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Thermophoresis and Brownian motion effects on chemically reacting Casson fluid flow past a nonlinear stretching sheet

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Abstract

In this study, we analyzed the effects of heat source/sink on boundary layer flow of a MHD Casson fluid past a nonlinear stretching sheet with thermophoresis and Brownian motion. The governing partial differential equations are transformed in to set of ordinary differential equations by using similarity transformation and solved numerically using bvp5c Matlab package. The effects of chemical reaction parameter, magnetic field parameter, heat source/sink, Brownian motion parameter and thermophoresis parameter on velocity, temperature and concentration profiles are discussed and presented through graphs. Results indicate that an increase in heat source/sink parameter enhances the heat transfer rate.

Keywords: Casson fluid, Radiation, MHD, Heat source/sink, Thermophoresis and Brownian motion.

1. Introduction

Heat and mass transfer over a stretching sheet have various applications like oil recovery, wire drawing, transpiration, hot rolling, paper production, cooling of continuous strips etc. The study of MHD flow over a stretching sheet has variety of applications in modern metallurgy and metal-working processes. During the last decade, the research on nano fluids was very much developed due to its applications in engineering such as transportation, micro mechanics, optical devices, electronics and cooling devices. All these applications are due to the enhancement in the heat transfer performance in nano fluids while compared with the ordinary fluids like water, propylene glycol etc. Chemical reaction has its great importance due to its universal occurrence in many branches of science and engineering. The influence of chemical reaction plays major role in the field of agriculture engineering to analyze the chemical changes in soil, filtration and purification process.

The boundary layer flow of an incompressible non-Newtonian fluid past a nonlinearly stretching surface was discussed by Khan and Shezad [1], and found that the skin friction coefficient decreases for higher values of power law index parameter. An unsteady convective heat transfer analysis of an EG-Nimonic 80a nanofluid flow past an infinite vertical plate in the presence of radiation was investigated by Sandeep at al. [2]. Stagnation-point flow and heat transfer towards horizontal and exponentially stretching or shrinking cylinders by considering Cu-water nano fluid was studied by Sulochana and Sandeep [3]. Jayachandra Babu et al. [4] discussed the influence of radiation and viscous dissipation on the stagnation-point flow of a micropolar fluid over a nonlinearly permeable stretching surface in the presence suction and injection effects. Further, the researchers [5-8] have analyzed the important aspects on the flow and heat transfer behaviour of some steady and unsteady magneto hydrodynamic flows. Sugunamma et al. [9] has been investigated the radiation and chemical reaction effects on MHD nanofluid.

The non-uniform heat source/sink effect on an unsteady magneto hydrodynamic nano fluid flow through a stretching sheet was considered by Sandeep et al. [10]. Sandeep and Sugunamma [11] investigated an unsteady free convection flow over a vertical plate in the presence of inclined magnetic field and viscous dissipation. Heat and mass transfer in magneto hydrodynamic Casson fluid over an exponentially permeable stretching surface studied by Raju et al. [12]. The researchers [13, 14] presented dual solutions for Newtonian and non-Newtonian fluid cases by considering various channels. Unequal diffusivities case of homogeneous–heterogeneous reactions within viscoelastic fluid flow in the presence of induced magnetic-field and nonlinear thermal radiation was studied by Animasaun et al. [15]. The researchers [16-20] studied the heat and mass transfer characteristics of MHD flows in the presence of thermal radiation, chemical reaction and some other pertinent parameters. Very recently, the researchers [21-26] studied the effects of various physical parameters on Newtonian and non-Newtonian flows by considering various physical models.

In this study, we analyzed the effects of heat source/sink on boundary layer flow of a MHD Casson fluid past a nonlinear stretching sheet with thermophoresis and Brownian motion. The governing partial differential equations are transformed in to set of ordinary differential equations by using similarity transformation and solved numerically using bvp5c Matlab package. The effects of chemical reaction parameter, magnetic field parameter, heat source/sink, Brownian motion parameter and thermophoresis parameter on velocity, temperature and concentration profiles are discussed and presented through graphs.

2. Mathematical formulation

Consider a steady, incompressible, two dimensional MHD boundary layer flow of Casson fluid past a nonlinear stretching sheet coinciding with the plane $y=0$ and the flow is assumed to be confined to $y>0$. It is assumed that the pressure gradient and external forces are neglected in this problem. The flow is along the x-axis where x is the coordinate measured along the stretching/shrinking sheet and y - axis is normal to the surface. A variable magnetic field $B(x)$ is applied in the y-direction. The boundary layer equations that governs the present flow subject to the Boussinesq approximations can be expressed as

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B^2(x)}{\rho_f}, \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\tau\left[D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right]-\frac{Q}{\left(\rho c_p\right)_{nf}}(T-T_\infty), \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2}-k_l(C-C_\infty), \tag{4}$$

with the boundary conditions

$$u = U_w, v = 0, T = T_w, C = C_w \ \ at \ \ y = 0,$$
$$u \to 0, \ \ T \to T_\infty, \ \ C \to C_\infty \ \ \ as \ \ y \to \infty, \tag{5}$$

where u and v are the velocity components in the x and y directions respectively, T is the temperature, C is the volume fraction, T_w is the surface temperature, T_∞ is the ambient temperature, C_w is the volume fraction near the plate and C_∞ is the volume fraction far from the plate, $\tau = (\rho c)_p / (\rho c)_f$, where $(\rho c)_p$ is the effective heat capacity of the nano particles, $(\rho c)_f$ is the heat capacity of the base fluid, $\alpha = k_f / (\rho c)_f$ is the thermal diffusivity of the fluid, ν is the kinematic viscosity, D_B is the Brownian diffusion coefficient, D_T is the thermophoretic diffusion coefficient, B is the transform magneticfield, ρ_f is fluid density, σ is electrical conductivity. The constant n is the nonlinearity parameter with $n = 1$ for the linear case and $n \neq 1$ is for the nonlinear case. It is assumed that the surface is stretched or is shrunk with the velocity $U_w = ax^n$, where $a > 0$ is a constant.

