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Effects of Chemical Reaction on MHD Stagnation point Flow over a Permeable Stretching Surface with Heat Generation/Absorption

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ABSTRACT: An analysis is presented for convective heat and mass transfer of stagnation point flow of an electrically conducting fluid in a porous medium over a permeable stretching surface with suction and internal heat generation/absorption. The present work examines the effects of chemical reaction, viscous dissipation and Joule heating on velocity, temperature and species concentration profiles. Governing partial differential equations of the problem are transformed into ordinary differential equations using similarity transformations. Resulting boundary value problem is then solved numerically using MATLAB's built in solver bvp4c. Results are obtained for velocity, temperature and species concentration of fluid for different flow governing parameters and are presented through graphs. Effects of all the parameters are prominent.

KEYWORDS: Chemical reaction, magnetic field, viscous dissipation, heat transfer, mass transfer.

I. INTRODUCTION

Stagnation point flows over a stretching plate are classical problems in the field of fluid dynamics and have been investigated by many researches. Stagnation-point flow has been found in numerous applications in engineering and technology. Hiemenz[1] and Homann [2] initiated the study of two-dimensional and axi-symmetric three dimensional stagnation point flows, respectively. The pioneering work of Sakiadis [3] extensive literature is available on this topic for a linearly stretching sheet. A broad effort has been made to gain information regarding the stretching flow problems in various situations. Such situations include consideration of non-Newtonian fluids, MHD fluid, heat transfer; mass transfer, porous medium, slip effects, etc.
Heat and mass transfer study on fluids with chemical reaction effect over an exponentially stretching sheet have important role in metallurgy and chemical engineering industries, such as food processing and polymer production. Moreover, coupled heat and mass transfer problems in the presence of chemical reaction are of importance in many processes, and have therefore received a considerable amount of attention in recent times. Possible applications can be found in processes such as drying, distribution of temperature and moisture over agricultural fields and groves of fruit trees, damage of crops due to freezing, evaporation at the surface of a water body and energy transfer in a wet cooling tower, and flow in a desert cooler.

Chambre and Acrivos[4] analyzed catalytic surface reactions in hydrodynamic flows. The paper was concerned with its counterpart, namely, an investigation of a certain special class of homogeneous volume reactions in flow systems. Chambre et al.[5] had studied the diffusion of a chemically reactive species in a laminar boundary layer flow. Goddard and Acrivos [6] analyzed the laminar forced convection mass transfer with homogeneous chemical reaction. A unified boundary layer analysis was applied to the problem of steady state mass transfer of a chemical species, diffusing from a surface and reacting isothermally in a linear fluid stream.

Yih [7] presented an analysis of the forced convection boundary layer flow over a wedge with uniform suction/blowing, whereas Watanabe [8] investigated the behavior of the boundary layer over a wedge with suction or injection in forced flow. MHD laminar boundary layer flow over a wedge with suction or injection had been discussed by Kafoussias and Nanousis [9] and Kumari[10] discussed the effect of large blowing rates on the steady laminar incompressible electrically conducting fluid over an infinite wedge with a magnetic field applied parallel to the wedge. Anjali Devi and Kandasamy [11] have studied the effects of heat and mass transfer on nonlinear boundary layer flow over a wedge with suction or injection. The effect of induced magnetic field is included in the analysis. Chamkha and Khaled [12]

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investigated the problem of coupled heat and mass transfer by MHD free convection from an inclined plate in the presence of internal heat generation or absorption. For the problem of coupled heat and mass transfer in MHD free convection, the effects of viscous dissipation and Ohmic heating with chemical reaction are not studied in the above investigation. Hossain et al.[13] analyzed the effects of radiation on free convection from a porous plate.

During chemical reaction between two species concentration, heat is also generated [14]. Here it has been assumed that the level of species concentration is very low and that the heat generated during chemical reaction can be neglected. The effects of mass transfer on flow past an impulsively started infinite vertical plate with constant heat flux and chemical reaction were studied [15]. Hence these results are found useful in chemical technology where ammonia and ethyl alcohol are used. The present investigation deals with the study of flow of an electrically conducting fluid in the presence of chemical reaction with a species concentration due to the MHD flow over an exponentially stretching sheet.

The basic equations governing the flow are in the form of partial differential equations and have been reduced to a set of non-linear ordinary differential equations by applying suitable similarity transformations. Governing equations of flow are then solved numerically using MATLAB's built in solver bvp4c.

