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Heat Source and Chemical Reaction Impact on Mhd Fluid Flow Past an Inclined Plate

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Abstract

In this manuscript we analyzed an unsteady MHD free convective flow of a radiating fluid past an inclined plate in the presence of heat source, chemical reaction and thermal radiation with uniform temperature and species diffusion. The dimensionless governing partial differential equations are solved by using closed analytical method. The effects of various physical parameters on the velocity, temperature and concentration are shown graphically and discussed in detail. Numerical results for the skin friction, rates of heat and mass transfer are presented in the form of tables and discussed.

Keywords: MHD, Radiating fluid, heat and mass transfer, heat source, chemical reaction.

1. INTRODUCTION

Several industrial applications involve the flow of non-Newtonian fluid and thus the flow behavior of such fluids finds a great relevance. Moltenmetal’s, plastic, pulps. Emulsions, slurries and raw materials and fluid state are some examples to mention. Non-Newtonian flow also finds practical applications in bio-engineering, where in blood circulation in human/animal artery is explained by an appropriate Visco-elastic pulsatile flow helps in understanding the mechanism of dialysis of blood through an artificial kidney. Rout et al. [1] investigated effects of heat source and chemical reaction on MHD flow past a vertical plate with variable temperature. Sandha et al. [2] discussed heat and mass transfer effects on MHD flow past an inclined porous plate in the presence of chemical reaction. Satya Narayana et al. [3] studied chemical reaction and heat source effects on MHD oscillatory flow in an irregular channel. Vijaya Ragavan et al. [4] developed heat and mass transfer on an unsteady MHD mixed convective casson fluid flow past a moving vertical porous plate with effects of the dufour and chemical reaction. Suresh et al. [5] discussed effect of chemical reaction and radiation on MHD flow along a moving vertical porous plate with heat source and suction. Ravi Kumar et al. [6] investigated MHD double diffusive and chemically reactive flow through porous medium bounded by two vertical plates. Panigrahi et al. [7] analyzed impact of chemical reaction, hall current, and radiation on MHD flow between vertical walls. Sreedhar and Bhupa Reddy [8] reported chemical reaction effect on unsteady MHD flow past an infinite vertical porous plate in the presence of heat absorption. Gurivi Redy et al. [9] discussed thermal diffusion effect on MHD heat and mass transfer flow past a semi-infinite moving vertical porous plate with heat generation and chemical reaction. Rout et al. [10] discussed effect of radiation and chemical reaction on natural convective MHD flow through a porous medium with double diffusion.

Nagi Reddy et al. [11] analyzed chemical reaction impact on MHD natural convection flow through porous medium past an exponentially stretching sheet in presence of heat source/sink and viscous dissipation. Prasanna kumar et al. [12] reported effect of heat source and chemical reaction on MHD flow past a vertical plate with variable temperature. Ramana Murthy and Ramana Reddy [13] studied radiation and chemical reaction effects on unsteady MHD free convective periodic heat transport modeling in a saturated porous medium for a rotating system. Swetha et al. [14] discussed effects of chemical reaction, heat and mass transfer along a wedge with heat source and concentration in the presence of suction or injection. Kandasamy et al. [15] investigated effects of chemical reaction, heat and mass transfer along a wedge with heat source and concentration in the presence of suction or injection. Reddy et al. [16] analyzed chemical reaction impact on MHD natural convection flow through porous medium past an exponentially stretching sheet in presence of heat source/sink and viscous dissipation. Matta et al. [17] discussed radiation and chemical reaction effects on unsteady MHD free convention mass transfer fluid flow in a porous plate. Bijoy Krishna et al. [18] reported MHD free convection flow across an inclined porous plate in the presence of heat source, Isoret effect, and chemical reaction affected by viscous dissipation ohmic heating. Ramakrishna et al. [19] discussed impacts of chemical reaction, diffusion-thermo and radiation on unsteady natural convective flow past an inclined vertical plate under aligned magnetic field. Suman and Ahmed [20] discussed MHD mass transfer flow past an inclined plate with variable temperature and plate velocity embedded in a porous medium. Rajput et al. [21] analyzed radiation effect on MHD flow past an inclined plate with variable temperature and mass diffusion. Hari Krishna et al. [22] studied effects of radiation and chemical reaction on MHD flow past an oscillating inclined porous plate with variable temperature and mass diffusion. Sandhya et al. [23] analyzed Steady on MHD heat and mass transfer flow of an inclined porous plate in the presence of radiation and chemical reaction

