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CHEMICAL REACTION EFFECTS ON MHD FLOW OF CONTINUOUSLY MOVING VERTICAL SURFACE WITH HEAT AND MASS FLUX THROUGH POROUS MEDIUM

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ABSTRACT: This paper is an analytical study of the heat generation/absorption effects on MHD flow of an electrically conducting, incompressible, viscous fluid past an impulsively moving isothermal vertical plate through porous medium in the presence of uniform suction and taking into the homogeneous chemical reaction of first order. A flow of this type represents a new class of boundary layer flow at a surface of finite length. The equations governing the flow field are solved by analytical method. The velocity, temperature and concentration have been evaluated for variation in the different governing parameters like Magnetic parameter (M), Prandtl number (Pr), Schmidt number (Sc), heat generation/absorption parameter (Q), thermal Grashof number (Gr), solutal Grashof number (Gc).

Keywords: MHD, Chemical reaction, Porous medium, Heat generation/absorption, Heat and Mass flux etc.

INTRODUCTION:

The study of natural convection heat and mass transfer phenomenon in porous media is gaining attention due to its interesting applications. Processes involving heat and mass transfer in porous media are often encountered in the chemical industry, in reservoir engineering in connection with thermal recovery process and in the study of dynamics of hot and salty springs of a sea. Underground spreading of chemical wastes and other pollutants, grain storage, evaporation, cooling and solidification are the few other application areas where the combined thermo-solute natural convection in porous media is observed. Sakiadis [2] studied the growth of the two-dimensional velocity boundary layer over a continuously moving flat plate. Vajravelu [6] studied the exact solutions for hydrodynamic boundary layer flow and heat transfer over a continuous, moving, horizontal flat surface with uniform suction and internal heat generation/absorption. Again, Vajravelu [5] extended the problem to a vertical surface.

Heat and Mass transfer of MHD flow have applications in meteorology, solar physics cosmic astrophysics, geophysics and fluid dynamics. Also, this process takes place in numerous industrial applications such as polymer production, manufacturing of ceramics or glassware and food processing. Rajeev Jha et al. [9] studied the MHD flow of viscous fluid past an impulsively moving isothermal vertical plate through porous medium with chemical reaction. Muthucumaraswamy and Ganesan [8] studied the first order chemical reaction on flow past an impulsively started vertical plate with uniform heat and mass flux. Sankar Reddy et al. [10] Heat and mass effects on MHD flow of a continuously moving vertical surface with uniform heat and mass flux.

The study of heat generation or absorption effects in moving fluids is important in fluids undergoing exothermic or endothermic chemical reactions. Heat

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generation effects may alter the temperature distribution and consequently, the particle deposition rate in nuclear reactors, electric chips and semiconductor wafers. Patil and Kulkarni [7] studied the effects of chemical reaction on free convective flow of a polar fluid through porous medium in the presence of internal heat generation. Effect of viscous dissipative heat and uniform magnetic field on the free convective flow through a porous medium with heat generation/absorption was studied by Amakiri and Ogulu [1]. Hady et al. [3] have analyzed the MHD free convection flow along a wavy surface with heat generation or absorption effect. Gireesh Kumar and Ramakrishan [4] have discussed the MHD flow of viscous fluid past an impulsively moving isothermal plate through porous medium with chemical reaction and heat generation/absorption.

Motivated by all these works we contemplate to study the chemical reaction and heat generation/absorption effects on MHD flow of an electrically conducting, incompressible, viscous fluid past an impulsively moving isothermal vertical plate through porous medium in the presence of uniform heat and mass flux. The equations governing the flow are solved by using the analytical method. The velocity, temperature and concentration have been evaluated with varying parameters like magnetic parameter, Prandtl number, Schmidt number, heat generation/absorption parameter, thermal Grashof number and solutal Grashof number.

FORMULATION OF THE PROBLEM:

Consider the steady, two-dimensional laminar, incompressible flow of a chemically reacting, viscous fluid on a continuously moving vertical surface in the presence of a uniform magnetic field with heat generation, uniform heat and mass flux effects issuing a slot and moving with uniform velocity u_w in a fluid at rest. Let the x-axis be taken along the direction of motion of the surface in the upward direction and y-axis is normal to the surface. The temperature and concentration levels near the surface are raised uniformly. The induced magnetic field, viscous dissipation are assumed to be neglected. Now, under the usual Boussinesq's approximation, the flow field is governed by the following equations.

Continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (1)$$

Momentum equation

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=g\beta\left(T^{'}-T_{\infty}^{'}\right)+g\beta^{*}\left(C^{'}-C_{\infty}^{'}\right)+\upsilon\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0^2}{\rho}u-\frac{\upsilon}{K_p}u \qquad (2)$$

Energy equation

$$\rho C_p\left(u\frac{\partial T^{'}}{\partial x}+v\frac{\partial T^{'}}{\partial y}\right)=k\frac{\partial^2 T^{'}}{\partial y^2}-Q_0\left(T^{'}-T_{\infty}^{'}\right) \qquad (3)$$

Diffusion Equation

$$u\frac{\partial C^{'}}{\partial x}+v\frac{\partial C^{'}}{\partial y}=D\frac{\partial^2 C^{'}}{\partial y^2}-k_l\,C^{'} \qquad (4)$$

The initial and boundary conditions

$$\left.\begin{array}{ll} u=u_w,\ v=v_0=const.<0, & \dfrac{\partial T^{'}}{\partial y}=\dfrac{-q}{k},\ \dfrac{\partial C^{'}}{\partial y}=\dfrac{-j''}{D}\quad at\ \ y=0 \\ u\to 0, & T^{'}\to T_{\infty}^{'},\quad C^{'}\to C_{\infty}^{'}\quad as\, y\to\infty \end{array}\right\} \qquad (5)$$

Where u, v are velocity components in x and y directions respectively. g is the acceleration due to gravity, β is volumetric coefficient of thermal expansion, β^{*} is the volumetric coefficient of expansion with concentration, $T^{'}$ is the temperature of the fluid, $C^{'}$ is the species concentration, $T_w^{'}$ is the wall temperature, $C_w^{'}$ is the concentration at the plate, $T_{\infty}^{'}$ is the free steam temperature far away from the plate, $C_{\infty}^{'}$ is the free steam concentration in fluid

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far away from the plate, υ is the kinematic viscosity, D is the species diffusion coefficient, k_l is the chemical reaction parameter. The term $Q_0\left(T^{'}-T_{\infty}^{'}\right)$ is assumed to be the amount of heat generated or absorbed per unit volume. Q_0 is a constant, which may take on either positive or negative values. When the wall temperature $T_w^{'}$ exceeds the free steam temperature $T_{\infty}^{'}$, the source term represents the heat source when $Q_0 < 0$ and heat sink when $Q_0 > 0$. The first term and second term on the right hand side of the momentum equation (2) denote the thermal and concentration buoyancy effects respectively.

In order to write the governing equations and the boundary conditions the following non-dimensional quantities are introduced.

$$\left.\begin{array}{l} Y=\dfrac{yv_0}{\upsilon},\ U=\dfrac{u}{u_w},\ Gr=\dfrac{vg\beta\left(\dfrac{qv}{kv_0}\right)}{u_w v_0^2},\ Gc=\dfrac{vg\beta^{*}\left(\dfrac{j''v}{kv_0}\right)}{u_w v_0^2} \\ \Pr=\dfrac{\mu C_p}{k},\ Sc=\dfrac{v}{D},\ k=\dfrac{K_p v_0^2}{v^2},\quad Q=\dfrac{vQ_0}{\rho C_p v_0^2} \\ Kr=\dfrac{k_l\upsilon}{v_0^2},\quad M=\dfrac{\sigma B_0^2 v}{\rho v_0^2},\quad T=\dfrac{T^{'}-T_{\infty}^{'}}{\left(\dfrac{qv}{kv_0}\right)},\quad C=\dfrac{C^{'}-C_{\infty}^{'}}{\left(\dfrac{j''v}{kv_0}\right)} \end{array}\right\} \tag{10}$$