II. MATHEMATICAL FORMULATION OF THE PROBLEM

We consider the steady two dimensional stagnation point flow of a viscous incompressible electrically conducting fluid near a stagnation point. Surface of the sheet coinciding with the plane y = 0, with the flow being restricted to y > 0. Two equal and opposing forces are applied along the x-axis so that the surface is stretched (while keeping the origin fixed). The potential flow that arrives from the y-axis (impinges on the flat wall at y = 0), divides into two streams on the wall and leaves in both directions. The flow is through a porous medium where the Darcy model is assumed. The viscous flow must adhere to the wall, whereas the potential flow slides along it. We denote the components of the fluid velocity by (u, v) at any point (x, y) for the viscous flow, while (U, V) denote the velocity components for the potential flow. We consider the case in which there may be a suction velocity (-W) on the stretching surface. Also, we denote the fluid temperature by T. The velocity distribution of the frictionless flow in the neighborhood of the stagnation point is becomes

$$U(x) = ax,\ V(x) = -ay \tag{1}$$

where the parameter $a > 0$ is proportional to the free stream velocity.

The analysis is based on the following assumptions:

- Viscous dissipation, Joule heating and heat generation are taken into account.
- Physical properties are assumed as constant.
- A transverse uniform magnetic field of strength B_0 is applied in *y*-direction.
- Magnetic Reynolds number is assumed to be small so that the induced magnetic field is negligible and hence $\vec{E} = \vec{0}$.
- In the beginning, plate and the fluid are kept at the same temperature *T* while *C* the species concentration all over the place in the fluid. Surface of the plate is maintained at a uniform constant temperature $T_w(>T_\infty)$ and species concentration $C_w(>C_\infty)$, where T_∞ and C_∞ respectively are corresponding values sufficiently far away from the flat surface.

Using the above assumptions together with usual boundary layer approximations we get the equations of motion as:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{2}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = U\frac{dU}{dx} + \upsilon\frac{\partial^2 u}{\partial y^2} + \frac{\mu}{\rho K}(U-u) + g\beta\left(T-T_\infty\right) + g\beta^*(C-C_\infty) - \frac{\sigma B_o^2}{\rho}u \tag{3}$$

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$$\rho c_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\lambda\frac{\partial^2 T}{\partial y^2}+Q_o\left(T-T_\infty\right)+\mu\left(\frac{\partial u}{\partial y}\right)^2+\frac{\vec{J}^2}{\sigma} \quad (4)$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_m\frac{\partial^2 C}{\partial y^2}-k_1(C-C_\infty) \quad (5)$$

where ρ is the fluid density in the free stream, μ is the viscosity of the fluid, g is the acceleration due to gravity, β and $\beta*$ are the thermal and concentration expansion coefficient respectively, T is the fluid temperature inside the boundary layer, T_∞ is the fluid temperature in the free-stream, $\vec{J}$ is the Electric current density, σ is the electrical conductivity, K is the Darcy permeability constant, c_p is the specific heat at constant pressure, λ is the thermal conductivity of fluid, Q_0 is the volumetric rate of heat generation, k_1 is the rate of chemical conversion, C is the species concentration of the fluid within the boundary layer, C_∞ is the species concentration in the free-stream, D_m is the molecular diffusivity of the species concentration.

The boundary conditions are given as:

$$\left.\begin{array}{llll} u=bx=u_0, \quad v=0, & T=T_w, & C=C_w, & \text{at } y=0, \\ u=ax, & T\to T_\infty, & C=C_\infty, & \text{as } y\to\infty. \end{array}\right\} \quad (6)$$

where b>0 is the stretching rate represents the permeability of the porous surface where its sign indicates suction (< 0) or injection (> 0).

Let us introduce the following similarity transformations,

$$u=bxf'(\eta),\ v=-\sqrt{\upsilon_\infty b}\,f(\eta),\ \eta=\sqrt{\frac{b}{\upsilon_\infty}}y,\ \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},\quad \varphi(\eta)=\frac{C-C_\infty}{C_w-C_\infty} \quad (7)$$

where υ_∞ is the kinematic viscosity of the fluid in the free stream, the prime $(')$ denotes derivative with respect to η.