Mathematical Analysis

The unsteady free convective and mass transfer flow of an electrically conducting visco-elastic fluid past an infinite vertical plate in the presence of heat source has been considered. A transverse magnetic field of uniform strength B_0 is applied normal to the direction of the flow. The induced magnetic field is neglected in comparison to the applied magnetic field as the magnetic Reynolds number of the flow is taken to be very small. The flow is assumed to be in x^* - direction which is taken along the vertical plate in upward direction against to the gravitational field and the y^*-axis is taken to be normal to the plate. Initially the plate and the surrounding fluid are at the same temperature T_∞^* with concentration level C_∞^* at all points is stationary condition. At time $t > 0$, the plate is given an impulsive motion with a velocity $u = u_0$ in its own plane and all at once the plate temperature and spices concentration are up stretched to T_∞^* and C_∞^* respectively. The effects of variation in density (ρ) with temperature and species concentration are considered only in the body force term in accordance with usual Boussineag's approximation. The fluid considered here is gray, absorbing /eliminating radiation but a non-scattering medium. Since the flow of the fluid is assumed to be in the direction of x^* axis, so the physical quantities are functions of the coordinates y^* and t^* only. Then by usual Boussinesq's approximation, the unsteady visco-elastic fluid flow is governed by the following equations.

Equation of Momentum

$$\frac{\partial u^*}{\partial t^*} = \nu \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta(T^* - T^*_\infty)\cos\alpha + g\beta^*(C^* - C^*_\infty)\cos\alpha - \frac{\sigma B_0^2 u^*}{\rho} \tag{1}$$

Equations of energy

$$\rho Cp \frac{\partial T^*}{\partial t^*} = k \frac{\partial^2 T^*}{\partial y^{*2}} - \frac{\partial q_r}{\partial y^*} + Q^*(T^* - T^*_\infty) \tag{2}$$

Equation of mass diffusion

$$\frac{\partial C^*}{\partial t^*} = D \frac{\partial^2 C^*}{\partial y^{*2}} - K_r^{\ *}(C^* - C^*_\infty) \tag{3}$$

With the initial and boundary conditions:

$$\begin{aligned} &t^* \le 0 : u^* = 0, T^* = T^*_\infty, C^* = C^*_\infty \text{ for all } y^* \\ &t^* > 0 : u^* = u_0, T^* = T^*_\infty, C^* = C^*_\infty \text{ at } y^* = 0 \\ &u^* \to 0, T^* \to T^*_\infty, C^* \to C^*_\infty \quad \text{as } y^* \to \infty \end{aligned} \tag{4}$$

Here $A = \frac{u_0^2}{\nu}$, The local radiant for the case of an optically thin gray gas is expressed by

$$\frac{\partial q_r}{\partial y^*} = -4a^*\sigma(T^*_\infty - T^{*4}) \tag{5}$$

It is assumed that the temperature difference within the flow are sufficiently small and that T^{*4} may be expressed as a linear function of the temperature. This is obtained by expanding T^{*4} in a Taylor series about T^*_∞ and neglecting the higher order terms, we get

$$T^{*4} \cong 4T_\infty^{*3} T^* - 3T_\infty^{*4} \tag{6}$$

Substituting equations (5) and (6) in equation (2), we get

$$\rho Cp \frac{\partial T^*}{\partial t^*} = k \frac{\partial^2 T^*}{\partial y^{*2}} + 16a^*\sigma T_\infty^{*3}(T^*_\infty - T^*) + Q^*(T^* - T^*_\infty) \tag{7}$$

