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Significance of Chemical Reaction on A Free Convective MHD Flow Past an Erect Plate Associate with Ramped Wall Temperature and Concentration

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Abstract
The current study is mainly focused to explore the significance of chemical reaction in association with ramped wall temperature and concentration in an unsteady MHD heat and mass transfer flow. The MHD boundary layer equations are solved by adopting Laplace Transform technique. The impact of chemical reaction as well as various pertinent physical parameters are graphically illustrated and discussed.

Keywords: Chemical reaction, Boundary layer, MHD, Laplace Transform Technique

INTRODUCTION

Magnetohydrodynamics or MHD is a branch of the science of the dynamics of matter moving in an electromagnetic field, especially where currents established in the matter by induction modify the field, so that the field and dynamics equations are coupled. It treats, in particular, conducting fluids, whether liquid or gaseous, in which certain simplifying postulates are accepted. These are, generally, that the Maxwell displacement current is neglected, and the fluid may be treated as a continuum, without mean-free-path effects. It is distinguished from the closely related plasma dynamics in which these postulates are relaxed, but there is still a large intermediate area in which similar treatment is possible.
Geothermal processes, liquid metal fluids, MHD power generators etc. are few examples where theories of MHD are used.
Numerous authors have reported analytical and numerical solutions of MHD flow problems which is very interesting due to promising magnetic field effects on the boundary layer are specified by Hayat et. al. [1], Fang and Zhang [2], Chien-Hsin [3], Pal and Chatterjee [4] and Bhattacharyya [5].
Chemical reaction is a route which transforms chemical properties between two substances. In any chemical reaction, the total mass of the reactants equals the total mass of the products. In addition, the number and types of atoms in the reactants equal the number and types of atoms in the products. Chemical reactions must be driven by external intervention for example, heat. Energy is created in chemical reactions. There is no loss of mass in a chemical reaction.
The impact of chemical reaction has got exceedingly sensible importance in the practical field of different areas of science and technology. The effect of chemical reaction under the fluid Characteristics with or without MHD has studied by several authors. Some of them are Sinha [6], Raju et. al. [7], Sinha and Sarma

[8], Ibrahim and Suneetha [9], Mahapatra et. al. [10] and Reddy et. al. [11].

In this proposed work, Laplace Transform technique is developed to work out the governing equations. The major goal of this work is to use the above mentioned method to explore the effect of chemical reaction on MHD fluid flow. The basic scheme of the present work is developed by considering the significance of chemical reaction as the generalization of the work of Mahanta and Sinha [12].

Mathematical formulation of the problem

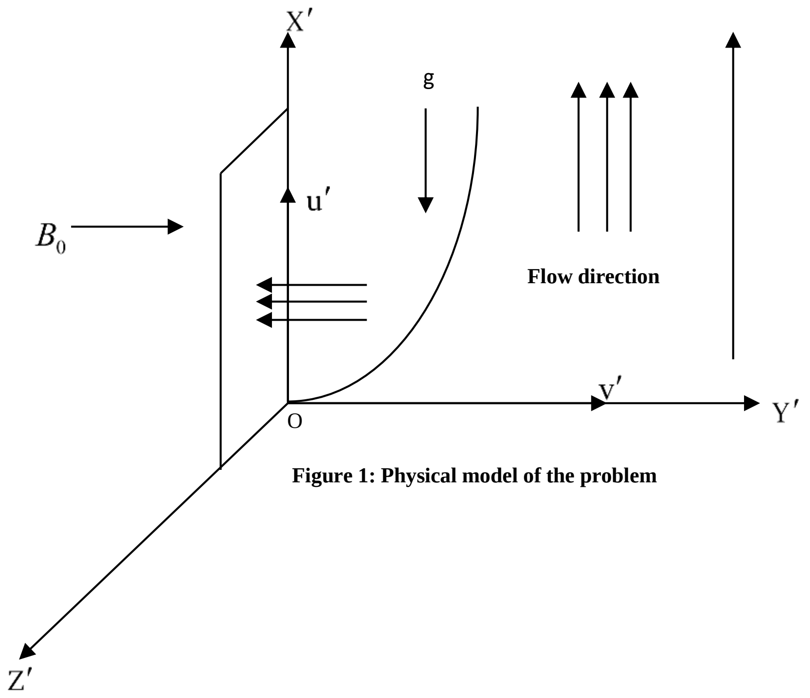


Figure 1: Physical model of the problem

The main intention of the present work is to investigate the influence of chemical reaction with a particular reference to ramped wall temperature and concentration in an unsteady MHD heat and mass transfer flow. A co-ordinate system is introduced, where X-axis is considered along vertical direction of the wall and Y-axis is taken along the normal to the wall as shown **in Figure 1**.