Substituting Eqn. (7) in (3)-(5), we get

$$f'''+ff''-f'^2-Mf'-\frac{1}{Da\,\mathrm{Re}}(A-f')+Gr\theta+Gm\varphi=0 \quad (8)$$

$$\theta''+\Pr f\theta'+\Pr Q\theta+\Pr Ecf''^2+\Pr MEcf'^2=0 \quad (9)$$

$$\varphi''+Sc(f\varphi'-\gamma\varphi)=0 \quad (10)$$

where the dimensionless parameters are defined as follows:

$Da=\dfrac{K}{x^2}$ is the Darcy number, $Gr=\dfrac{g\beta(T_w-T_\infty)}{c^2x}$ is the Grashof number,

$Gm=\dfrac{g\beta^*(T_w-T_\infty)}{c^2x}$ is the solutal Grashof number, $M=\dfrac{\sigma B_0^2}{\rho c}$ is the magnetic field parameter,

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$Re = \frac{u_0 x}{\upsilon}$ is the Reynolds number,

υ = the kinematic viscosity in free stream,

$Pr = \frac{\mu c_p}{\lambda}$ is the Prandtl number,

$Ec = \frac{u_0^2}{c_p (T_w - T_\infty)}$ is the Eckert number,

$Q = \frac{Q_0}{c \rho c_p}$ is the heat generating parameter,

Q_0 = the volumetric rate of heat generation,

$Sc = \frac{\upsilon}{D_m}$ is the Schmidt number,

$\gamma = \frac{k_1}{b}$ is the chemical reaction parameter.

The boundary conditions (6) become:

$$\left.\begin{aligned} & f=0,\; f'=1,\; \theta=1,\; \varphi=1 \quad \text{at} \quad \eta=0 \\ & f'=0,\; \theta=0,\; \varphi=0 \quad \text{as} \quad \eta\to\infty \end{aligned}\right\} \tag{11}$$

III. RESULTS AND DISCUSSION

In order to get a physical insight into the problem, a representative set of numerical results is shown graphically in Fig. 1 to Fig. 6 to illustrate the influence of physical parameters viz., chemical reaction parameter(γ), magnetic parameter(M) and Schmidt number(Sc) on the velocity $f'(\eta)$, temperature $\theta(\eta)$ and species concentration $\varphi(\eta)$. Values of the parameters are taken as: *Q=0.1, Re=100, Da=0.5, Gm=Gr=0.1, M=0.5, Pr=0.71, Sc=0.22, Ec=0.05,* γ *=0.1*, unless otherwise stated.

Fig.1 to Fig.3 depict the effect of chemical reaction parameter on velocity, temperature and concentration profiles, respectively. It is observed that an increase in the value of chemical reaction parameter decreases the concentration of species in the boundary layer, whereas the velocity and temperature of the fluid are not significantly changed with increase of chemical reaction parameter. This is due to the fact that chemical reaction in this system results in consumption of the chemical and hence results in decrease of concentration profile. The most important effect is that the first order chemical reaction has a tendency to diminish the overshoot in the profiles of the solute concentration in the solutal boundary layer.

The effects of magnetic parameter (M) on dimensionless velocity and temperature distribution are shown in Fig. 4 and Fig. 5, respectively. In the presence of a magnetic field in an electrically conducting fluid induces a force called Lorentz force, which opposes the flow. This resistive force tends to slow down the flow, so the effect of increase in M is to decrease the velocity and also causes increases in its temperature. Fig. 6 plotted to explain the effect of Schimdt number(Sc) on concentration profiles. It is observed that concentration of species decreases with increasing value of Sc.

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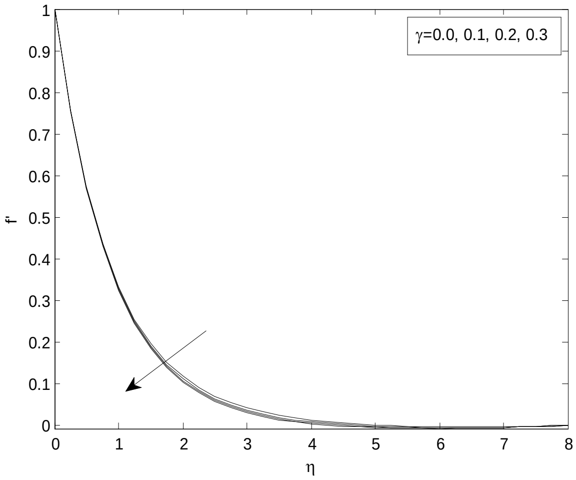

