtl number and of course magnetic parameter, Grashof number and modified Grashof number have no influence on Nusselt number. Similarly the presence of Schmidt number and chemical reaction parameters increase the Sherwood number, whereas the Prandtl number has reverse tendency on the Sherwood number. Raju et al. [28, 29] also obtained similar results.

5. **Conclusion**

A theoretical analysis is presented for a problem of radiation absorption, chemical reaction and heat source effects on hydro magnetic free convection heat and mass transfer flow of visco-elastic fluid through porous medium bounded by an oscillating porous plate in the slip flow regime with constant suction and temperature dependent heat source. Governing equations are solved by usual perturbation method and the expressions for velocity, temperature and concentration are obtained. With the aid of these expressions for Skin friction, Nusselt number and Sherwood number are also derived. The effects of various physical parameters on flow quantities are studied graphically. The conclusions of the problem are as follows:

(i) Velocity increases with an increase in porosity parameter, radiation absorption, Grashof number, modified Grashof number and it decreases with an increase in magnetic parameter, Schmidt number, chemical reaction parameter, Prandtl number.

(ii) Temperature decreases with an increase in source parameter where as it has reverse tendency in the case of radiation absorption parameter and slip parameter.

Table 1(b): Variations in Skin friction, Nusselt number and Sherwood number

R	R_1	K_p	K_1	t	S	**τ**	**Nu**	**Sh**
0.5	1	0.5	0.1	1	0.05	**8.5221**	**3.0918**	**0.1288**
0.6	1	0.5	0.1	1	0.05	**8.5644**	**3.0918**	**0.1288**
0.7	1	0.5	0.1	1	0.05	**8.1591**	**3.0918**	**0.1288**
0.8	1	0.5	0.1	1	0.05	**7.4227**	**3.0918**	**0.1288**
0.9	1	0.5	0.1	1	0.05	**6.4346**	**3.0918**	**0.1288**
0.5	1	0.5	0.1	1	0.05	**2.0569**	**3.0918**	**0.1288**
0.5	2	0.5	0.1	1	0.05	**17.7138**	**6.6384**	**0.1288**
0.5	3	0.5	0.1	1	0.05	**37.4848**	**10.1850**	**0.1288**
0.5	4	0.5	0.1	1	0.05	**-7.2551**	**13.7316**	**0.1288**
0.5	5	0.5	0.1	1	0.05	**77.0258**	**17.2781**	**0.1288**
0.5	1	0.5	0.1	1	0.05	**8.8260**	**2.0427**	**0.5866**

0.5	1	0.6	0.1	1	0.05	**9.4173**	**2.0427**	**0.5866**
0.5	1	0.7	0.1	1	0.05	**9.8919**	**2.0427**	**0.5866**
0.5	1	0.8	0.1	1	0.05	**10.2813**	**2.0427**	**0.5866**
0.5	1	0.9	0.1	1	0.05	**10.6065**	**2.0427**	**0.5866**
0.5	1	0.5	0.2	1	0.05	**35.4554**	**2.0427**	**0.5866**
0.5	1	0.5	0.3	1	0.05	**35.3972**	**2.0427**	**0.5866**
0.5	1	0.5	0.4	1	0.05	**35.3385**	**2.0427**	**0.5866**
0.5	1	0.5	0.5	1	0.05	**35.2795**	**2.0427**	**0.5866**
0.5	1	0.5	0.5	2	0.05	**34.9838**	**2.9280**	**0.1288**
0.5	1	0.5	0.5	3	0.05	**36.2021**	**3.3326**	**0.1674**
0.5	1	0.5	0.5	4	0.05	**38.4066**	**2.9804**	**0.1285**
0.5	1	0.5	0.5	5	0.05	**40.3404**	**2.0859**	**0.2227**
0.5	1	0.5	0.5	1	0.05	**2.0569**	**3.0918**	**0.1288**
0.5	1	0.5	0.5	1	0.06	**1.7011**	**3.0806**	**0.1288**
0.5	1	0.5	0.5	1	0.07	**1.3481**	**3.0690**	**0.1288**
0.5	1	0.5	0.5	1	0.08	**0.9975**	**3.0572**	**0.1288**
0.5	1	0.5	0.5	1	0.09	**0.6493**	**3.0452**	**0.1288**

(iii) Concentration decreases with an increase in Schmidt number and chemical reaction parameter.

(iv) Skin friction increases with an increase in Schmidt number, chemical reaction parameter, Grashof number and it decreases in the case of Prandtl number, modified Grashof number and magnetic parameter. Nusselt number increases with an increase in Schmidt number, chemical reaction parameter, Prandtl number. Similarly the presence of Schmidt number and chemical reaction parameters increase the Sherwood number, whereas the Prandtl number has reverse tendency on the Sherwood number

6. **References**

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