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MHD Nanofluid flow of a Convection Slip over a Radiating Stretching Sheet with binary chemical reaction and activation energy

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Abstract

We have investigated a two dimensional convection slip flow of nanofluid over a stretching sheet with binary chemical reaction and activation energy. This model used Modified Arrhenius for activation energy in Mass transfer process. A mathematical formulation has designed for momentum, temperature and concentration profiles. The coupled partial differential equations are reduced to a system of ordinary differential equations and then solved by using the Nactsheim-Swigert shooting technique with the six order Runge-Kutta iteration Method. The results for the dimensionless velocity, temperature, and concentration profiles are discussed with the help of graphs.

Keywords: *Nanofluid, Magentohydrodynamics(MHD), Porous media, Stretching sheet, Chemical Reaction, Activation energy.*

1. INTRODUCTION

The significant advancement in the nanotechnology due to its rich applications in the industrial and physiological process. Mass transfer process with binary chemical reaction and activation energy is the major application of Nanofluid. Nanofluids are declared as super coolants because their heat absorption capacity is higher than other liquids. Some of the applications involve bio-engineering, polymeric liquids, petroleum productions, plastic manufacturing, food processing and copper wires. Viscous dissipation effects on unsteady free convection flow past an infinite plate was developed by Pop and Soundalgekar [1]. Gorla *et al.* [2] investigated Natural convective boundary layer flow over a plate embedded in a porous medium saturated with a nanofluid. Makinde and Aziz [3] analyzed Boundary layer flow of a nanofluid past a stretching sheet with a convective boundary condition. Hasim *et al.* [4] established Heat and mass transfer of thermophoretic MHD flow over an inclined permeable surface. Hossain *et al.* [5] studied Heat and mass transfer in MHD free convection flow over an inclined plate with hall current. MHD convection slip flow of thermosolutal nanofluid in a saturated porous media over radiating stretching sheet with heat source/sink was discussed by Maripala and Naikoti [6]. Sandeep and Sulochana [7] investigated MHD flow over a permeable stretching /shrinking sheet of a nanofluid with suction and injuction. Maripala and Naikoti [8] analyzed MHD mixed convective heat and mass transfer flow over a thermal radiative stretching cylinder. MHD flow and heat transfer of couple stress fluid over an oscillatory stretching sheet with heat source/sink in porous medium was developed by Ali *et al.* [9]. Maripala and Naikoti [10] studied Micropolar nanofluid flow over a radiative stretching surface with thermal conductivity and heat source/sink. Mustafa *et al.* [11] analyzed the mixed convective flow of MHD nanofluid with chemical reaction and activation energy. In this present paper, we have investigated the two dimensional MHD Nanofluid convection slip flow in a saturated porous media over a radiating stretching sheet with binary chemical reaction and activation energy. The governing partial differential equations are reduced to a system of ordinary differential equations. and then solved numerically by using Nactsheim-Swigert shooting technique with sixth order Runge-Kutta Method. The results of dimensionless parameters velocity, temperature and concentration profiles are discussed with the help of graphs.

2. MATHEMATICAL FORMULATION OF THE PROBLEM

Let us consider the MHD Nanofluid convection slip flow in a saturated porous media over a radiating stretching sheet with binary chemical reaction and activation energy. $\bar{u}$ and $\bar{v}$ are represents the velocity components in $\bar{x}$ and $\bar{y}$ directions. B_0 is the transverse magnetic field acts normal to the boundary surface. The induced magnetic field is effectively negligible when compared to the applied magnetic field. The fluid temperature $T_f\left(>T_w>T_\infty\right)$, which provides a variable heat transfer coefficient $h_f\left(\bar{x}\right)$. Assume that plate and free stream concentration C_f, C_∞, which provides a variable mass transfer coefficient $h_m\left(\bar{x}\right)$.The Oberbeck - Boussinesq approximation is utilized and the conservation of mass, momentum, energy and concentration equations are written as

