HEAT AND MASS TRANSFER IN MHD MIXED CONVECTION FLOW OVER AN INCLINED STRETCHING WITH BINARY CHEMICAL REACTION AND ACTIVATION ENERGY

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ABSTRACT

The present analysis of this research focuses on Heat and Mass transfer through MHD boundary layer mixed convection flow of a viscous fluid over an inclined stretching sheet with binary chemical reaction and activation energy. The suitable similarity transformations are used to transform the governing equations of MHD mixed convection flow into a set of ordinary differential equations. The solutions for the governing equations are obtained by employing Nactsheim-Swigert shooting technique with the six order Runge-Kutta iteration Method. The results of the flow characteristics are presented graphically.

KEYWORDS: *MHD, Mixed convective flow, Heat transfer, Mass transfer, Binary chemical reaction, Activation Energy*

I. Introduction

MHD mixed convection flow behavior over a stretching sheet is an important role on several engineering, science and industrial applications. The modern researchers are engaged to explore the mechanisms through the materials. Petroleum resources ,Cooling and metal foundries, nuclear power plants, microelectronics, glass manufacturing and crude oil purifications etc are some applications of these fields. Slip effects on MHD mixed convection stagnation point flow of a micropolar fluid towards a shrinking vertical sheet was analyzed by Das [1]. Bhattacharya *et al.* [2] studied similarity solution of mixed convection boundary layer slip flow over a vertical plate. Turkyilmazoglu [3] investigated an analytical solution of mixed convection heat transfer and fluid flow over a permeable stretching surface. Numerical study of entropy generation for forced convection flow and heat transfer of a Jeffrey fluid over a stretching sheet was established by Dalir[4]. Hayat *et al.* [5] was developed by mixedconvection flowof viscoelastic fluid with thermal radiation and convective conditions in three dimensional. MHD mixed convection flow over an inclined stretching sheet was investigated by Afridi*et al.* [6]. An entropy generation in MHD and slip flow over a rotating disk was discussed by Rashidi*et al.*[7]. Micropolarfluid flow and heat transfer over a porous shrinking sheet was studied by Turkyilmazoglu [8] .Hayat and Alsaedi [9] was established MHD flow of nanofluid over a permeable stretching sheet with convective boundary conditions. Stagnation electrical MHD nanofluid mixed convection with slip boundary on a stretching sheet was analyzed by Kai Hsiao [10].

In the present work a systematic study of parameters which influence the MHD boundary layer mixed convection flow of a viscous fluid over an inclined stretching sheet with binary chemical reaction and activation energy such as Magnetic parameter (M), Prandtl number(Pr), Eckert number(Ec), Brownian motion parameter(Nb), Thermophoresis parameter (Nt), non-dimensional energy (E),temperature difference parameter δ, fitted rate constant n and reaction rate σ has been carried out and the results of flow characteristic analyzed graphically

II. Formulation of the Problem

Consider a steady two dimensional MHD incompressible boundary layer flow induced by the inclined stretching sheet with the linear stretching velocity $u_w(x)=cx$.The magnetic field of a constant strength B_0 is applied to the normal to direction of the flow. Under the usual boundary layer approximation, the continuity, momentum, and energy equations are

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}+g\beta(T-T_\infty)\cos\alpha+g\beta^*(C-C_\infty)\cos\alpha-\frac{\sigma B_0^2 u}{\rho} \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha^*\frac{\partial^2 T}{\partial y^2}+\frac{\upsilon}{c_p}\left(\frac{\partial u}{\partial y}\right)^2-k_r(T-T_\infty)+\frac{\partial q_r}{\partial y} \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2}-K_r^2(\mathrm{C}-C_\infty)\left(\frac{T}{T_\infty}\right)^n e^{\left(-\frac{E_a}{\kappa T}\right)} \tag{4}$$

In the above equations, u and v are the velocity components in x and y directions respectively. g represent gravitational acceleration, α^* is the thermal diffusivity, υ is the kinematic viscosity of the fluid, ρ is the density , T_∞ is the free stream temperature, α is the inclination of the stretching sheet , c_p is the specific heat of the fluid at constant pressure , the thermal expansion coefficient β and q_r is the radiative heat transfer.

The boundary conditions are

$$u=u_w(x)=cx, v=0, T=T_w(x)=T_\infty+ax^2, \mathrm{C}=C_w(x) \text{ at } y=0$$
$$u\to 0, T\to 0, \mathrm{C}\to 0 \text{ as } y\to 0 \tag{5}$$

The similarity transformations are

$$\eta=\sqrt{\frac{c}{\upsilon}}y, u=cxf'(\eta), v=-\sqrt{c\upsilon}f(\eta), \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty}, \phi(\eta)=\frac{C-C_\infty}{C_w-C_\infty}, \tag{6}$$

The radiative heat flux defined as

$$q_r=\frac{-4\sigma_1}{3k^*}\left(\frac{\partial T^4}{\partial y}\right)$$

Where σ_1 is the Stefan Boltzmann constant and k^* is Rosseland mean absorption coefficient.