A similarity solution may obtain by assuming the magneticfield term $B(x)$ as of the form $B(x) = \mathrm{B}_0 \, x^{(n-1)/2}$ where B_0 is the constant magneticfield. The similarity solutions of equations (2) to (4) subject to the boundary conditions (5) by introducing the following similarity transforms

$$u = ax^n f^{'}(\eta), v = -\sqrt{\frac{a\nu(n+1)}{2}} x^{(n-1)/2} \left[f(\eta) + \frac{n-1}{n+1} \eta f^{'}(\eta) \right],$$
$$\theta(\eta) = (T - T_\infty)/(T_w - T_\infty), \phi(\eta) = (C - C_\infty)/(C_w - C_\infty),$$
$$\eta = y\sqrt{\frac{a(n+1)}{2\nu}} x^{(n-1)/2}, \ M = \frac{\sigma B_0^2}{a\rho_f},$$
$$Nb = D_B \frac{\tau(C_w - C_\infty)}{\nu}, \ Nt = D_T \frac{\tau(T_w - T_\infty)}{\nu T_\infty}, Ec = \frac{U_w^2}{c_p (T_w - T_\infty)}, \tag{6}$$

Substituting equations (6) into equations (2) to (4), where equation (1) is identically satisfied, we obtain the following ordinary differential equations:

$$\left(1 + \frac{1}{\beta}\right) f''' + ff'' - \frac{2n}{n+1} (f')^2 - Mf' = 0, \tag{7}$$

$$\theta'' + \Pr f\theta' + Nb\theta'\phi' + Nt(\theta')^2 - \Pr Q_H \theta = 0, \tag{8}$$

$$\phi'' + \frac{1}{2} Lef\phi' + \frac{Nt}{Nb}\theta'' - Kr\phi = 0, \tag{9}$$

The boundary conditions (5) reduce to

$$f(0) = 0, f'(0) = 1, \theta(0) = 1, \phi(0) = 1,$$
$$f^{'}(\eta) \to 0, \theta(\eta) \to 0, \phi(\eta) \to 0 \ \ as \ n \to \infty,$$

(10)

where $\Pr = \nu/\alpha$ the Prandtl is number and $Le = \nu/D_B$ is the Lewis number, Nb is the Brownian motion parameter, Nt the Thermophoresis parameter, M is the magnetic field parameter, Q_H is the heat source/sink parameter and Kr is the chemical reaction parameter.

3. Results and discussion

The system of nonlinear ordinary differential equations (7) to (9) with the boundary conditions (10) are solved numerically using bvp5c MATLAB Package. The results obtained shows the influences of the non dimensional governing parameters, magneticfield parameter M, heat source/sink parameter Q_H , thermophoresis parameter Nt , Brownian motion parameter Nb etc. on the velocity, temperature and concentration profiles. For the numerical results we considered the non-dimensional parameters as $\Pr = 6.2, Nb = 0.1, Nt = 0.1, Le = 1,$ $Q_H = 0.5, M = 1, Kr = .2, n = 1.5,$. These values are kept as constant in entire study except the varied values as shown in respective graphs.

Figs. 1-3 exhibits effect of magnetic field parameter on velocity temperature and concentration. It is evident that increase in magnetic field parameter decreases the velocity profiles. Generally, an increase in magnetic field generates the opposite force to the flow, called Lorentz force. This force causes to reduce the momentum boundary layer. It is also observed that an increase in magnetic field parameter increases the temperature and concentration. The reason behind this is increasing in magnetic field enhances the boundary layer thickness of thermal and concentration. The similar type of results has been observed for rising values of Casson parameter, which is displayed in Figs. 4-6.

Figs. 7 and 8 give the effect of the thermophoresis parameter on temperature and concentration fields. It is observed that the temperature profiles as well as the boundary layer thickness of the concentration field increases for increasing values of *Nt*. Figs. 9 and 10 represents the effect of Brownian motion parameter on temperature and concentration profiles. It is evident that the Brownian motion parameter have tendency to reduce the concentration field and enhance the temperature field.

Figs. 11 and 12 depict the effect of chemical reaction parameter and heat source/sink parameter on concentration and temperature fields respectively. It is clear that rising values of chemical reaction parameter and heat source/sink parameter declines the concentration and thermal boundary layer thicknesses. Generally, rising values of the heat source parameter enhance the fluid temperature. But in this study we observed a reverse trend that of expected. This concludes that Q_H is acts like heat observer.