Continuity equation

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

Momentum equation

$$\rho_f \left(\bar{u}\frac{\partial \bar{u}}{\partial \bar{x}} + \bar{v}\frac{\partial \bar{u}}{\partial \bar{y}} \right) = \mu \frac{\partial^2 \bar{u}}{\partial \bar{y}^2} - \frac{\mu}{K_p}\bar{u} - \sigma B_{\circ}^{2}\bar{u} \tag{2}$$

$$\rho_f \left(\bar{u}\frac{\partial \bar{v}}{\partial \bar{x}} + \bar{v}\frac{\partial \bar{v}}{\partial \bar{y}} \right) = \mu \frac{\partial^2 \bar{v}}{\partial \bar{y}^2} - \frac{\mu}{K_p}\bar{v} - \sigma B_{\circ}^{2}\bar{v} \tag{3}$$

Energy equation

$$\bar{u}\frac{\partial T}{\partial \bar{x}} + \bar{v}\frac{\partial T}{\partial \bar{y}} = \alpha \frac{\partial^2 T}{\partial \bar{y}^2} + \tau \left\{ D_B \frac{\partial C}{\partial \bar{y}}\frac{\partial T}{\partial \bar{y}} + \left(\frac{\partial T}{\partial \bar{y}} \right)^2 \right\} - \frac{1}{\rho_f c_f}\frac{\partial q_r}{\partial \bar{y}} + \frac{Q_{\circ}}{(\rho c)_f}(T - T_\infty) \tag{4}$$

Concentration equation

$$\bar{u}\frac{\partial C}{\partial \bar{x}} + \bar{v}\frac{\partial C}{\partial \bar{y}} = D_B \frac{\partial^2 C}{\partial \bar{y}^2} + \left(\frac{D_T}{T_\infty} \right)\frac{\partial^2 T}{\partial \bar{y}^2} - K_r^2(\phi - \phi_\infty)\left(\frac{T}{T_\infty} \right)^n e^{\left(-\frac{E_a}{\kappa T}\right)} \tag{5}$$

The appropriate boundary conditions are

$$\bar{u} = \bar{u}_w + \bar{u}_{slip}; \bar{v} = 0, -k\frac{\partial T}{\partial \bar{y}} = h_f(\mathrm{T}_f - \mathrm{T}), -\mathrm{D}_B\frac{\partial C}{\partial \bar{y}} = h_m(\mathrm{C}_f - \mathrm{C}) \quad \text{at} \quad \bar{\mathrm{y}} = 0$$

$$\bar{u} \to 0, T \to T_\infty, C \to C_\infty \quad \text{as} \quad \bar{y} \to \infty \tag{6}$$

Where $\alpha = k/(\rho c)_f$ (Thermal diffusivity), $\tau = (\rho c)_p / (\rho c)_f$ (Ratio of heat capacity of the nanoparticle and fluid), $\bar{u}_w = U_r\left(\bar{x}/L\right)$(Velocity of the plate), $\bar{u}_{Slip} = N_1 v\frac{\partial \bar{u}}{\partial \bar{y}}$ (Linear slip velocity), ρ_f is density of the Base fluid, σ electric conductivity of the fluid, μ is dynamic viscosity of the base fluid, ρ_p is density of the nanoparticles, Q_0 is volumetric heat generation/ absorption , ε is porosity, D_B

Brownian diffusion coefficient , D_T is thermophoretic diffusion coefficient and q_r is radiative heat transfer. The term $K_r^2(\phi-\phi_\infty)\left(\frac{T}{T_\infty}\right)^n e^{\left(-\frac{E_a}{\kappa T}\right)}$ in equation (4) represents the modified Arrhenius equation in which K_r^2 is the reaction rate, E_a the activation energy, κ =8.61x10^{-5}eV/K the Boltzmann constant and n fitted rate constant which generally lies in the range -1 < n < 1.

A stream function $\psi(x,y)$ defined as

$$u=\frac{\partial\psi}{\partial y} \qquad v=-\frac{\partial\psi}{\partial x}$$

The similarity transformations are

$$\eta=\frac{\bar{y}}{\sqrt{k_p}} \qquad \psi=U_r\left(\bar{x}/L\right)\sqrt{k_p}\,f(\eta) \qquad \theta(\eta)=\frac{T-T_\infty}{T_f-T_\infty} \qquad \phi(\eta)=\frac{C-C_\infty}{C_f-C_\infty} \tag{7}$$

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.