The following are non-dimensional quantities

$$\begin{aligned} &u = \frac{u^*}{u_0},\ t = \frac{t^* u_0^2}{\nu},\ y = \frac{y^* u_0}{\nu},\ \theta = \frac{T^* - T^*_\infty}{T^*_w - T^*_\infty},\ Gr = \frac{g\beta\nu(T^*_w - T^*_\infty)}{u_0^3} \\ &Gm = \frac{g\beta^*(C^*_w - C^*_\infty)}{u_0^3}, C = \frac{C^* - C^*_\infty}{C^*_w - C^*_\infty}, k = \frac{\nu K_r}{u_0^2}, P_r = \frac{\mu C_P}{k}, Sc = \frac{\nu}{D} \\ &M = \frac{\sigma B_0^2 \nu}{\rho u_0^2}, R = \frac{16a^*\nu^2\sigma T_\infty^{*3}}{k u_0^2},\ Q = \frac{Q^*\nu^2}{K u_0^2}, Kr = \frac{\nu K_r^*}{u_0^2}, \end{aligned} \tag{8}$$

Equation (1), (3) and (7) leads to

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + Gr\cos\alpha\theta + Gm\cos\alpha c - Mu \tag{9}$$

$$P_r \frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} - R\theta + Q\theta \tag{10}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - KrC \tag{11}$$

The non-dimensional boundary conditions are given by

$$\begin{aligned} & t \le 0\,; u = 0, \theta = 0; C = 0 \text{ For all } y \\ & t > 0; u = 1, \theta = 1, C = 1 \text{ At } y = 0 \\ & u \to 0, \theta \to 0, C \to 0 \text{ As } y \to \infty \end{aligned} \tag{12}$$

Solution of the problem:

The numerical solution for governing equations with boundary conditions is not obtained. The governing equations are solved by using the closed numerical method.

We assume the trail solution for the velocity, temperature and concentration are as follows

$$u(y,t) = u_0(y)e^{nt} \tag{13}$$

$$\theta(y,t) = \theta_0(y)e^{nt} \tag{14}$$

$$C(y,t) = C_0(y)e^{nt} \tag{15}$$

Substituting equation (9) and (11) in Equations (13), (14) and (15), we obtain OD equations The corresponding boundary conditions can be written as

$$u_0 = e^{-nt}, \theta_0 = e^{-nt}\ , C_0 = e^{-nt} \text{ at } y = 0 \tag{16}$$

$$u_0 \to 0, \theta_0 \to 0,\ C_0 \to 0 \text{ as } y \to \infty$$

The analytical solution of ordinary differential equations with satisfying the boundary conditions (16) are given by

$$u = (1 - A_4 - A_5)e^{-\sqrt{A_3}y} + A_4 e^{-\sqrt{A_2}y} + A_5 e^{-\sqrt{A_1}y} \tag{17}$$

$$\theta = e^{\sqrt{-A_2 y}} \tag{18}$$

$$C = e^{\sqrt{-A_1 y}} \tag{19}$$

The skin friction, Nusselt number and Sherwood number are important physical parameters for this type of boundary layer flow.

Skin Friction

Knowing the velocity field, the skin-friction at the plate can be obtained, which is non-dimensional form is given by

$$\tau = -\left(\frac{\partial u}{\partial y}\right)_{y=0} = \sqrt{A_3}\left(1 - A_4 - A_5\right) + \sqrt{A_2}A_4 + \sqrt{A_1}A_5$$

Nusselt number

Knowing the temperature field, the rate of heat transfer coefficient can be obtained, which in non-dimensional form is given, in terms of the Nusselt number, is given by

$$N_u = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \sqrt{A_2}$$

Sherwood number

Knowing the concentration field, the rate of mass transfer coefficient can be obtained, which in non-dimensional form, in terms of the Sherwood number, is given by

$$S_h = -\left(\frac{\partial c}{\partial y}\right)_{y=0} = \sqrt{A_1}$$

2. RESULT AND DISCUSSION

A closed analytical solution to the problem of Unsteady MHD free convective chemically reacting, radiating fluid flow past a moving vertical plate in the presence of thermal radiation have been presented in the preceding section. In order to get the physical insight into the problem, then numerical values of the velocity field is computed for the different values of the system parameters such as magnetic parameter (M), solutal Grashof number(Gm), thermal Grashof number (Gr),radiation parameter (R), Prandtl number (Pr), chemical reaction parameter (Kr),Schmidt number(Sc), heat source (Q) respectively. Throughout the computations we employ Gr=5, Gm=5, M=0.5, Pr=0.71, R=0.5, Q=0.5, Sc=0.22, Kr=0.5, n=1.

