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HEAT AND MASS TRANSFER IN MHD BOUNDARY LAYER SLIP FLOW WITH BINARY CHEMICAL REACTION AND ACTIVATION ENERGY

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ABSTRACT

The present study reports MHD boundary layer slip flow over a flat porous plate embedded in a porous medium with effects of chemical reaction and activation energy. The flow governing equations have been altered as ODE with similarity transformation and then solved by finite differences method using shooting technique. The concentration profile analyzed numerically and graphically. The effects of non-dimensional parameters Lewis numer(Le), Brownian Motion parameter (Nb), Thermophoresis parameter (Nt),Prandtl number (Pr),non-dimensional energy (E), temperature difference parameter (δ), dimensionless reaction rate (σ) and fitted rate constant (n) on the flow field were discussed .

KEYWORDS: MHD, Slip flow, Heat transfer, Binary Chemical reaction, Activation Energy

1. INTRODUCTION

In recent years MHD boundary layer flow over a porous flat plate has vital importance because of its possible applications in several branches of science and technology. Some industrial applications such as glassware, artificial fibers, cable coatings, roofing shingles and metallic plates etc. Laminar boundary layer with slip flow in momentum and heat transfer was studied by martin *et al* [1] .Bhattacharyya *et al.* [2] investigated slip effects on boundary layer stagnation point flow and heat transfer towards a shrinking sheet. MHD unsteady flow and heat transfer toward a flat plate was studied by Makinde [3]. Zheng *et al.* [4] established MHD flow over a porous shrinking surface with velocity slip. Bhattacharyya [5] presented slip effects on boundary layer flow and mass transfer over a flat plate in a porous medium. Steady boundary layer slip flow along with heat and mass transfer over a flat plate in a porous medium was investigated by Aziz *et al.* [6]. Swati and Iswar [7] analyzed MHD mixed convection slip flow and heat transfer over a vertical porous plate. Heat transfer analysis for stationery boundary layer slip flow of a power law fluid in a darcy porous medium was established by Aziz *et al.*[8] . Sharma and Sinha [9] studied MHD mixed convection slip flow heat and mass transfer along a vertical porous plate. Slip flow and heat transfer of nanofluid over a porous plate in a porous medium with thermal conductivity was analyzed by Hussain *et al.*[10]. Jat *et al.*[11] explained MHD boundary layer slip flow with slip conditions at the boundary. In this study, we have investigated MHD boundary layer slip flow over a flat porous plate embedded in a porous medium with effects of chemical reaction and activation energy.

2. FORMULATION OF THE PROBLEM

Consider the steady two dimensional viscous incompressible boundary layer flow of electrically conducting fluid embedded in a porous medium. In the presence of applied magnetic field strength B_0 . The induced magnetic field is small as compared to magnetic field so it is neglected. Assume that all the fluid properties to be constant throughout the motion. u and v are the velocity components in x and y directions respectively. υ is the kinematic viscosity, ρ is the density, μ is the coefficient of viscosity, U_∞ is the free stream velocity, T is the temperature, C is the concentration and σ_c is the electrical conductivity of the fluid. The governing momentum, temperature and concentration equation with Arrhenius activation energy are

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

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$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}-\frac{\upsilon}{k}\left(u-U_\infty\right)+\frac{\sigma_c B_0^2}{\rho}\left(u-U_\infty\right) \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2}+\frac{\rho c_p}{\rho c_f}\left(D_B\left(\frac{\partial T}{\partial y}\frac{\partial C}{\partial y}\right)+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right) \tag{3}$$

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

In equation (4), $K_r^2(\phi-\phi_\infty)\left(\frac{T}{T_\infty}\right)^n e^{\left(-\frac{E_a}{\kappa T}\right)}$ = The modified Arrhenius equation in which K_r^2 = 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.