Mahanta and Sinha [12] projected some usual assumptions, based on which the following main equations defining physical circumstances are evaluated.

1. **Momentum Equation:**

$$\frac{\partial u}{\partial t'} = \upsilon \frac{\partial^2 u}{\partial y^2} + g\beta^* \left(T - T_\infty\right) - \frac{\upsilon}{K^*} u - \frac{\sigma B_0^2 u}{\rho} \quad (1)$$

2. **Energy Equation:**

$$\frac{\partial T}{\partial t'} = \frac{k}{\rho C_p} \frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho C_p} \frac{\partial q_r}{\partial y} \quad (2)$$

3. **Concentration Equation:**

$$\frac{\partial C}{\partial t'} = D\frac{\partial^2 C}{\partial y^2} + Kr'(C_\infty - C) \tag{3}$$

Initial and boundary conditions for velocity, temperature and concentration fields are:

$$y \ge 0:\ u = 0,\ T = T_\infty,\ C = C_\infty \quad for\ t' \le 0 \tag{4.1}$$

$$y = 0:\ u = U_0,\quad for\ t' > 0$$

$$T = T_\infty + (T_w - T_\infty)\frac{t'}{t_0},\ C = C_\infty + (C_w - C_\infty) \quad for\quad 0 < t' \le t_0$$

$$T = T_w,\ C = C_w \quad for\ t' > t_0 \tag{4.2}$$

$$y \to \infty:\ u \to 0, T \to T_\infty,\ C = C_\infty \quad for\ t' > 0 \tag{4.3}$$

The radiative heat flux term is associated as

$$\frac{\partial q_r}{\partial y} = 4(T - T_\infty)\int_0^\infty K_{\lambda_0}\left(\frac{\partial e_{\lambda h}}{\partial T}\right)_0 d\lambda \tag{5}$$

Where K_{λ_o} is the absorption co-efficient, λ is wave length, $e_{\lambda h}$ denotes Planck's function. Subscript 0 means that all physical quantities have been found out at temperature T_∞. Substituting equation (5) in equation (2), then

$$\frac{\partial T}{\partial t'} = \frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2} - \frac{4}{\rho C_p}(T - T_\infty)\, I \tag{6}$$

$$Where,\ I = \int_0^\infty K_{\lambda_0}\left(\frac{\partial e_{\lambda h}}{\lambda T}\right)_0 d\lambda$$

To standardize the dimensional governing equations, the following non-dimensional variables and parameters are introduced:

$$\eta = \frac{y}{U_0 t_0},\ t = \frac{t'}{t_0},\ u_1 = \frac{u}{U_0},\ \theta = \frac{T - T_\infty}{T_w - T_\infty},\ \phi = \frac{C - C_\infty}{C_w - C_\infty},$$

$$M = \frac{\sigma B_0^2 t_0}{\rho},\ Gr = \frac{g\beta^* \upsilon (T - T_\infty)}{U_0^3},\ Gm = \frac{g\beta' \upsilon (C - C_\infty)}{U_0^3},\ \Pr = \frac{\upsilon \rho C_p}{k},$$

$$\mathrm{K} = \frac{K^* U_0^2}{\upsilon^2},\ t_0 = \frac{\upsilon}{U_0^2},\ Sc = \frac{\upsilon}{D},\ Kr = \frac{Kr' \upsilon}{U_0^2} \tag{7}$$

By virtue of equation (7), the boundary layer equations represented by equation (1), (3) and (6) are transformed to the following non-dimensional form as:

$$\frac{\partial u_1}{\partial t}=\frac{\partial^2 u_1}{\partial \eta^2}+Gr\,\theta+Gm\,\phi-\frac{u_1}{K}-M\,u_1 \tag{8}$$

$$\frac{\partial \theta}{\partial t}=\frac{1}{\Pr}\frac{\partial^2 \theta}{\partial \eta^2}-Ra\,\theta\,,$$

Where, (9)

$$Ra=\frac{4\upsilon I}{\rho C p U_0^2},\quad I=\int_0^\infty K_{\lambda_0}\left(\frac{\partial e_{\lambda h}}{\partial T}\right)_0 d\lambda$$

$$\frac{\partial \phi}{\partial t}=\frac{1}{Sc}\frac{\partial^2 \phi}{\partial \eta^2}-Kr\,\phi \tag{10}$$