In view of (10) the equations (2), (9) and (4) are reduced to the following non-dimensional form

$$\frac{d^2U}{dY^2}+\frac{dU}{dY}-\left(M+\frac{1}{k}\right)U=-\left(GrT+GcC\right) \tag{11}$$

$$\frac{d^2T}{dY^2}+\Pr\frac{dT}{dY}-Q\Pr T=0 \tag{12}$$

$$\frac{d^2C}{dY^2}+Sc\frac{dC}{dY}-KrScC=0 \tag{13}$$

The corresponding initial and boundary conditions in non-dimensional form are

$$\left.\begin{array}{llll} U=1, & \dfrac{\partial T}{\partial Y}=-1, & \dfrac{\partial C}{\partial Y}=-1 & at\ \ Y=0 \\ U\to 0, & T\to 0, & C\to 0 & as\ \ Y\to\infty \end{array}\right\} \tag{14}$$

Where Gr is the thermal Grashof number, Gc is the solutal Grashof number, Pr is the fluid Prandtl number, Sc is the Schmidt number and Kr is the chemical reaction parameter, Q is the heat generation/absorption parameter.

METHOD OF SOLUTION:

The study of ordinary differential equations (11), (12) and (13) along with their initial and boundary conditions (14) have been solved by using the method of ordinary linear differential equations with constant coefficients. We get the following analytical solutions for the velocity, temperature and concentration

$$U=A_3e^{a_6Y}+A_1e^{a_4Y}+A_2e^{a_2Y} \tag{15}$$

$$T=-\frac{1}{a_4}e^{a_4Y} \tag{16}$$

$$C=-\frac{1}{a_2}\,e^{a_2Y} \tag{17}$$

The computed solution for the velocity is valid at some distance from the slot, even though suction is applied from the slot onward. This is due to the assumption that velocity field is independent of the distance parallel to the plate. The fluids considered in this study are air (Pr = 0.71) and water (Pr = 7.0).

RESULTS AND DISCUSSION:

A representative set of numerical results is shown graphically in figures to illustrate the influence of physical parameter viz., Chemical reaction parameter (Kr = 0.5), Magnetic parameter (M = 1.0), Prandtl number (Pr = 0.7), Schmidt number (Sc = 0.6), Permeability parameter (k = 10), thermal Grashof number (Gr = 2 and Gr = -2), solutal Grashof number (Gc = 2 and Gc = -2), Heat generation parameter (Q = 2.0) on velocity, temperature and concentration profiles, on two-dimensional, incompressible and chemically reacting flow of a viscous fluid on a continuously moving vertical plate in the presence of magnetic field with heat generation. The thermal Grashof number Gr and solutal Grashof number Gc represents here the effects of free convection currents, and receives positive,

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zero or negative values. The case Gr < 0 and Gc < 0 corresponds physically to an externally heated surface as the free convection currents are moving towards the surface. The case Gr > 0 and Gc > 0 corresponds to an externally cooled surface and the case Gr = 0 and Gc = 0 corresponds to absence of the free convection currents.

From figures 1 and 2 we observe that when Gr > 0, Gc > 0 and Gr < 0, Gc < 0 an increase in magnetic parameter (M) and heat generation parameter (Q) leads to fall the velocity.

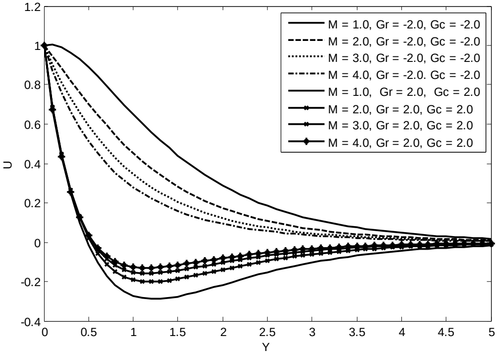
Figure - 1: Velocity profile when Sc = 0.6, Pr = 0.71, Q = 2, Kr = 0.5, k = 10

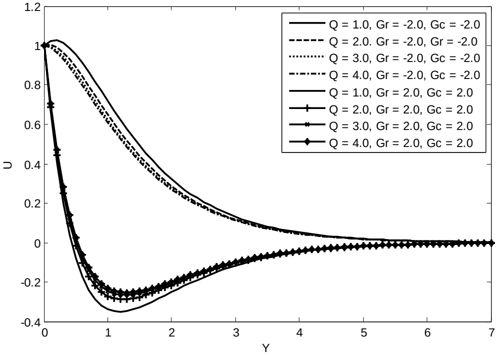
Figure - 2: Veocity profile when M = 1.0, Pr = 0.71, Sc = 0.6, Kr = 0.5, k = 10

From figure 3 it is noticed that when Gr > 0 and Gc > 0, an increase in chemical reaction parameter (Kr) causes to decrease in velocity. It is also observed from the figure 4 when increase in permeable parameter (k) leads to increase in velocity for both positive and negative cases of Gr and Gc.