The concentration profiles are plotted in figure 1 for various values of chemical reaction Kr. From this figure, it is notice that the concentration decreases with an increase in the values of chemical reaction Kr. A comparison of curves in the figures shows a decrease in concentration with an increase of chemical reaction Kr. Actually it is true, since the increase of Kr means decrease of molecular diffusively and therefore decreases in concentration boundary layer. The effects of increasing the Schmidt number Sc on the species concentration profiles have been shown in figure2. From this figure, it is noticed that an increase in Schmidt number Sc results an decrease in the concentration profile. Figure 3 revels the temperature profiles for different values of Prandtl number Pr. It is observed that the temperature decreases as an increase in the values of Prandtl number Pr. The reason is that smaller values of Prandtl number are equivalent to increase in the thermal conductivity of the fluid and therefore heat is able to diffuse away from the heated surface extra rapidly for higher values of Prandtl number Pr (Appendix).. Hence, in the case of larger Prandtl number the thermal boundary layer is thinner and the rate of heat transfer is reduced. Figure 4 shows the temperature profile for different values of radiation parameter R. From this figure it is noticed that an increase in the value of R results a decrease in the temperature profiles. Figure 5 shows the temperature profile for different values of heat source. From this figure it is noticed that an increase in the value of heat source results a increase in the temperature profile. The effects of thermal Grashof number Gr on velocity profile is presented in figure 6. It is observed that an increase in Gr leads to a rise in the velocity boundary layer. Figure 7 shows the velocity profile for different values of solutal Grashof number Gm. From this figure it is observed that an increase in the vales of solutal Grashof number Gm results in increase velocity profiles. Figure 8 illustrates the effects of velocity profiles for different values of magnetic parameter M. From this figure it is notice that velocity decreases with an increase in magnetic parameter M. Figure 9 reveals the effect of angle of inclination (α) on the transient velocity profile. It is evident from the figure that the velocity decreases with increase in angle of inclination.

Table 1 depicts the effects of various physical parameters on Skin friction. From this table, it is noticed that τ increase with an increase in magnetic parameter M, angle of inclination α, Prandtl number Pr. From table 2, it is seen that an increase in Prandtl number Pr, radiation parameter R, heat source Q leads to an increase in Nusselt number. It is clear that from table3, as Schmidt number Sc, Kr increases the magnitude of Sherwood number increases.

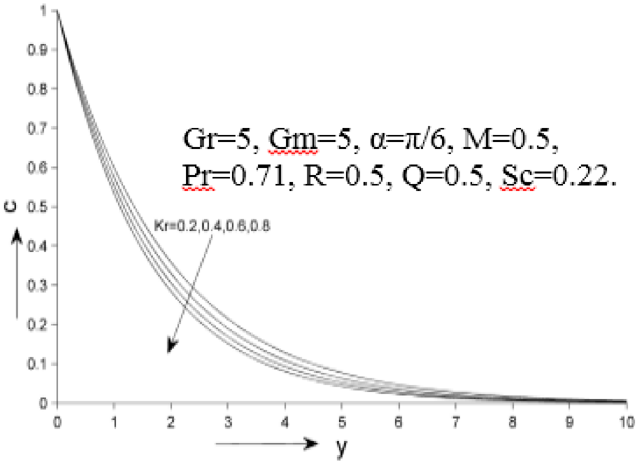

Fig. 1. Concentration profile for different values of Kr.