The corresponding boundary conditions of (1) to (4) are

$$u=L_1\left(\frac{\partial u}{\partial y}\right), v=v_w, T=T_w+D_T\left(\frac{\partial T}{\partial y}\right), \mathrm{C}=C_w+D_c\left(\frac{\partial C}{\partial y}\right) \quad \text{at} \quad y=0$$

$$u\to U_\infty, T\to T_\infty, C\to C_\infty \quad \text{as} \quad y\to\infty \tag{5}$$

To solve the governing equations (1) to (4) under the boundary conditions (5), Similarity transformations are defined as

$$u=\frac{\partial\psi}{\partial y},\ v=-\frac{\partial\psi}{\partial x},\ \psi(x,y)=\sqrt{U_\infty\upsilon x}\,f(\eta),\ \eta=y\sqrt{\frac{U_\infty}{\upsilon x}},\ \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},\ \phi(\eta)=\frac{C-C_\infty}{C_w-C_\infty} \tag{6}$$

The equations (1) to (4) by (6) are reduced to

$$f'''+\frac{1}{2}ff''-K\left(f'-1\right)+M\left(f'-1\right)=0 \tag{7}$$

$$\theta''+\Pr\left[\frac{1}{2}f\theta'+Nb\theta'\phi'+Nt\theta'^2+S_1\theta\right]=0 \tag{8}$$

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

The corresponding boundary condition is

$$f(\eta)=S,\ f'(\eta)=\delta f''(\eta),\theta(\eta)=1+\beta\theta'(\eta),\phi(\eta)=1+\beta\phi'(\eta) \quad \text{at} \quad \eta=0$$

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

Where the non dimensional parameters are

$K=\dfrac{1}{\left(Da_x \operatorname{Re}_x\right)}$ (Permeability parameter), $Da_x=\dfrac{k_0}{x}$ (Local Darcy parameter), $\operatorname{Re}_x=\dfrac{U_\infty x}{\upsilon}$ (Reynolds number) , $M=\dfrac{\sigma_c B_0^2 x}{\rho U_\infty}$ (Magnetic parameter), $\Pr=\dfrac{\mu c_p}{k}$ (Prandtl number), $N_b=\dfrac{(\rho c)_p D_B\left(C_w-C_\infty\right)}{(\rho c)_f\,\upsilon}$ (Brownian motion parameter), $N_t=\dfrac{(\rho c)_p D_T\left(T_w-T_\infty\right)}{(\rho c)_f\,\upsilon T_\infty}$ (Thermophoresis parameter) , $Le=\dfrac{\upsilon}{D_B}$ (Lewis number). $\sigma=\dfrac{K_r^2}{c}$ (Dimensionless reaction rate). $\delta=\dfrac{T_w-T\infty}{T\infty}$ (Temperature difference parameter). $E=\dfrac{E_a}{\kappa T}$ (Non-dimensional energy)

3. RESULTS AND DISCUSSION

The governing equations (7) to (9) under (10) are solved by finite differences method using shooting technique; the computed solutions of self-similar ODEs are obtained for several values of non-dimensional parameters involved, namely, Lewis number(Le), Brownian Motion parameter (Nb), Thermophoresis parameter (Nt),Prandtl number (Pr),non-dimensional energy (E), temperature difference parameter (δ), dimensionless reaction rate (σ) and fitted rate constant *(n)* and they have been presented graphically.

Fig.1 shows the effects of Prandtl number (Pr) on concentration profile. The increase in Prandtl number (Pr) is to decrease mass transfer boundary layer thickness.

Fig.2 displays of effect of increasing Brownian motion parameter (Nb) on concentration profile. The concentration profile decreases with an increasing value of Brownian motion parameter (Nb).

In Fig.3, the effects of Thermophoresis parameter (Nt) on concentration profile presented. An increasing value of Thermophoresis parameter (Nt) enhances the concentration profile.

Fig.4 shows the variations of increasing non-dimensional energy (E) on concentration profile, It causes the thickening of the concentration boundary layer.

In Fig.5, the effects of Lewis number (Le) on concentration profile noticed .The concentration profile decreases with an increasing values Lewis number (Le) which reveals thinning of concentration boundary layer.

It can be observed that in Fig.6, concentration decreases with an increasing value of temperature difference parameter (δ) and which reduces concentration boundary layer thickness.

Fig.7 analyzed the influence of dimensionless reaction rate (σ) on concentration profile which illustrates that concentration profile decreases with an increasing value of dimensionless reaction rate (σ).