Substitution of (7) into (2) – (5) generates the following similarity equations

$$f''''+\operatorname{Re}Da\left(ff'''-f''^2-Mf''\right)-f''=0 \tag{8}$$

$$f''-\operatorname{Re}Da\left(Mf-ff'\right)-f=0 \tag{9}$$

$$\theta''+\operatorname{Re}\Pr Daf\theta'+\Pr\left[Nb\theta' f\varphi'+Nt\theta'^2\right]+\frac{4}{3R}\left[\left\{1+\left(T_r-1\right)\theta\right\}^3\theta'\right]'+Q\theta=0 \tag{10}$$

$$\varphi''+\operatorname{Re}LeDaf\varphi'+\frac{Nt}{Nb}\theta''-Le\sigma(1+\delta\theta)^n fe^{\left(-\frac{E}{1+\delta\theta}\right)}=0 \tag{11}$$

The relevant boundary conditions are

$$f(0)=0, f'(0)=1+af''(0), f'(\infty)=0$$

$$\theta'(0)=-Nc\lfloor 1-\theta(0)\rfloor, \theta(\infty)=0$$

$$\varphi'(0)=-Nd\lfloor 1-\varphi(0)\rfloor, \varphi(\infty)=0 \tag{12}$$

The thermo physical thermo physical dimensionless parameters in (8)-(11) are defined as follows:

$\mathrm{Re}=\frac{U_r L}{\upsilon}$ is the Reynolds number, $Da=\frac{k_p}{L^2}$ is the Darcy number, $M=\frac{\sigma B_0^2 L}{U_r \rho}$ is the Magnetic field parameter, $Pr=\frac{\upsilon}{\alpha}$ is the prandtl number, $N_t=\frac{\tau D_T\left(T_f-T_\infty\right)}{\upsilon T_\infty}$ is the thermophoresis parameter, $N_b=\frac{\tau D_B\left(C_f-C_\infty\right)}{\upsilon}$ is the Brownian motion parameter, $R=\frac{kk_1}{4\sigma_1 T_\infty^3}$ is the convection radiation parameter, $Le=\frac{\upsilon}{D_B}$ is the Lewis number, $Nd=\frac{h_m\sqrt{k_p}}{D_B}$ is the convection diffusion parameter, $Nc=\frac{h_f\sqrt{k_p}}{k}$ is the convection conduction parameter, $E=\frac{E_a}{\kappa T}$ is the activation energy, $\sigma=\frac{K_r^2}{c}$ is reaction rate parameter.

3. NUMERICAL ANALYSIS

The set of non dimensional equations (8) – (11) with boundary conditions (12) has been solved numerically by using the Nactsheim- Swigert shooting iteration technique together with a sixth- order Runge-Kutta iterations scheme. The effects of binary chemical reaction and activation energy on two-dimensional Radiative MHD Nanofluid flow of convection slip over a stretching sheet analyzed numerically and graphically.

4. RESULT AND DISCUSSIONS

From the process of numerical computation, the effects of dimensionless governing parameters such as Prandtl Number Pr, rate constant n, reaction rate σ, temperature difference parameter δ on dimensionless velocity, temperature, concentration profiles are analyzed using graphs.

Fig.1 represents the velocity profile for different values of Re. the increase of Reynolds number Re increase the velocity gradient.Fig.2 and Fig.3 shows the effect of Reynolds number in Temperature and concentration profiles. Both Temperature and concentration profiles decreases with the increasing values of Re.

Fig.4,5,6 illustrate velocity, temperature and concentration profiles for values temperature difference parameter δ. Velocity and temperature profiles increases with an increasing values of temperature difference parameter δ. Concentration profile decreases with the increasing value of temperature difference parameter δ.

Fig.7, 8,9 depicts the influence of reaction rate σ on velocity, temperature and concentration profiles. Velocity and temperature profile increases with an increasing values of reaction rate σ and concentration profile decreases with the increasing value of reaction rate σ .