By applying equation (7) in the boundary conditions defined by equations (4.1), (4.2) and (4.3), the following equations of non-dimensional boundary conditions are obtained:

$$\eta=0:\quad u_1=0,\ \theta=0,\ \phi=0,\ \ for\ \ t\le 0 \tag{11.1}$$

$$\begin{aligned}\eta=0:\quad & u_1=1,\quad for\ \ t>0\\ & \theta=t,\ \phi=t,\quad for\ 0<t\le 1,\\ & \theta=1,\ \phi=1,\quad \text{for}\ \ t>1,\end{aligned} \tag{11.2}$$

$$\eta\to\infty:\quad u_1\to 0,\ \theta\to 0,\ \phi\to 0\ \ for\ \ t>0 \tag{11.3}$$

Method of Solution

Applying Laplace Transform technique in the equation (8) to (10), solutions are written in the following way:

$$\frac{d^2\bar{u}_1}{d\eta^2}-\left(s+M_1\right)\bar{u}_1=-Gr\,\bar{\theta}-Gm\,\bar{\phi}\ ,\ Where\ M_1=\frac{1+MK}{K} \tag{12}$$

$$\frac{d^2\bar{\theta}}{d\eta^2}-\Pr\bar{\theta}\left(s+M_1\right)=0 \tag{13}$$

$$\frac{d^2\bar{\phi}}{d\eta^2}-Sc\left(s+Kr\right)\bar{\phi}=0 \tag{14}$$

The boundary condition equations (11.1) to (11.3) are also transformed to equation no. (15) by using Laplace Transform technique as:

$$\bar{u}_1=\frac{1}{s},\ \ \bar{\theta}=\frac{1}{s^2}\left(1-e^{-s}\right),\ \bar{\phi}=\frac{1}{s^2}\left(1-e^{-s}\right)\ \ at\ \ \eta=0$$

(15)

$$\bar{u}_1\to 0,\ \bar{\theta}\to 0,\ \bar{\phi}\to 0\ \ as\ \ \eta\to\infty$$

The solutions which are in terms of velocity, temperature and concentration field of the above ordinary differential equations are obtained by adopting Laplace Transform method.

The expressions for viscous drag, Nusselt number and Sherwood number are given by

$$\tau = \xi_1 + s_1\xi_2 + s_2\xi_3$$

$$Nu = \xi_3 - \xi_4$$

$$Sh = \xi_5 - \xi_6 - A\xi_7 - B\xi_8 + E\xi_9 + F(\xi_3 - \xi_4) + G\xi_{10} - H\xi_{11}$$

The constants and the functions are not shown here due to shake of brevity.

Results and discussions

Numerical computations from the analytical solutions for the representative boundary layer equations and their rate of coefficients are made to acquire the significant approaching in to the problem. A variety of graphs of the fluid flow distribution have been carried out against different physical parameters viz Chemical reaction number (Kr), Magnetic parameter (M) and Schmdit number (Sc) implicated in the problem.

An effort has been made to point up the performance of velocity distribution versus η under the influence of magnetic intensity and chemical reaction as revealed in **figures 2-3**. From figure 2, it is observed that magnetic parameter tends to reduce the fluid rapidity. From this evident actuality it is obvious that high magnetic strength compelled the fluid motion to slow down. i.e the fluid movement is resisted by the potency of the applied magnetic field. From figure 3, it is established that the utilization of chemical species reduces the motion of the flow. From this phenomenon it can be inferred that high chemical reaction prohibited the flow pattern.

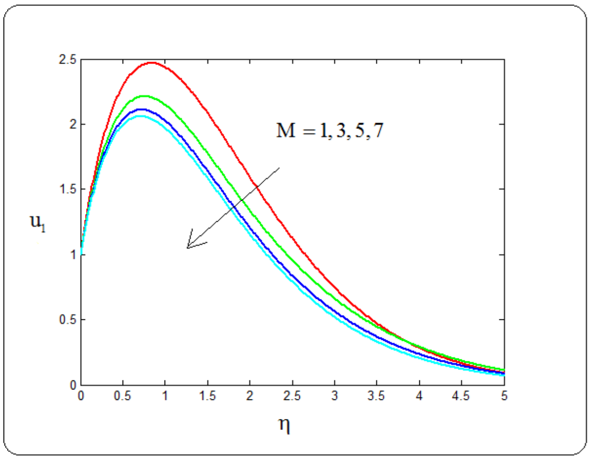


Figure 3: Velocity u versus η for K=0.04, Ra=2, Pr=0.71, Gr=25, Gm=25, M=5, Sc=0.60, t=0.5