In Fig.8, the variations of fitted rate constant (*n)* on concentration profile can be shown .The concentration profile decreases with an increasing value of fitted rate constant (*n)* which leads to considerable thinning within the boundary layer.

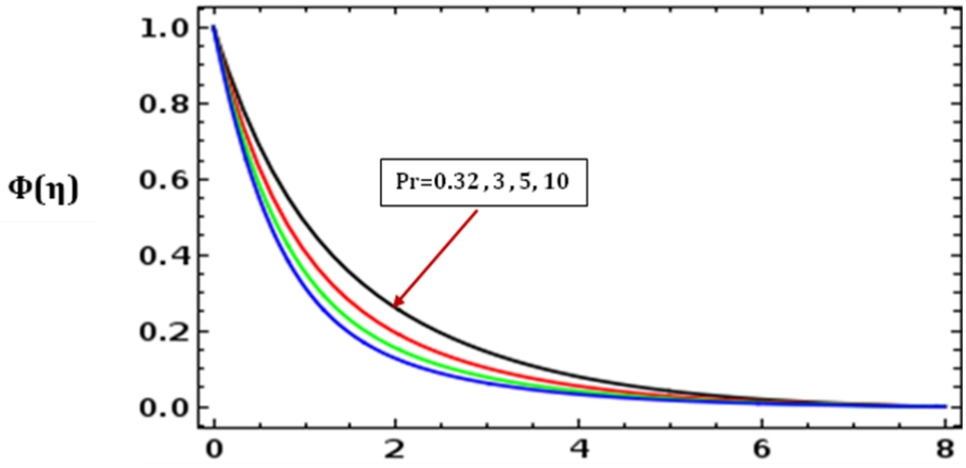

Fig.1: Effects of Prandtl number on concentration Profile
Nt=0.1,Nb=0.5,Le=1, δ=1, σ=5, E=1,Le = 1

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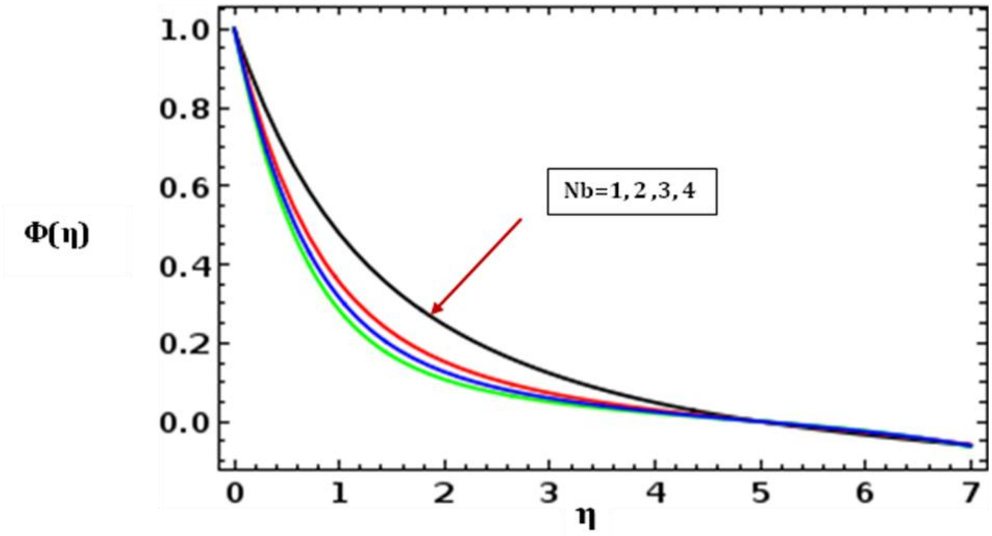

Fig.2: Effects of **Brownian motion parameter** on concentration
Profile Nt=0.1,Le=1, δ=1, σ=5, E=1,Le = 1,Pr=1