It is observed that Fig.10,11,12 demonstrates the influence of fitted rate constant *n* on velocity, temperature and concentration profiles. Velocity and temperature profile increases with an increasing values of fitted rate constant *n* and concentration profile decreases with the increasing value of fitted rate constant *n*.

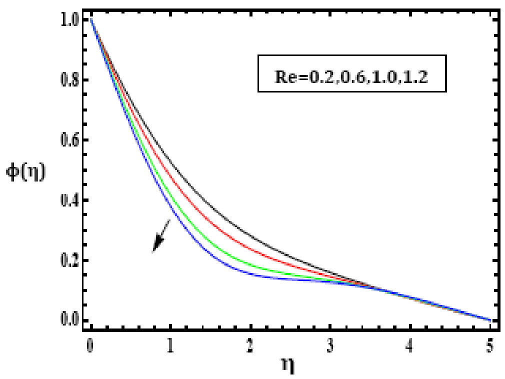

Fig.3: Effects of Renolds number (Re) on Concentration Profiles Pr=2,Ec=0.5,Nt=0.5,Nr=0.1, Le=1,M=0.5,n=0, δ,σ,E=1

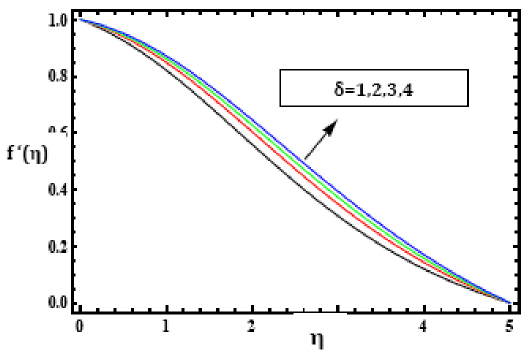

Fig.4: Effects of temperature difference parameter (δ) on Velocity Profiles Pr=2,Ec=0.5,Nt=0.5,Nr=0.1, Le=1,M=0.5,n=0, σ,E=1

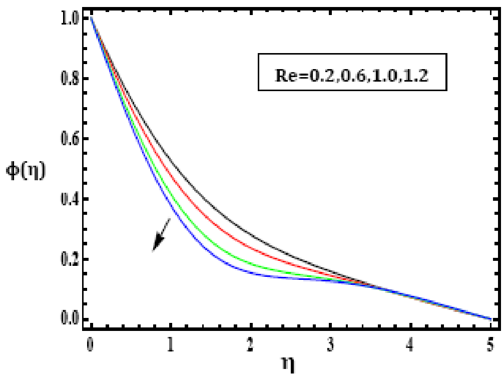

Fig.3: Effects of Renolds number (Re) on Concentration Profiles Pr=2,Ec=0.5,Nt=0.5,Nr=0.1, Le=1,M=0.5,n=0, δ,σ,E=1

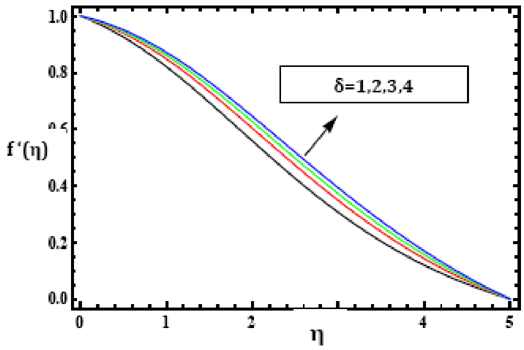

Fig.4: Effects of temperature difference parameter (δ) on Velocity Profiles Pr=2,Ec=0.5,Nt=0.5,Nr=0.1, Le=1,M=0.5,n=0, σ,E=1