Fig.1: Velocity profile for different γ

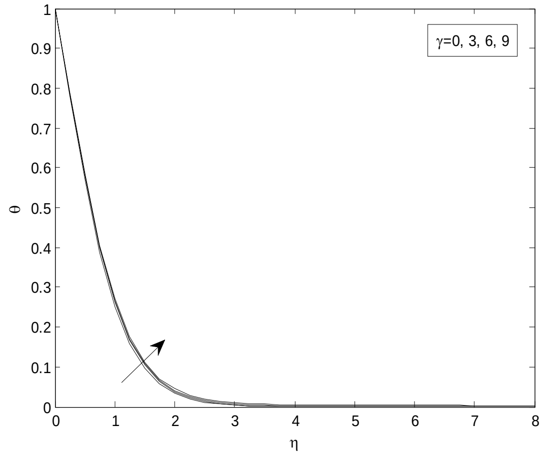

Fig.2: Temperature profile for different γ

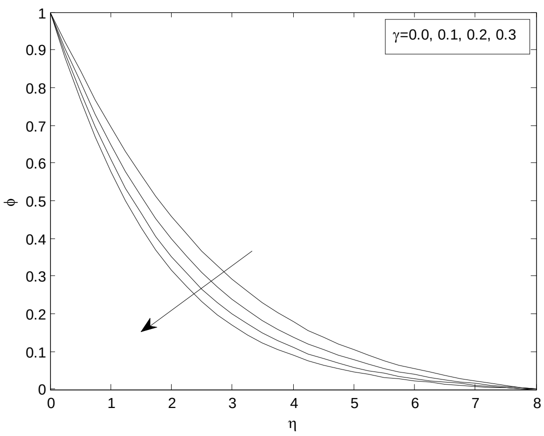

Fig.3: Concentration profile for different γ

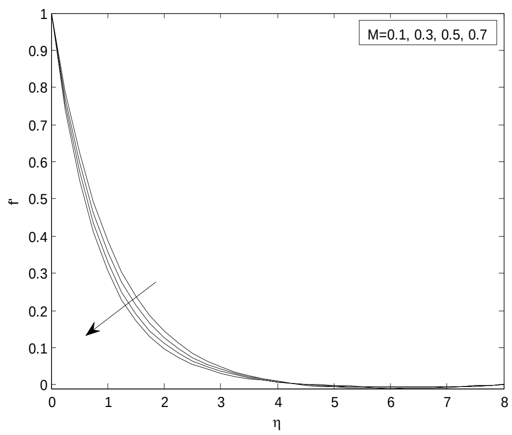

Fig.4: Velocity profile for different M

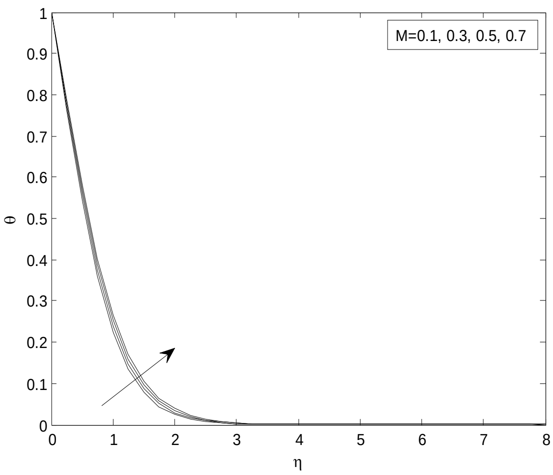

Fig.5: Temperature profile for different M

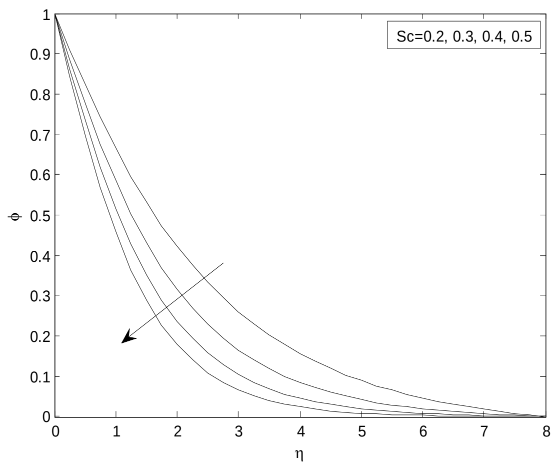

Fig.6: Concentration profile for different Sc

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IV. CONCLUSION

In this study we analyzed the effects of chemical reaction on convective heat and mass transfer of stagnation point flow of an electrically conducting fluid in a porous medium over a permeable stretching surface with suction and internal heat generation/absorption. The transformed, non-linear ordinary differential equations governing the flow are solved numerically by MATLAB's bvp4c. The results for velocity, temperature and concentration distributions are presented graphically for different values of the pertinent parameters. A chemical reaction is said to be first-order if the rate of reaction is directly proportional to concentration itself. The diffusive species can be generated or absorbed due to different types of chemical reaction with the ambient fluid, which can greatly affect the properties and quality of finished products. From the above study we have made following observations viz.

- Velocity of the fluid decreases and temperature increases with the increasing magnetic field intensity.
- The increase in the chemical reaction parameter and Schimdt number lead to a fall in the species concentration.

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