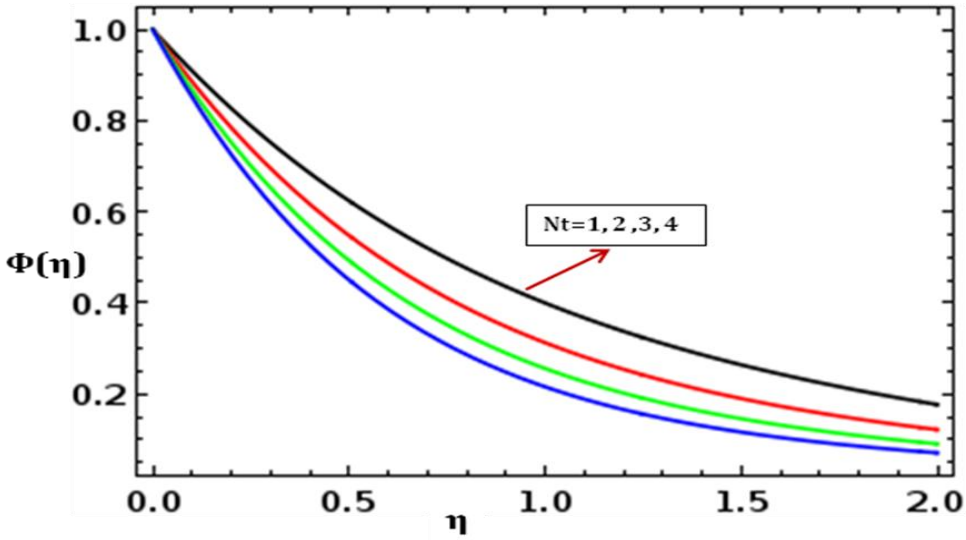

Fig.3: Effects of Brownian motion parameter on concentration
Profile Nb=0.1,Le=1, δ=1, σ=5, E=1,Le = 1,Pr=1

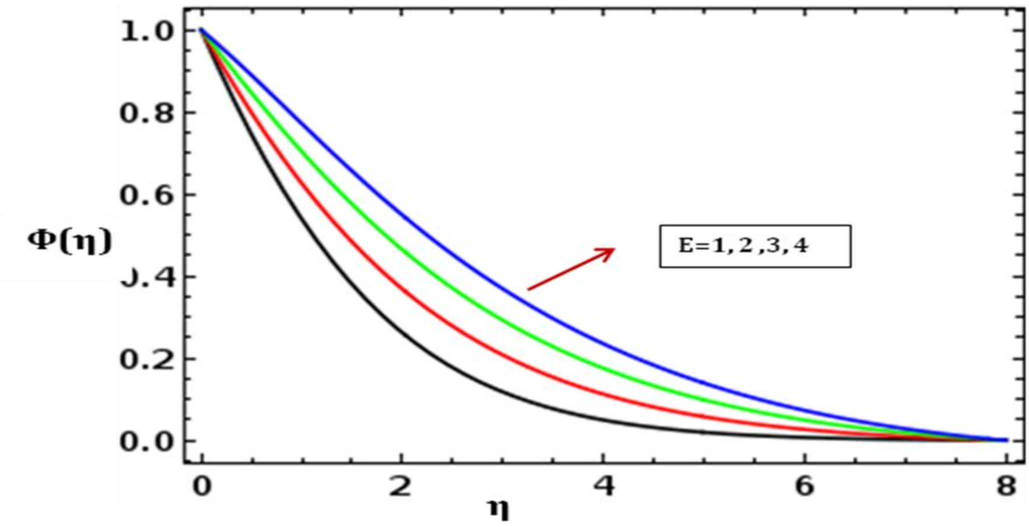

Fig.4: Effects of non-dimensional energy(E) on concentration Profile Nb=0.1,Le=1, δ=1, σ=5, Nt=1,Le = 1,Pr=1