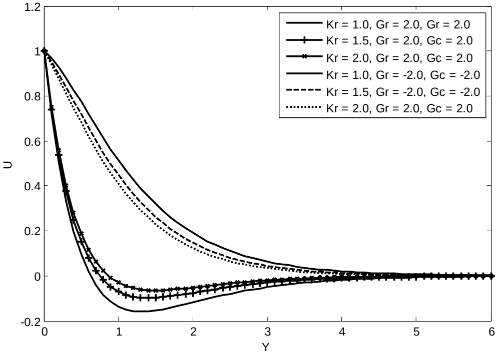
Figure - 3: Velocity profile when M = 1.0, Q = 2.0, Pr = 0.71, Sc = 0.60, k = 10

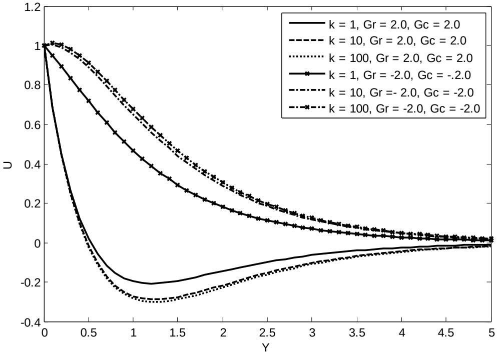
Figure - 4: Velocity profile when M = 1.0, Sc = 0.6, Q = 2.0, Kr = 0.5, Pr = 0.71

From figure 5 it is noticed that an increase in thermal Grashof number and solutal Grashof number causes to increase in velocity in both positive and negative of Gr and Gc. It is also observed from the figure 6 when increase in Schmidt parameter (Sc) leads to decrease in velocity for both positive and negative cases of Gr and Gc.

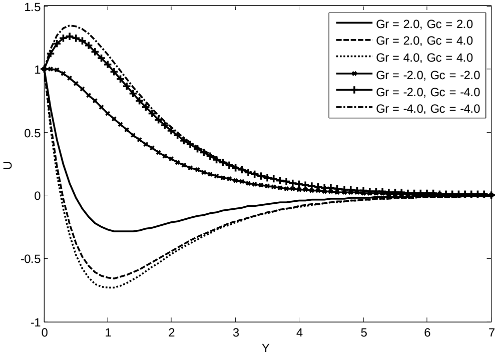
Figure - 5: Velocity profile when M = 1.0, Q = 2.0, Pr = 0.71, Sc = 0.6, k = 10, Kr = 0.5

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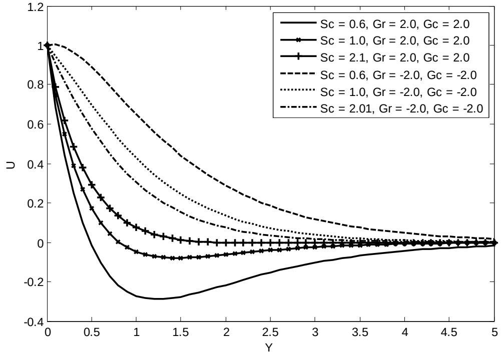
Figure - 6: Velocity profile when M = 1.0, Q = 2.0, Pr = 0.71, Kr = 0.5, k = 10



From figure 7 it is noticed that an increase in Prandtl number (Pr) decrease in velocity in both positive and negative of Gr and Gc. It is also observed from the figure 8 when increase in heat generation parameter (Q) leads to decrease in temperature.