Incompressibility condition (1) is automatically satisfied, whereas the other equations (2), (3) lead to the following expressions

$$f'''+ff''-f'^2+Gr\theta\cos\alpha+Gm\phi\cos\alpha-M^2 f'=0 \tag{7}$$

$$\frac{1}{\mathrm{Pr}_{eff}}\theta''+f\theta'-2f'\theta+Ecf''^2-\gamma\theta=0 \tag{8}$$

$$\varphi''+Le\left(f'-\frac{\eta}{2}f''\right)\varphi'+\left(\frac{Nt}{Nb}\right)\theta''-Le\sigma(1+\delta\theta)^n\varphi e^{\left(-\frac{E}{1+\delta\theta}\right)}=0 \tag{9}$$

The boundary conditions are

$$f(0)=0, f'(0)=1, \theta(0)=1, \phi(0)=1 \quad \text{at} \quad \eta=0$$
$$f'(\eta)\to 0, \theta(\eta)\to 0, \phi(\eta)\to 0 \quad \text{as} \quad \eta\to\infty \tag{10}$$

The dimensionless numbers appearing in equations (7)- (9) are

$\Pr_{eff} = \dfrac{\Pr}{\left(1+\dfrac{4R}{3}\right)}$ is Prandtl Number, $M = \dfrac{\sigma_e B_0^2}{(\rho C)_f}$ is Magnetic Parameter, $\delta = \dfrac{\mu}{k_\rho} u$ is Permeable Parameter, $Le = \dfrac{\alpha}{D_B}$ is Lewis Number, $Nt = \dfrac{\tau D_T (T_{w-} T_\infty)}{v T_\infty}$ is the Thermophoresis Parameter, $E = \dfrac{E_a}{\kappa T}$ is the activation energy, $Nb = \dfrac{\tau D_B (C_{w-} C_\infty)}{v}$ is Brownian motion Parameter , $\sigma = \dfrac{K_r^2}{c}$ is the reaction rate parameter.

III. Numerical Analysis

A Mathematical model has framed for MHD boundary layer mixed convection flow of a viscous fluid over an inclined stretching sheet with binary chemical reaction. The governing boundary layer equations (1) - (4) under the boundary conditions (5) has been transformed into ordinary differential equations (7) – (9) with corresponding boundary condition (10) by using suitable similarity transformation. Then they are solved by employing Nactsheim-Swigert shooting technique with the six order Runge-Kutta iteration Method. In order to investigate the flow characteristic, non-dimensional parameters on velocity, temperature and concentration profiles are illustrated graphically and numerically.

IV. Results and Discussion

In this present work, a systematic study of parameters which influence the flow such as Magnetic parameter (M), Prandtl number(Pr), Eckert number(Ec), Brownian motion parameter(Nb), Thermophoresis parameter (Nt), non-dimensional energy (E) ,temperature difference parameter δ, fitted rate constant *n* and reaction rate σ has been carried out and the results are shown in Figures.1-9

Fig.1 and 2 depict the behaviour of magnetic parameter (M) on the velocity, temperature and concentration profiles. It illustrates that the velocity and concentration field decreases with an increasing value of Magnetic parameter (M) and the temperature field increases with an increasing value of Magnetic parameter (M).

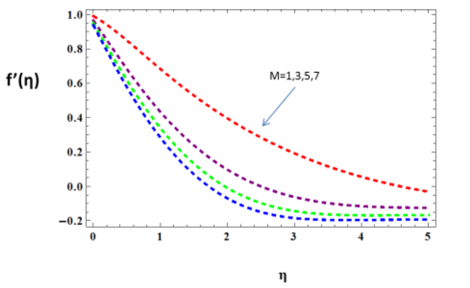

Figure.1.Influence of Magnetic parameter (*M*) on Velocity Profile Pr=0.72, Nb=0.5, Nt=0.5, Gr=1,Gm=1, Le=2,σ =0.1, E=1, δ =0.1, Ec=1

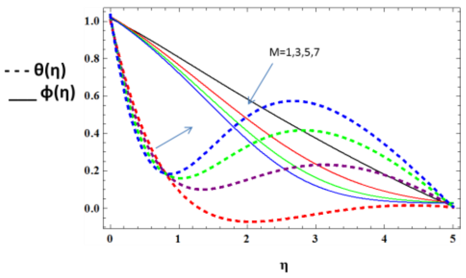

Figure.2.Influence of Magnetic parameter (*M*) on temperature and concentration Profiles Pr=0.72, Nb=0.5, Nt=0.5, Gr=1,Gm=1, Le=2, σ =0.1, E=1, δ =0.1, Ec=1

Fig.3 represents the impact of Prandtl number (Pr) on the velocity profile. Increasing values of Prandtl number decreases the velocity profile. Fig.4 demonstrates that larger values of Prandtl number increases the temperature and concentration profiles.