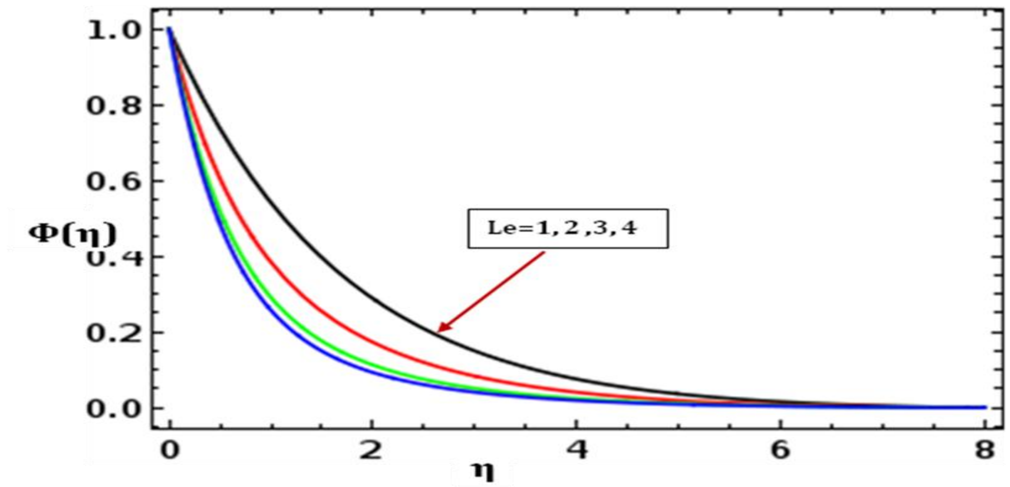

Fig.5: Effects of Lewis number on concentration Profile Nb=0.1,E=1, δ=1, σ=5, Nt=1,Le= 1,Pr=1

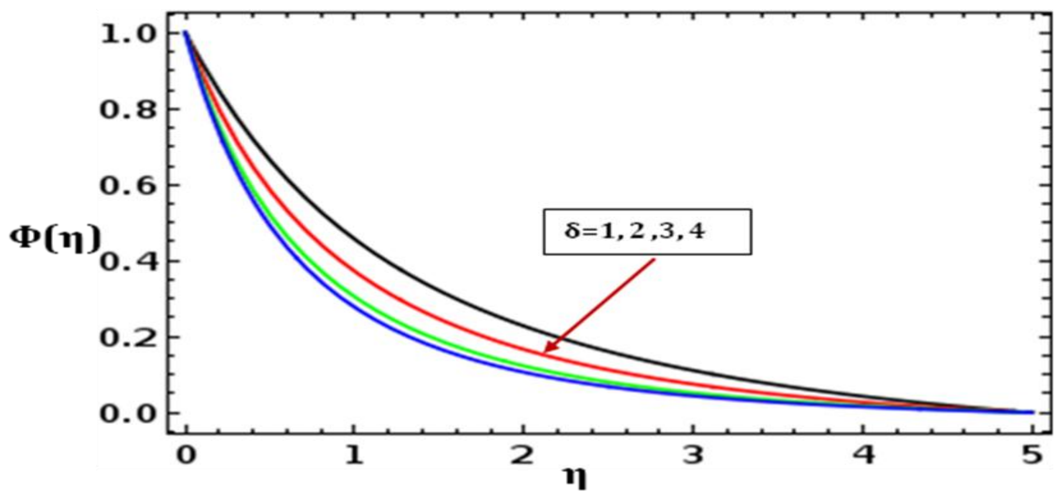

Fig.6: Effects of temperature difference parameteron concentration Profile Nb=0.1,E=1, σ=5, Nt=1,Le= 1,Pr=1