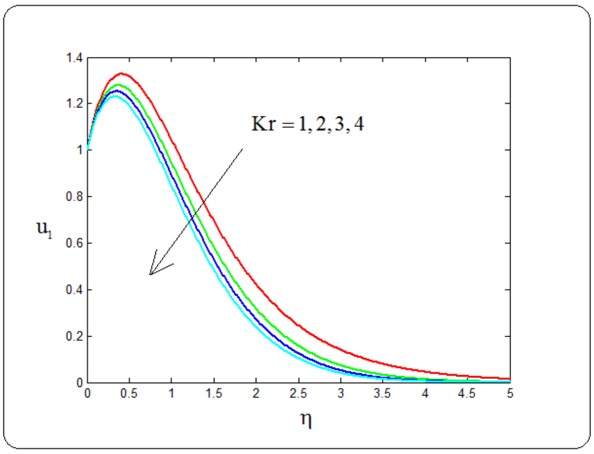


Figure 2: Velocity u versus η for K=0.04, Ra=2, Kr=1, Pr=0.71, Gr=25, Gm=25, Sc=0.60, t=0.5

The effects of Sc and Kr on fluid concentration are demonstrated in **figures 4-5.** Figure 4 presents the distinction of the species concentration under the control of Schmdit number. The figure predicts that the species concentration decreases to zero in the infinite direction. This observable fact physically states that for enlarging the mass diffusivity of the flow, the species concentration gets mounted up. Figure 5 elaborates the higher behavior of the concentration level of the fluid on account of chemical reaction.

Figure 5: Concentration ϕ versus η for Sc=0.60, t=0.5

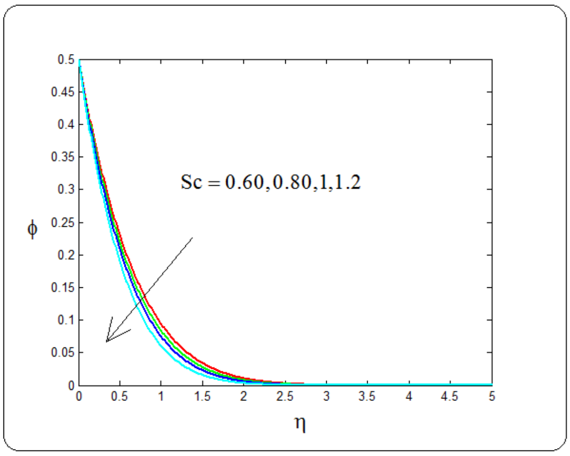
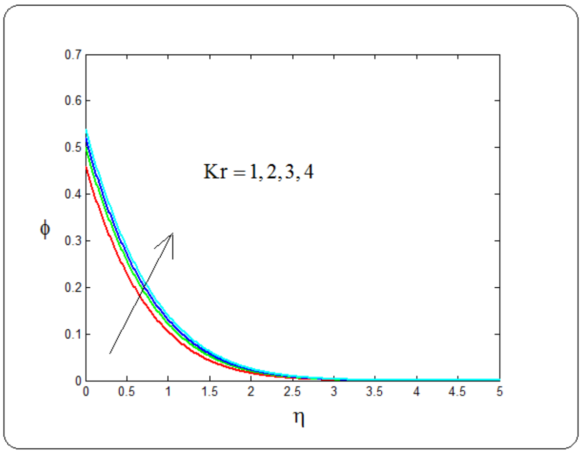


Figure 4: Concentration ϕ versus η for Kr=1, t=0.5



In **figures 6-7,** the co-efficient of Skin-friction τ against t under the action of magnetic parameter and chemical reaction parameter Kr is depicted. It is explained from these two figures that high magnetic intensity tends to maximize the co-efficient of Skin-friction while the viscous drag from the plate to the fluid gets reduced by virtue of chemical species.