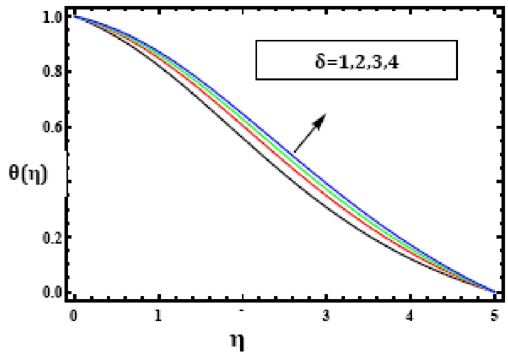

Fig.5: Effects of temperature difference parameter (δ) on temperature Profiles Pr=2,Ec=0.5,Nt=0.5,Nr=0.1, Le=1,M=0.5,n=0, σ,E=1

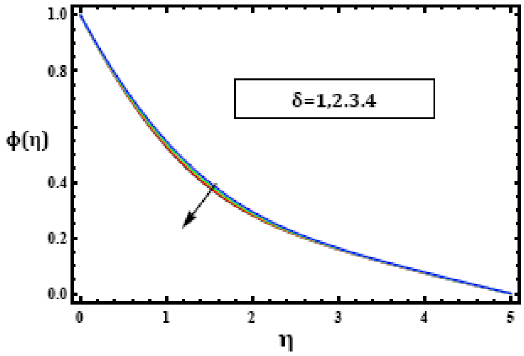

Fig.6: Effects of Concentration difference parameter (δ] on temperature Profiles Pr=2,Ec=0.5,Nt=0.5,Nr=0.1, Le=1,M=0.5,n=0, σ,E=1

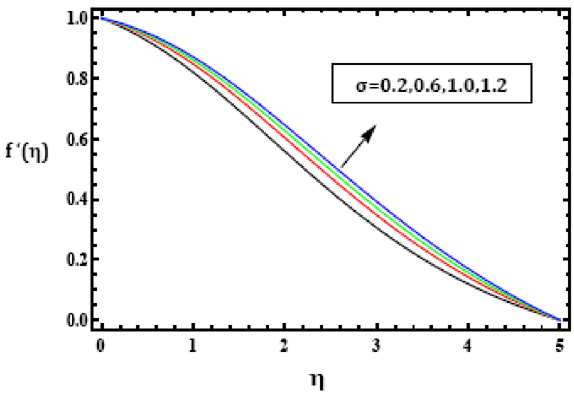

Fig.7: Effects of reaction rate (σ) on velocity Profiles Pr=2,Ec=0.5,Nt=0.5,Nr=0.1, Le=1,M=0.5,n=0, δ,E=1

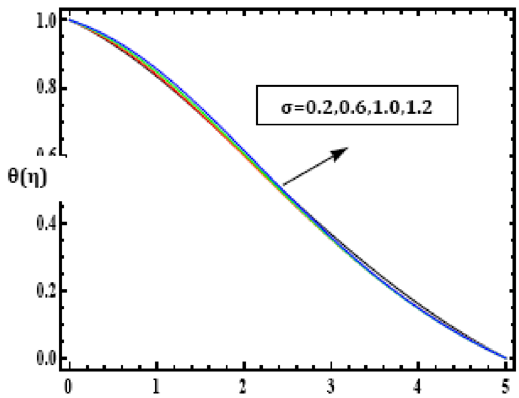

Fig.8: Effects of reaction rate (σ) on temperature Profiles Pr=2,Ec=0.5,Nt=0.5,Nr=0.1, Le=1,M=0.5,n=0, δ,E=1

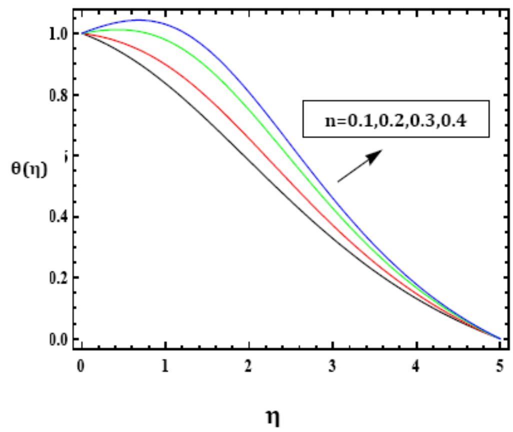

Fig.11: Effects of fitted rate constant *n* on temperature Profiles Pr=2,Ec=0.5,Nt=0.5,Nr=0.1, Le=1,M=0.5,n=0, δ,σ,E=1