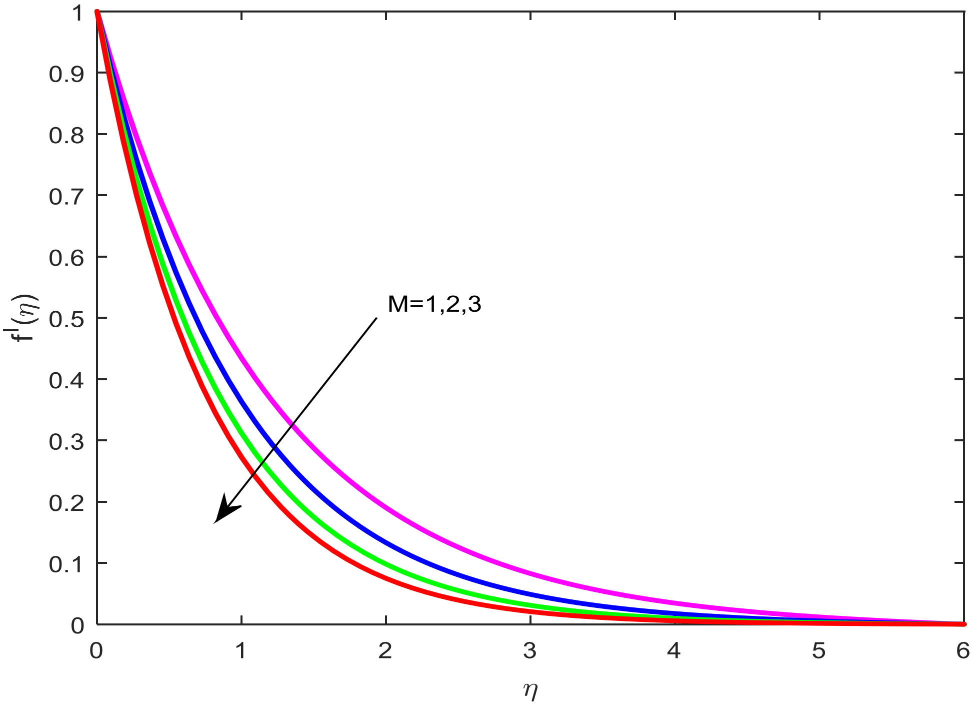

Fig.1 Velocity field for different values of M

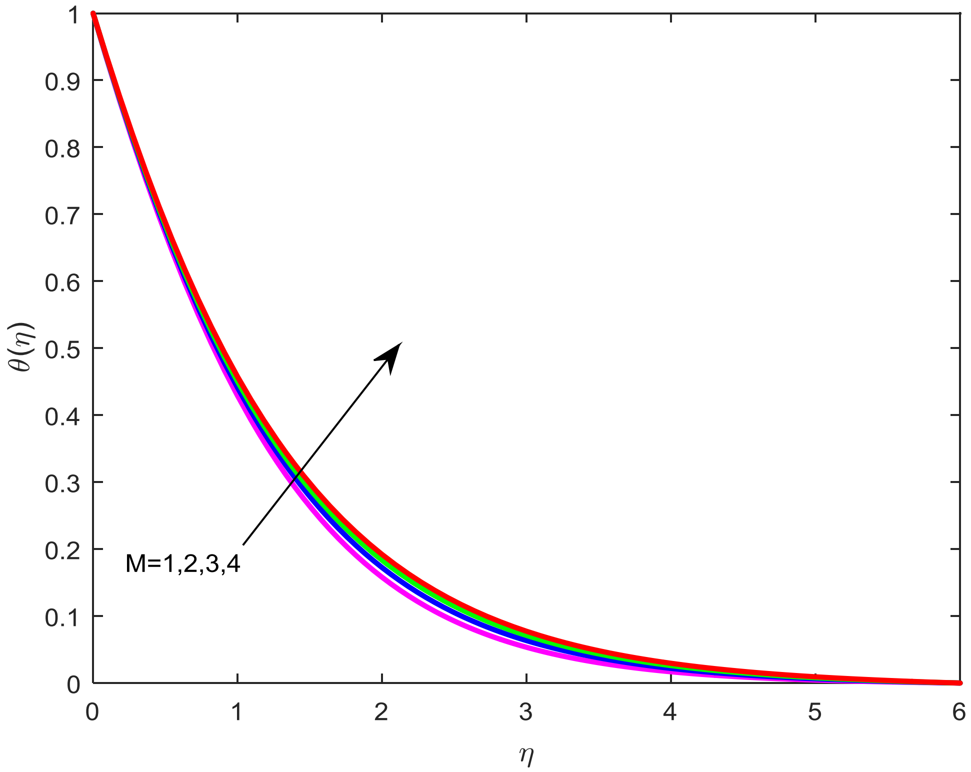

Fig.2 Temperature field for different values of M

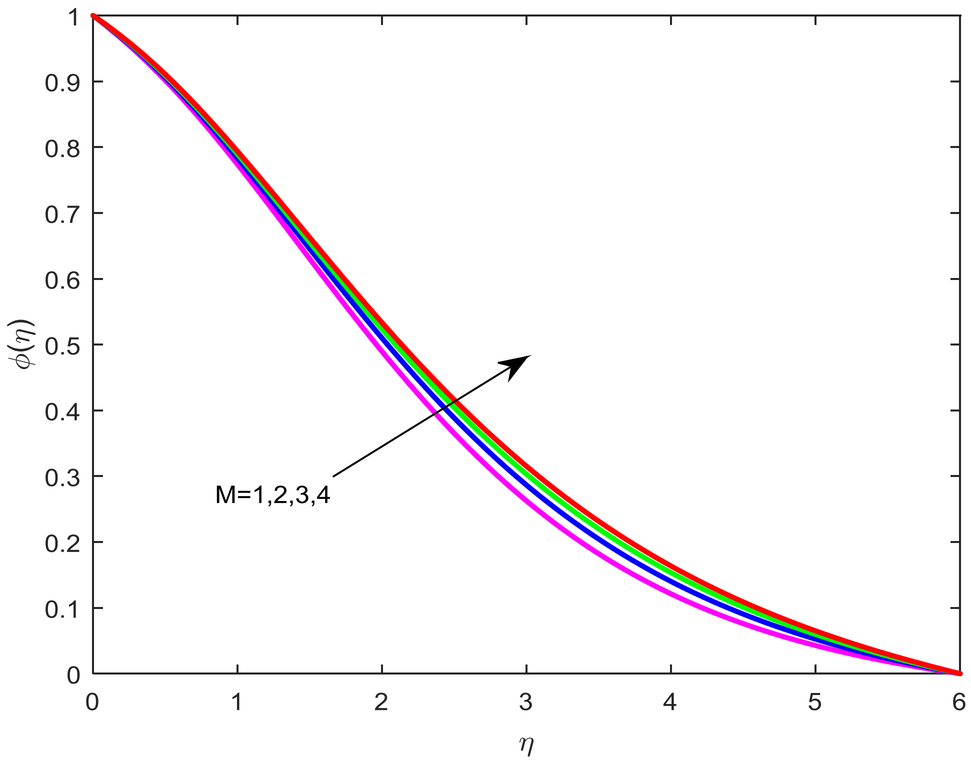

Fig.3 Concentration field for different values of M

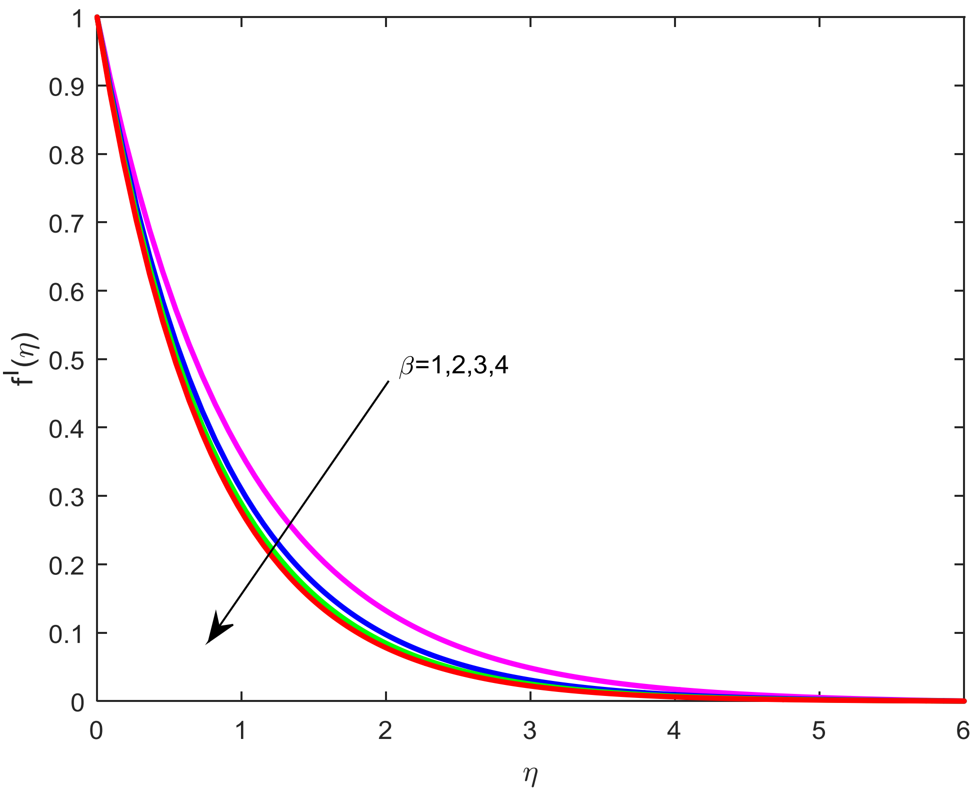

Fig.4 Velocity field for different values of β

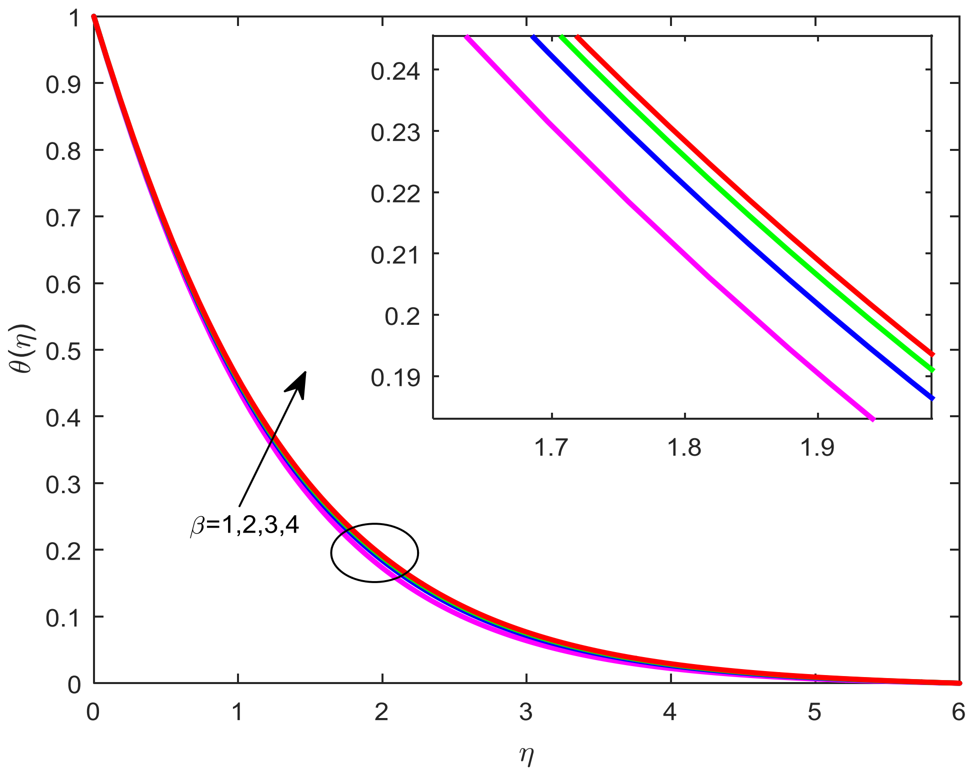

Fig.5 Temperature field for different values of β

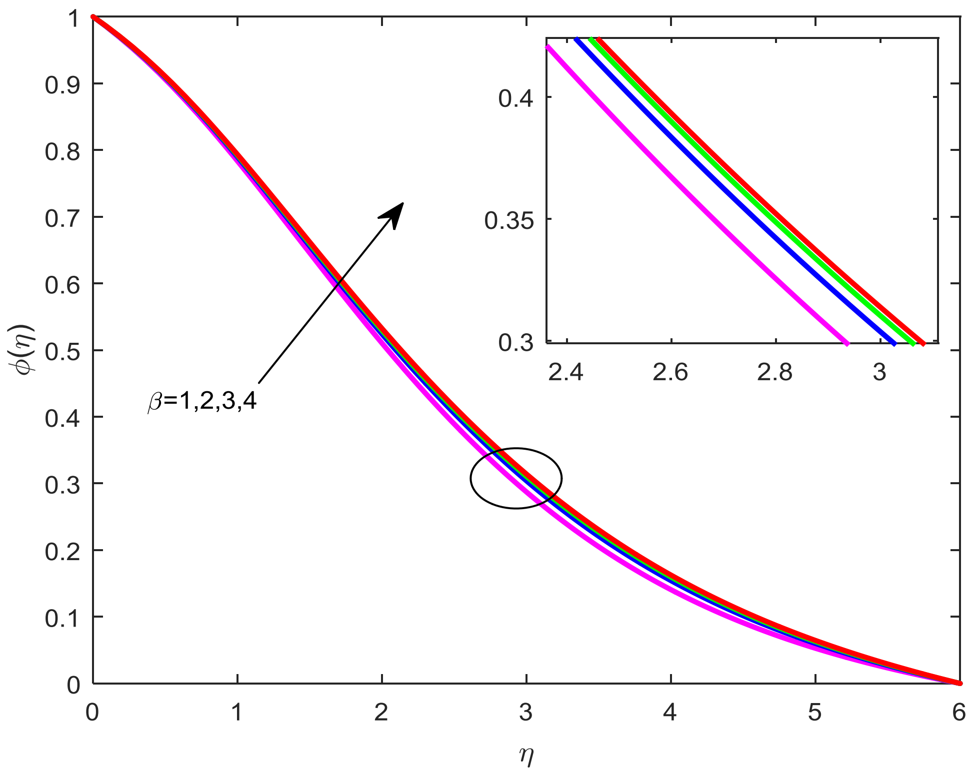

Fig.6 Concentration field for different values of β

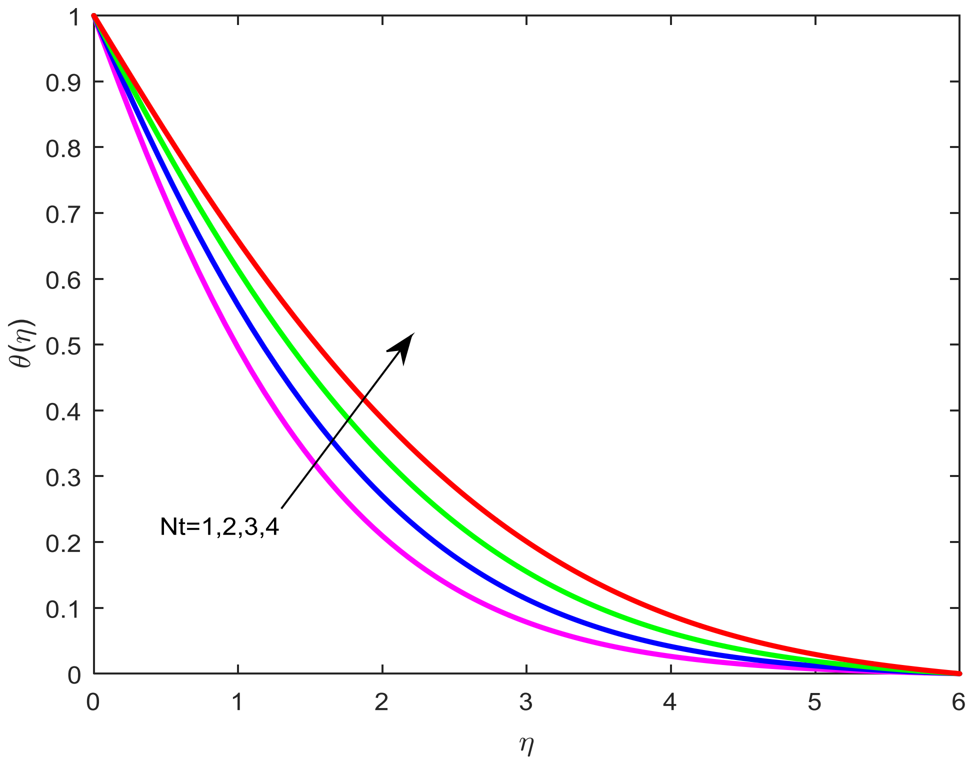