Figure - 7: Velocity profile when M = 1.0, Sc = 0.6, Kr = 0.5. k = 10, Q = 2.0

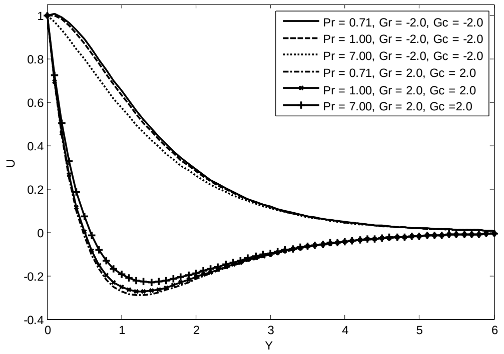
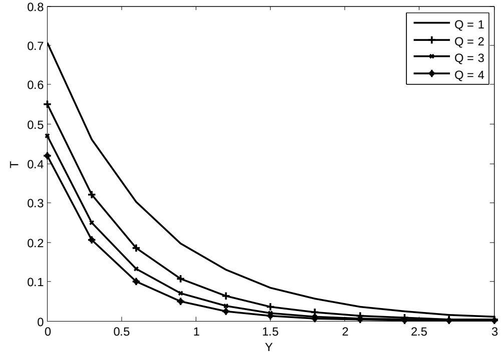


Figure - 8: Temperature profile when Pr = 0.71



From the figure 9 when increase in Prandtl number (Pr) leads to decrease in temperature.

It is also observed from the figure 10 when increase in chemical reaction parameter (Kr) leads to decrease in concentration.

Figure - 9: Temperature profile when Q = 2.0

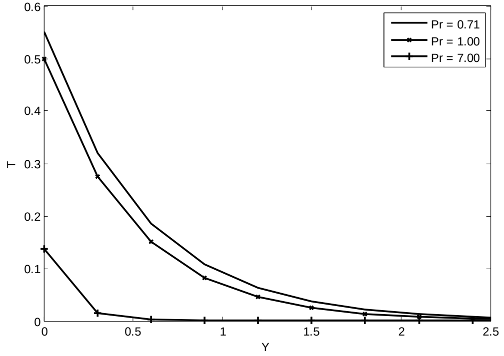
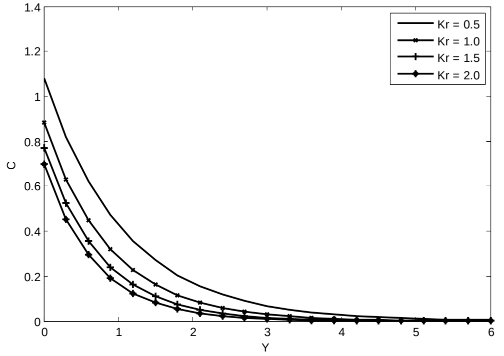
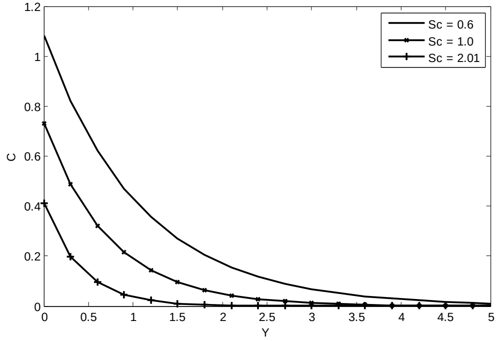


Figure - 10: Concentration profile when Sc = 0.6



From the figure 11 when increase in Schmidt number (Sc) leads to decrease in concentration.

Figure - 11: Concentration profile when Kr = 0.5



APPENDIX

$$a_1=\frac{-Sc+\sqrt{Sc^2+4KrSc}}{2},$$

$$a_2=\frac{-Sc-\sqrt{Sc^2+4KrSc}}{2},$$

$$a_3=\frac{-\Pr+\sqrt{\Pr^2+4Q}}{2A}, \quad a_4=\frac{-\Pr-\sqrt{\Pr^2+4Q}}{2A},$$

$$a_5=\frac{-1+\sqrt{1+4\left(M+\frac{1}{k}\right)}}{2}$$

$$a_6=\frac{-1-\sqrt{1+4\left(M+\frac{1}{k}\right)}}{2}$$

$$A_1 = \frac{-Gr}{(a_4)\left(a_4^2 + a_4 - \left(M + \frac{1}{k}\right)\right)}$$

$$A_2 = \frac{-Gc}{(a_2)\left(a_2^2 + a_2 - \left(M + \frac{1}{k}\right)\right)}$$

$$A_3 = [1 - A_1 - A_2]$$

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