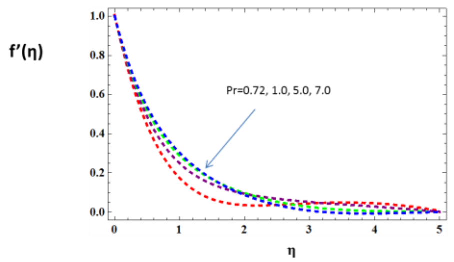

Figure.3.Influence of Prandtl number (Pr) on Velocity Profile M=1, Nb=0.5, Nt=0.5, Gr=1,Gm=1, Le=2,σ =0.1, E=1, δ =0.1, Ec=1

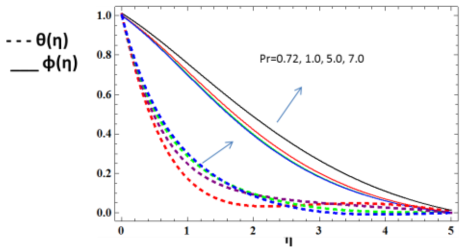

Figure.4.Influence of Prandtl number (Pr) on temperature and concentration Profiles M=1, Nb=0.5, Nt=0.5, Gr=1,Gm=1, Le=2, σ =0.1, E=1, δ =0.1, Ec=1

Fig.5 and Fig.6 reveals the effects of values Brownian motion parameter(Nb) and Thermophoresis parameter (Nt) on the velocity, temperature and concentration profile. Velocity and temperature profiles enhances with an increasing values Brownian motion parameter(Nb) and Thermophoresis parameter (Nt) .Concentration profile has an opposite effect in the values of Brownian motion parameter(Nb) and Thermophoresis parameter (Nt).

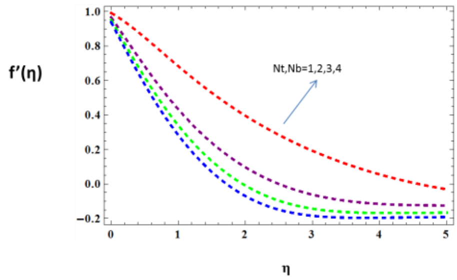

Figure.5.Influence of Nt, Nb on Velocity Profile Pr=0.72, M=1, Gr=1,Gm=1, Le=2,σ =0.1, E=1, δ =0.1, Ec=1

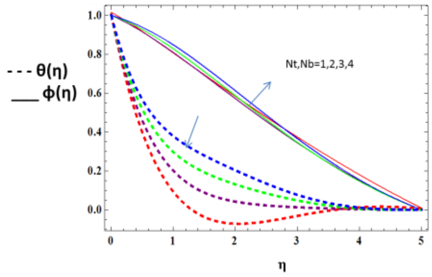

Figure..6.Influence of Nt, Nb on temperature and concentration Profiles M=1, Gr=1,Gm=1, Le=2,Pr=0.72,σ =0.1, E=1, δ =0.1, Ec=1

Fig.7 and Fig.8 illustrates the effect of Eckert number (Ec). It is seen that velocity and temperature profile enhances with an increasing values of Eckert number (Ec) and the effect of increasing Eckert number(Ec) decreases concentration profile.

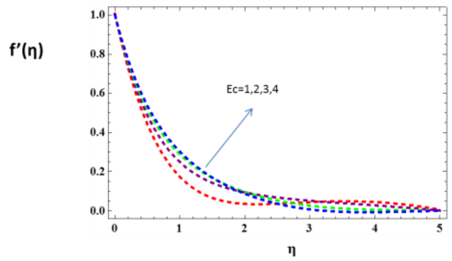

Figure.7.Influence of Eckert number (Ec) on velocity Profiles Pr=0.72, Nb=0.5, Nt=0.5, Gr=1,Gm=1, Le=2,σ =0.1, E=1, δ =0.1, M=1