Fig.7 Temperature field for different values of *Nt*

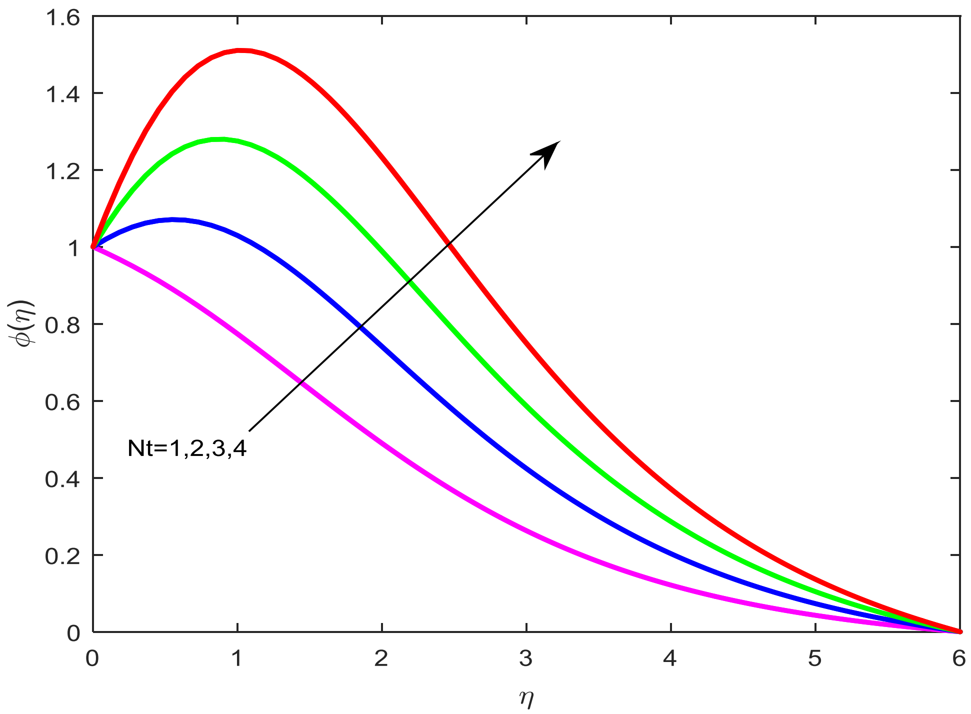

Fig.8 Concentration field for different values of *Nt*

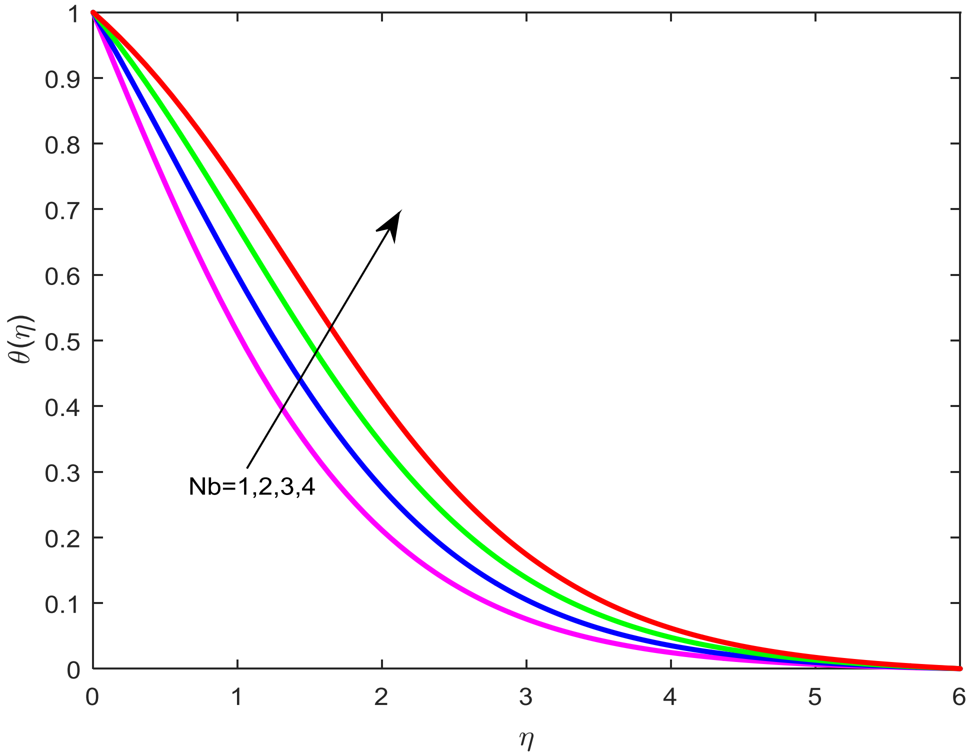

Fig.9 Concentration field for different values of *Nb*

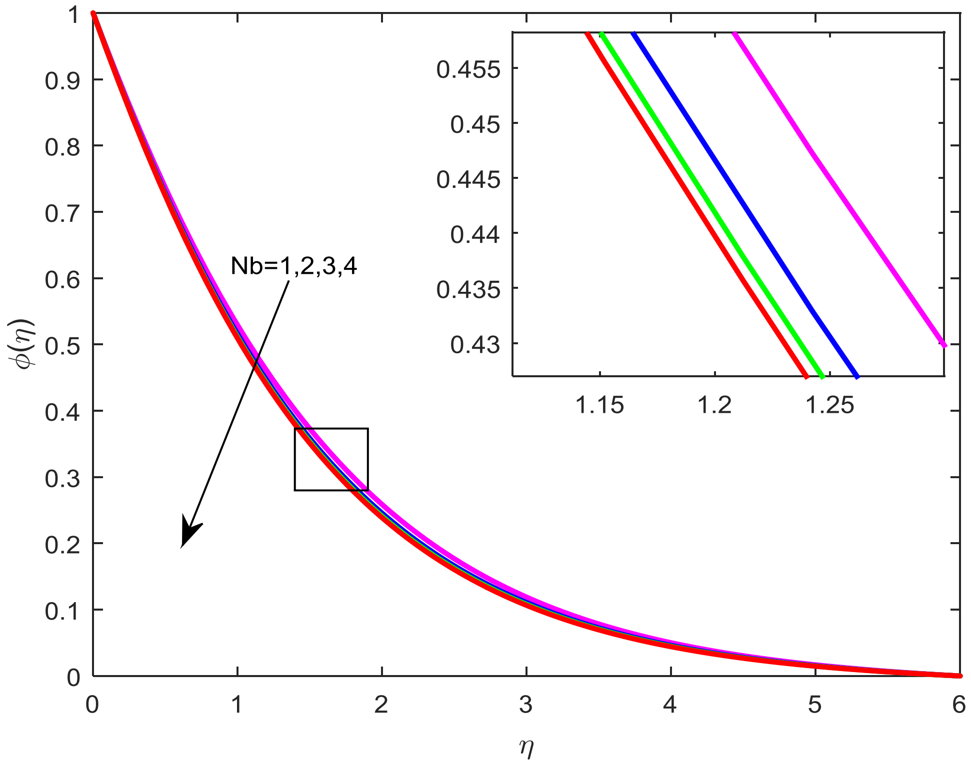

Fig.10 Concentration field for different values of *Nb*

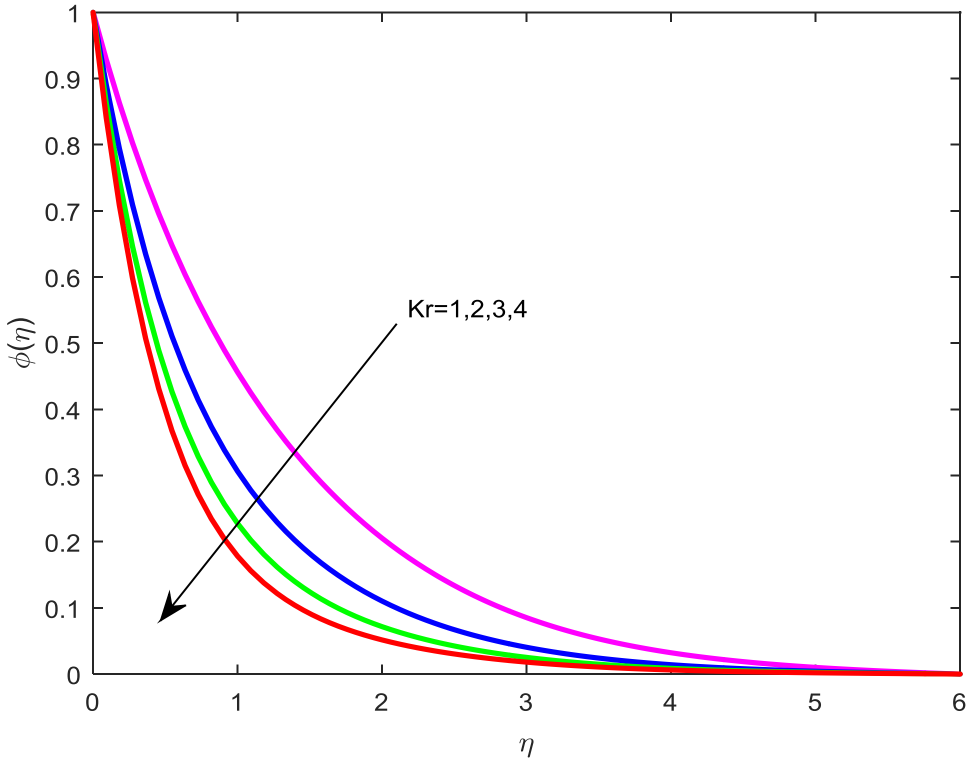

Fig.11 Concentration field for different values of *Kr*

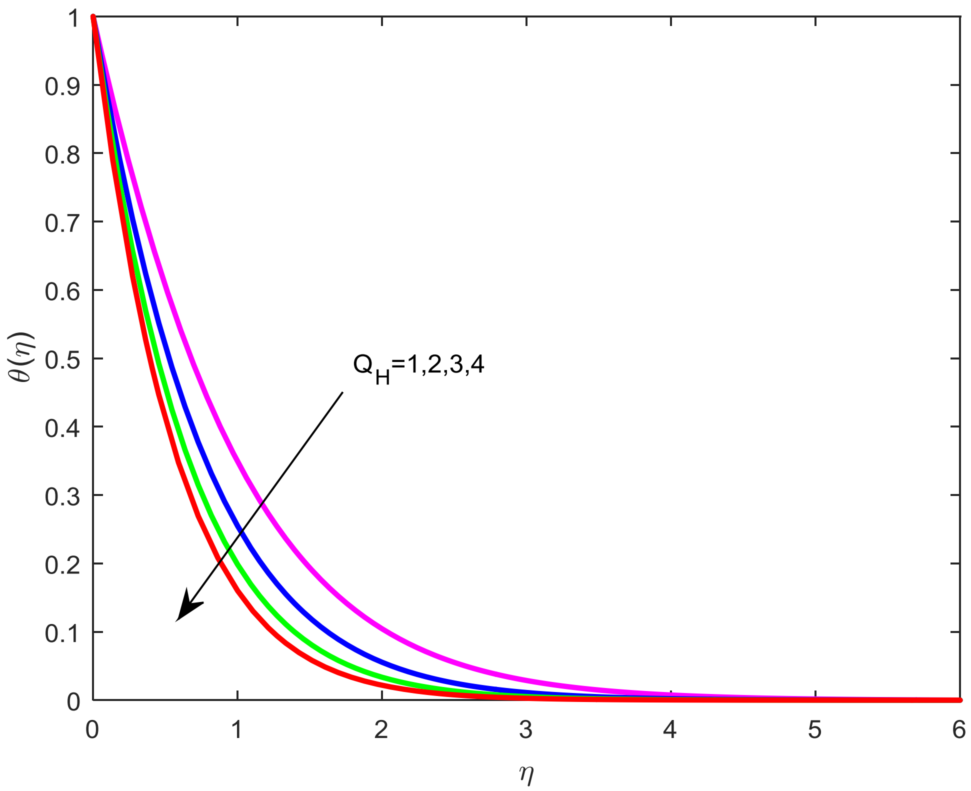

Fig.12 Temperature field for different values of Q_H

4. Conclusion