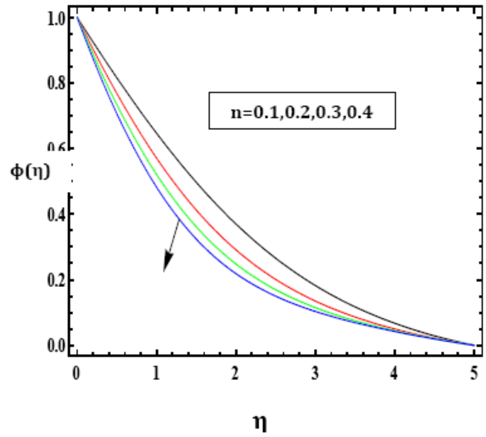

Fig.12: Effects of fitted rate constant *n* on temperature Profiles Pr=2,Ec=0.5,Nt=0.5,Nr=0.1, Le=1,M=0.5,n=0, δ,σ,E=1

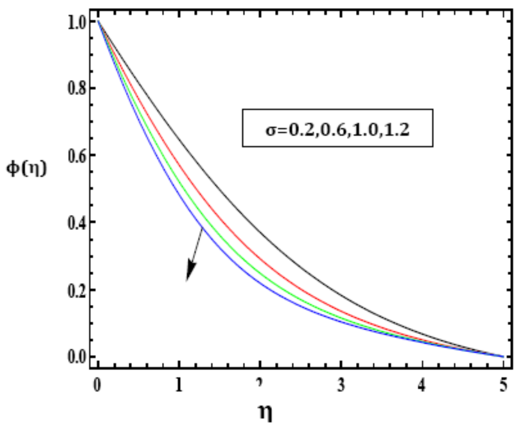

Fig.9: Effects of reaction rate (σ) on Velocity Profiles Pr=2,Ec=0.5,Nt=0.5,Nr=0.1, Le=1,M=0.5,n=0, δ,E=1

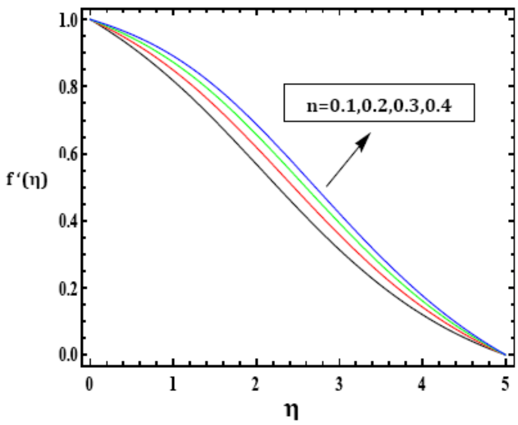

Fig10: Effects of fitted rate constant *n* on temperature Profiles Pr=2,Ec=0.5,Nt=0.5,Nr=0.1, Le=1,M=0.5,n=0, δ,σ,E=1

5. CONCLUSION

In this present paper, we have investigated the two dimensional MHD Nanofluid convection slip flow in a saturated porous media over a radiating stretching sheet with binary chemical reaction and activation energy. The governing partial differential equations are reduced to a system of ordinary differential equations. and then solved numerically by using Nactsheim-Swigert shooting technique with sixth order Runge-Kutta Method. The results of dimensionless parameters velocity, temperature and concentration profiles are discussed with the help of graphs.

- The increase of Reynolds number Re increase the velocity gradient.The effect of Reynolds number in Temperature and concentration profiles. Both Temperature and concentration profiles decreases with the increasing values of Re.

- Velocity and concentration profiles increases with an increasing values of temperature difference parameter δ. Concentration profile decreases with the increasing value of temperature difference parameter δ.
- Velocity and temperature profile increases with an increasing values of reaction rate σ and concentration profile decreases with the increasing value of reaction rate σ.
- Velocity and temperature profile increases with an increasing values of fitted rate constant *n* and concentration profile decreases with the increasing value of fitted rate constant *n*.

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