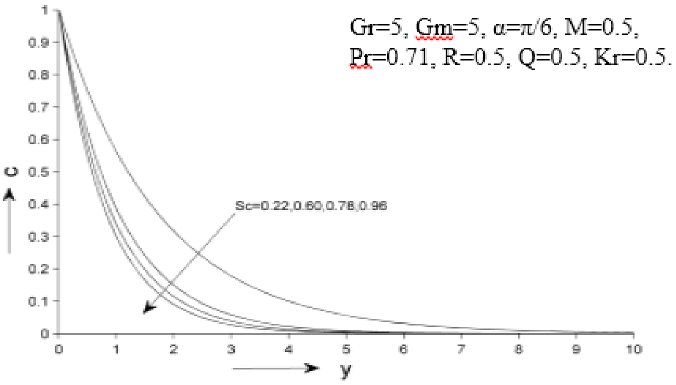

Fig. 2. Concentration profile for different values of Sc.

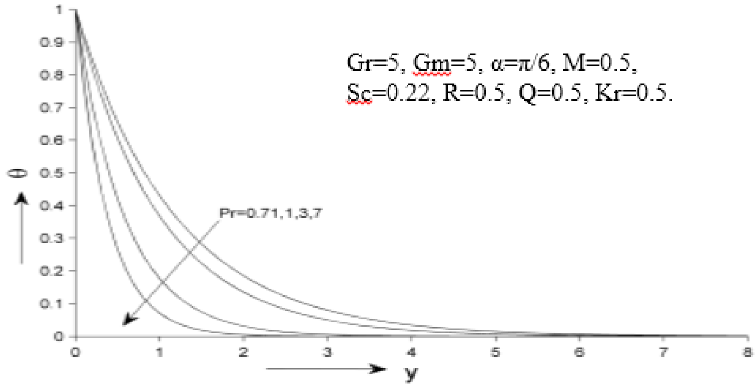

Fig. 3. Temperature profile for different values of Pr.

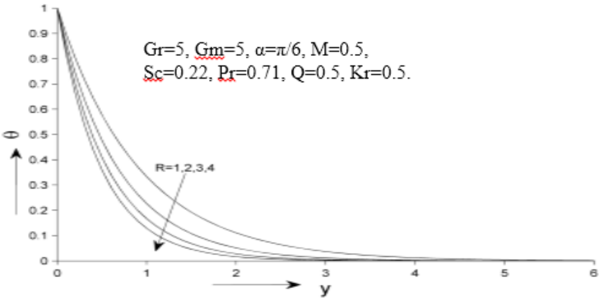

Fig. 4. Temperature profile for different values of R.

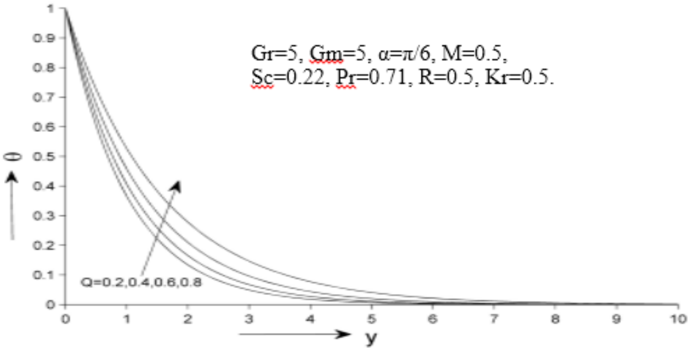

Fig. 5. Temperature profile for different values of Q.