The effects of heat source/sink on boundary layer flow of a MHD Casson fluid past a nonlinear stretching sheet with thermophoresis and Brownian motion. The governing partial differential equations are transformed in to set of ordinary differential equations by using similarity transformation and solved numerically using bvp5c Matlab package. The effects of chemical reaction parameter, magnetic field parameter, heat source/sink, Brownian motion parameter and thermophoresis parameter on velocity, temperature and concentration profiles are discussed and presented through graphs.. Conclusions are as follows:

- Magnetic field parameter have tendency to control the thermal, concentration boundary layers.
- Thermophoresis parameter have tendency to enhance the temperature and concentration filed.
- Brownian motion parameters decline the concentration and increase the temperature filed.
- Rising values of heat source/sink parameter reduces the temperature filed.
- Casson parameter have tendency to enhance the temperature and concentration fields.

References

[1] M. Khan, A. Shazad, On boundary layer flow of a sisko fluid over a stretching sheet, Quaestiones Mathematicae 36 (2013) 137-151.

[2] N. Sandeep, V. Sugunamma, P. Mohan Krishna, Effects of radiation on an unsteady natural convective flow of a EG-Nimonic 80a nanofluid past an infinite vertical plate, Advances in Physics Theories and Applications 23 (2013) 36-43.

[3] C.Sulochana, N.Sandeep, Stagnation-point flow and heat transfer behaviour of Cu-water nanofluid towards horizontal and exponentially stretching/shrinking cylinders, Applied Nanoscience 5 (2015) DOI: 10.1007/s13204-015-0451-5.

[4] M. Jayachandra Babu, R. Gupta, N.Sandeep, Effect of radiation and viscous dissipation on stagnation-point flow of a micropolar fluid over a nonlinearly stretching surface with suction/injection, J. Basic and App.Res. Int.7 (2) (2015) 73-82.