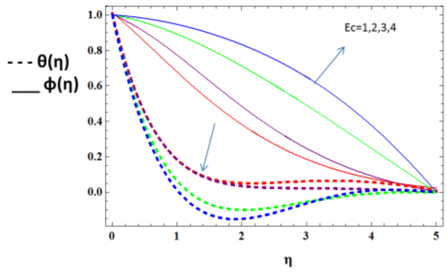

Figure.8.Influence of Eckert number (Ec) on temperature and concentration Profiles Pr=0.72, Nb=0.5, Nt=0.5, Gr=1,Gm=1, Le=2, σ =0.1, E=1, δ =0.1, M=1

Fig.9 portrays the effects of non-dimensional energy (E) on concentration profile. An increasing value of non-dimensional energy (E) enhances concentration profile which thins the boundary layer. Fig.10 depicts the impact of temperature difference parameter (δ) on concentration profile. The concentration profile decreases with increasing values of temperature difference parameter (δ).

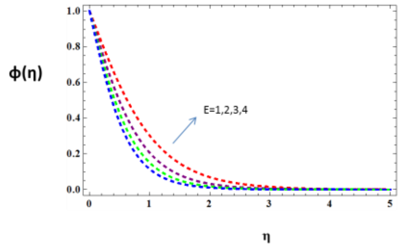

Figure.9.Influence of non-dimensional energy (E) on concentration Profiles M=1, Nb=0.5, Nt=0.5, Gr=1,Gm=1, Le=2,σ =0.1, Ec=1, δ =0.1, Ec=1

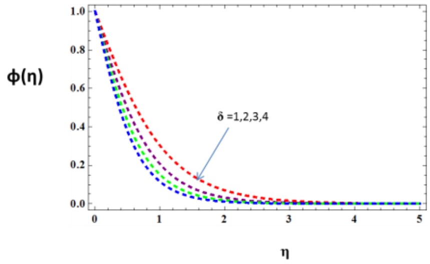

Figure.10.Influence of temperature difference parameter (δ) on concentration Profiles M=1, Nb=0.5, Nt=0.5, Gr=1,Gm=1, Le=2,σ =0.1, Ec=1, E=1, Ec=1

It is observed that the effect of dimensionless reaction rate (σ) on concentration profile has shown in the Fig.11. The concentration profile reduces with larger value of dimensionless reaction rate (σ) within boundary layer region. Fig.12 demonstrates the effect of fitted rate constant *(n)* on concentration profile which decreases with an increasing value of fitted rate constant *(n).*

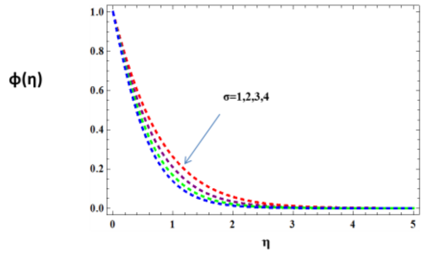

Figure.11.Influence of reaction rate (σ) on concentration Profiles M=1, Nb=0.5, Nt=0.5, Gr=1,Gm=1, Le=2, δ =0.1, Ec=1, E=1, Ec=1

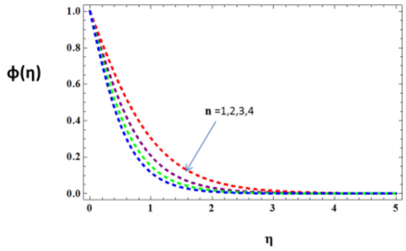

Figure.12.Influence of fitted rate constant (n) on concentration Profiles M=1, Nb=0.5, Nt=0.5, Gr=1,Gm=1, Le=2,σ =0.1, Ec=1, E=1, Ec=1, δ=1

V. Conclusion

The main concluding remarks of this present research are as follows:

- Velocity and concentration field decreases with an increasing value of Magnetic parameter (M) and the temperature field increases with an increasing value of Magnetic parameter (M).
- Increasing values of Prandtl number decreases the velocity profile. Larger values of Prandtl number increases the temperature and concentration profiles.
- Velocity and temperature profiles enhances with an increasing values Brownian motion parameter(Nb) and Thermophoresis parameter (Nt) .Concentration profile has an opposite effect in the values of Brownian motion parameter(Nb) and Thermophoresis parameter (Nt).
- It is seen that velocity and temperature profile enhances with an increasing values of Eckert number (Ec) and the effect of increasing Eckert number(Ec) decreases concentration profile.
- An increasing value of non-dimensional energy (E) enhances concentration profile which thins the boundary layer.
- The concentration profile decreases with increasing values of temperature difference parameter (δ).
- It is observed that concentration profile reduces with larger value of dimensionless reaction rate (σ) within boundary layer region.
- concentration profile decreases with an increasing value of fitted rate constant *(n).*

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