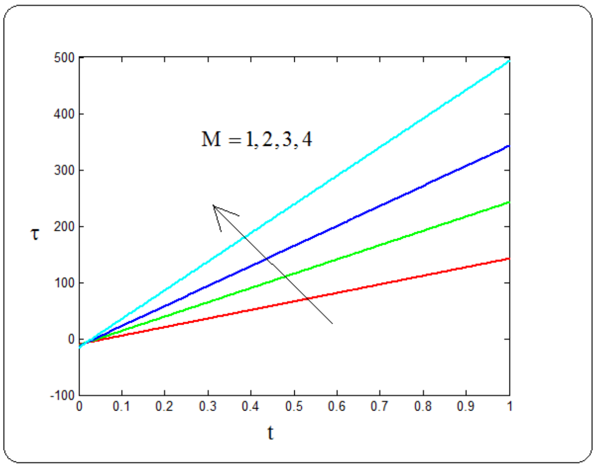


Figure 6: Skin friction τ versus t for K=0.04, Ra=2, Kr=2, Pr=0.71, Gr=25, Gm=25, Sc=0.60

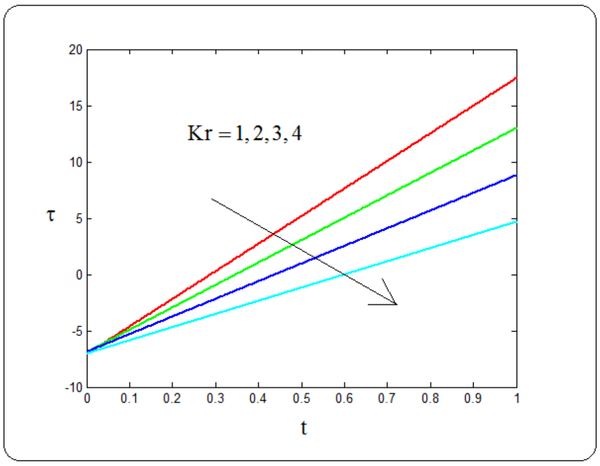


Figure 7: Skin friction τ versus t for K=0.04, Ra=2, M=5, Pr=0.71, Gr=25, Gm=25, Sc=0.60

The co-efficient of rate of mass transfer in terms of Sherwood number from the plate to the fluid under the effect of Schmdit number and Kr have been illustrated in **figure 8-9.** Figure 8 demonstrates that high mass diffusivity has made an increase in Sherwood number. It suggests that the Sherwood number accelerates for any increasing value of Sc, i.e. mass flux from the plate to the fluid gets accelerated under the influence of mass diffusivity. Consequence of chemical reaction on Sherwood number is established in figure 9. From this figure, it is evident that Kr made the mass flux to accelerate.

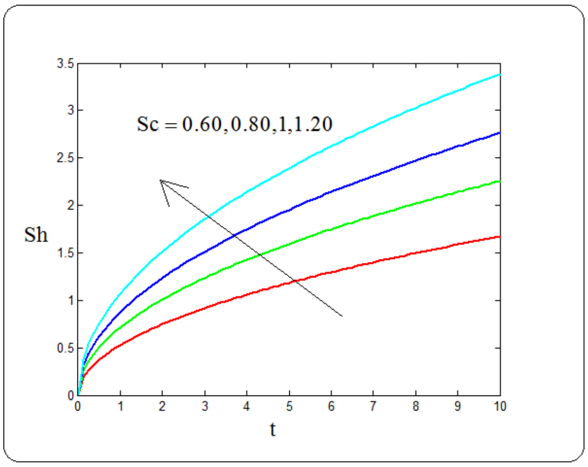


Figure 8: Sherwood number Sh versus t for Kr=1

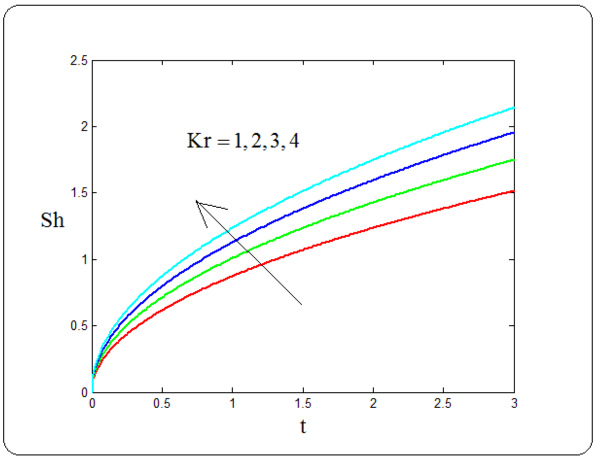


Figure 9: Sherwood number Sh versus t for Sc=0.60

Conclusion

1. The fluid motion is resisted by the strength of the applied magnetic field and the high chemical reaction made the fluid velocity to rise.
2. The enlargement of mass diffusivity of the flow mounted up the species concentration and the chemical reaction parameter made the species to minimize.
3. High magnetic intensity tends to maximize the co-efficient of Skin-friction while the viscous drag from the plate to the fluid gets reduced on account of chemical species.
4. High mass diffusivity Sc and chemical reaction Kr is found to enhance the mass flux.

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