[5] N. Sandeep, C. Sulochana, Dual solutions for unsteady mixed flow of MHD micro polar fluid over a stretching/shrinking sheet with non-uniform heat source/sink, Engineering Science and Technology an International. 18 (2015) 738-745.

[6] N. Sandeep, C. Sulochana, C. S. K. Raju, M. Jayachandrababu, V. Sugunamma, Unsteady boundary layer flow of thermophoretic MHD nano fluid past a stretching sheet with space and time dependent internal heat source/sink, Applications & Applied Mathematics, 10(1) (2015) 312-327.

[7] J.V.Ramana Reddy, V.Sugunamma, N.Sandeep, Thermo diffusion and hall current effects on an unsteady flow of a nanofluid under the influence of inclined magnetic field, Int.J.Eng. Resaech in Afrika , 20 (2016) 61-79.

[8] C.S.K.Raju, N.Sandeep, Dual solutions for unsteady heat and mass transfer in bio-convection flow towards a rotating cone/plate in a rotating fluid, Int.J.Eng. Resaech in Afrika, 20 (2016)161-176.

[9]. V.Sugunamma, J.V.Ramana Reddy, C.S.K.Raju, M.Jayachandra, N.Sandeep, Efffects of radiation and magnetic field on the flow and heat transfer of a nanofluid in a rotating frame. Industrial engineering letters 4(14) (2014) 8-20.

[10] N. Sandeep, C. Sulochana, C. S. K. Raju, M. Jayachandrababu, V. Sugunamma, Unsteady boundary layer flow of thermophoretic MHD nano fluid past a stretching sheet with space and time dependent internal heat source/sink, Applications & Applied Mathematics, 10(1) (2015) 312-327.

[11] N. Sandeep, V. Sugunamma, Effect of inclined magnetic field on unsteady free convective flow of dissipative fluid past a vertical plate, World Applied Sciences J., 22(7) (2013) 975-984.

[12] C. S. K. Raju, N. Sandeep, V. Sugunamma, M. Jayachandrababu, J. V. Ramanareddy, Heat and mass transfer in magneto hydrodynamic Casson fluid over an exponentially permeable stretching surface, Eng. Sci. Tech., an Int. J. , http://dx.doi.org/10.1016/j.jestch.2015.05.010.

[13] N. Sandeep, C. Sulochana, Dual solutions of radiative MHD nanofluid flow over an exponentially stretching sheet with heat generation/absorption, Applied Nanoscience, (2015) 1-9, DOI: 10.1007/s13204-015-0420-z.

[14] N. Sandeep, C. Sulochana, Dual solutions for unsteady mixed flow of MHD micro polar fluid over a stretching/shrinking sheet with non-uniform heat source/sink, Engineering Science and Technology an International. 18 (2015) 738-745.

[15] I. L. Annimasun, C. S. K. Raju, N. Sandeep, Unequal diffusivities case of homogeneous–heterogeneous reactions within viscoelastic fluid flow in the presence of induced magnetic-field and nonlinear thermal radiation, Alexandia Engineering Journal, (2016) , In press, http://dx.doi.org/10.1016/j.aej.2016.01.018.

[16] C. S. K. Raju, N. Sandeep, M. Jayachandrababu, V. Sugunamma, Dual solutions for three-dimensional MHD flow of a nanofluid over a nonlinearly permeable stretching sheet, Alexandria Engineering Journal, 55(1) (2016) 151-162.

[17] C. S. K. Raju, M. Jayachandrababu, N. Sandeep, Chemically reacting radiative MHD Jefferey nanofluid flow over a cone in porous medium, Int. J. Eng. Res. Africa 19 (2016) 75-90.

[18] P.Mohankrishna, V.Sugunamma, N.Sandeep, Radiation and magneticfield effects on unsteady natural convection flow of a nanofluid past an infinite vertical plate with heat source, Chemical and Process Engineering Research 25 (2014) 39-52.

[19] N.Sandeep, A.V.B Reddy, V.Sugunamma, Effect of radiation and chemical reaction on transient MHD free convective flow over a vertical plate through porous media, Chemical and process engineering Research 2 (2012) 1-9.

[20] N.Sandeep and V.Sugunamma, Radiation and Inclined Magnetic Field Effects on Unsteady Hydromagnetic Free Convection Flow past an Impulsively Moving Vertical Plate in a Porous Medium, Journal of Applied Fluid Mechanics 7 (2) (2014) 275-286.

[21] C.Sulochana, J.Prakash, N.Sandeep, Unsteady MHD flow of a dusty nanofluid past a vertical stretching surface with non-uniform heat source/sink, Int.J. Science and Eng. (In Press) (2016).

[22] C.Sulochana, S.P.Samrat, N.Sandeep, Non-uniform heat source or sink effect on the flow of 3D Casson fluid in the presence of Soret and thermal radiation, Int.J.Eng. Resaech in Afrika, 20 (2016) 112-129.

[23] N.Sandeep, C.Sulochana, I.L.Animasaun, Stagnation-point flow of a Jeffrey nano fluid over a stretching surface with induced magnetic field and chemical reaction, Int.J.Eng. Resaech in Afrika, 20 (2016) 93-111.
[24] I.L. Animasaun, Effects of thermophoresis, variable viscosity and thermal conductivity on free convective heat and mass transfer of non-darcian MHD dissipative Casson fluid flow with suction and nth order of chemical reaction, Journal of the Nigerian Mathematical Society, 34 (2015) 11–31.
[25] I. L. Animasaun, Dynamics of Unsteady MHD Convective Flow with Thermophoresis of Particles and Variable Thermo-Physical Properties past a Vertical Surface Moving through Binary Mixture, Open Journal of Fluid Dynamics, 5 (2015) 106-120.
[26] I. L. Animasaun, Casson Fluid Flow of Variable Viscosity and Thermal Conductivity along Exponentially Stretching Sheet Embedded in a Thermally Stratified Medium with Exponentially Heat Generation, Journal of Heat and Mass Transfer Research, in-press. (2015)