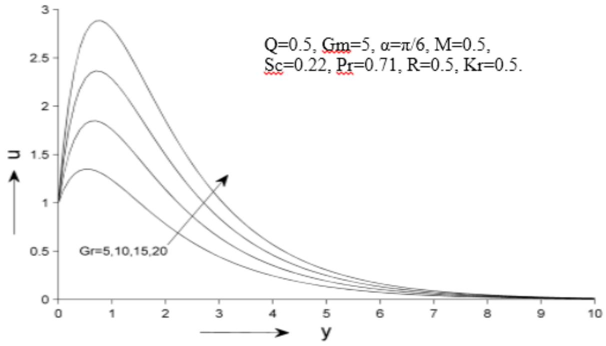

Fig .6. Velocity profile for diffrernt values of Gr

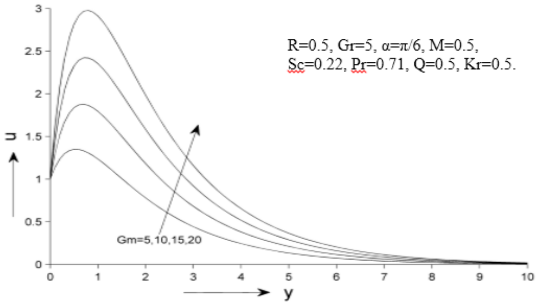

Fig. 7. Velocity profile for different values of Gm.

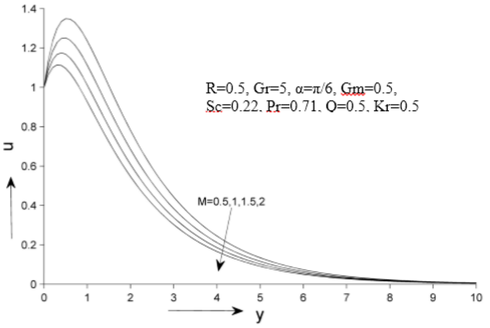

Fig. 8. Velocity profile for different values of M.

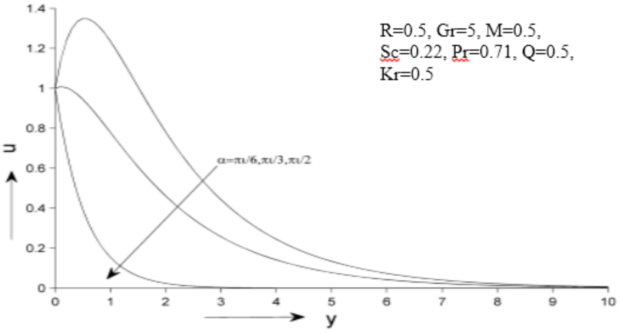

Fig. 9. Velocity profile for different values of α.

Table 1: Skin friction

M	α	Pr	τ
2	π/6	0.71	-0.9565
4	π/6	0.71	-0.1676
6	π/6	0.71	0.5085
8	π/6	0.71	1.0918
2	π/6	0.71	-1.9887
2	π/3	0.71	0.3966
2	π/2	0.71	3.6535
2	2π/3	0.71	6.9096
2	π/6	0.71	-1.9587
2	π/6	1	-1.9476
2	π/6	5	-1.5299
2	π/6	7.1	-1.3874

Table 2: Nusselt Number

Pr	R	Q	Nu
0.71	4	0.8	1.7876
1	4	0.8	1.8656
5	4	0.8	2.7176
7.1	4	0.8	3.0745
0.71	4	0.8	1.7872
0.71	5	0.8	2.0387
0.71	6	0.8	2.2654
0.71	7	0.8	2.4730
0.71	4	0.8	1.7871
0.71	4	1	1.7323
0.71	4	1.2	1.6767
0.71	4	1.4	1.6187

Table 3: Sherwood Number

Sc	Kr	Sh
0.22	0.5	0.5754
0.60	0.5	0.9491
0.78	0.5	1.0825
0.96	0.5	1.2008
0.78	0.5	1.0834
0.78	1.0	1.2499
0.78	1.5	1.3986
0.78	2.0	1.5297

3. CONCLUSION

We have examined the unsteady MHD free convective chemically reacting, radiation flow past an infinite vertical plate with uniform temperature and also with uniform mass diffusion in the presence of thermal radiation. The dimensionless governing partial equations are solved by usual closed analytical method, we conclude the following:

- Concentration distributed is observed to decrease with increase in Kr and Sc.
- Temperature decreases with increase in Pr, R and it increase with increase in Q.
- Velocity increases with increase in Gr and Gm while it decreases with increase in M and α.
- Skin friction increase with an increase in M, α, Pr.
- Nusselt number increases with increase in Pr, R and Q.
- Sherwood number increases within increase in Sc and Kr

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