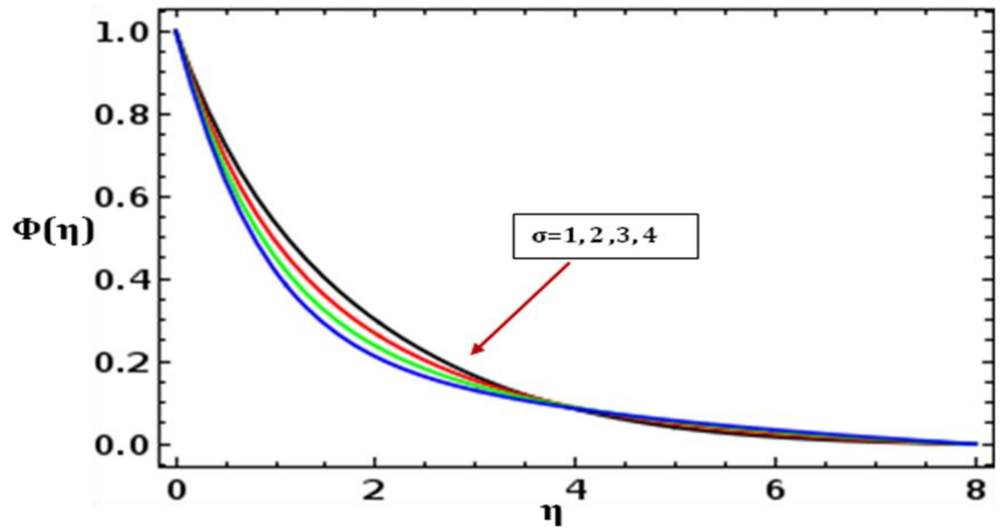

Fig.7 Effects of dimensionless reaction rate on concentration Profile Nb=0.1,E=1, δ=5, Nt=1,Le = 1,Pr=1

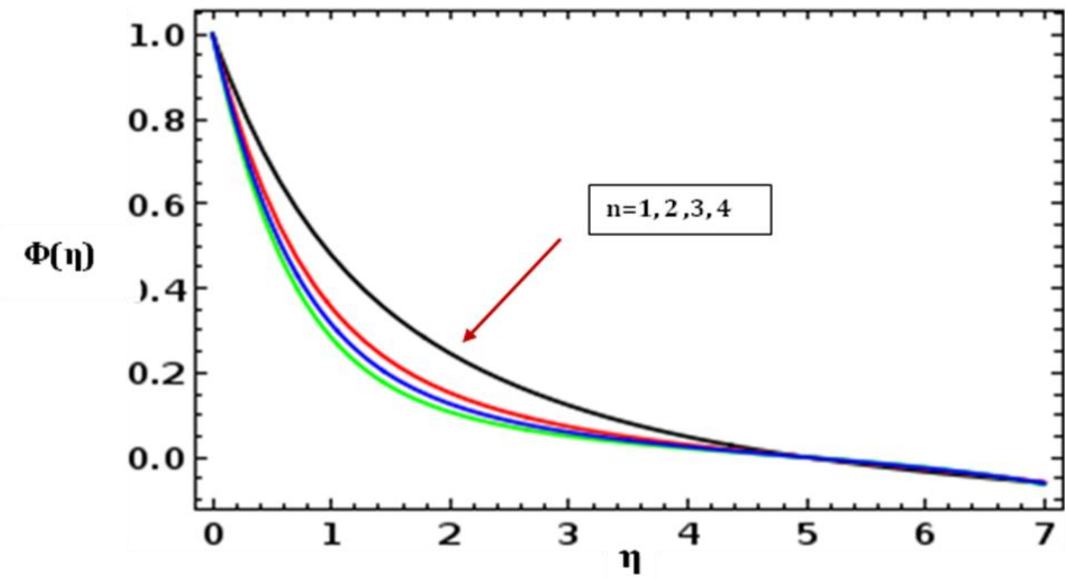

Fig.8: Effects of fitted rate constant on concentration Profile Nb=1,Le=1, δ=1, σ=5, E=1,Le = 1,Pr=1

4. CONCLUSIONS

In this paper, we have considered a Mathematical model of MHD boundary layer slip flow over a flat porous plate embedded in a porous medium with effects of chemical reaction and activation energy. The effects of various non-dimensional parameters are analyzed numerically and graphically.

- The increase in Prandtl number (Pr) and Brownian motion parameter (Nb) decrease the concentration profile. An increasing value of Thermophoresis parameter (Nt) enhances the concentration profile.
- The variations of increasing non-dimensional energy (E) on concentration profile, It causes the thickening of the concentration boundary layer.
- The concentration profile decreases with an increasing values Lewis number (Le) which demonstrates thinning of concentration boundary layer.
- An increasing value of temperature difference parameter (δ) and which decreases concentration boundary layer thickness.
- Concentration profile decreases with an increasing value of dimensionless reaction rate (σ).
- The concentration profile decreases with an increasing value of fitted rate constant (*n)* which leads to considerable thinning within the boundary layer.

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