Radiation and Chemical Reaction Effects on MHD Thermosolutal Nanofluid Flow over a Vertical Plate in Porous Medium

C.Sulochana* M.K.Kishor Kumar N.Sandeep
Department of Mathematics, Gulbarga University, Gulbarga-585106, India
Email: math.sulochana@gmail.com

Abstract
In this study we discussed the influence of radiation and chemical reaction on MHD thermosolutal nanofluid convective slip flow over a vertical plate in porous medium in presence of thermophoresis and Brownian motion effects. The governing boundary layer partial differential equations are transformed into system of ordinary differential equations by using similarity transformation and then solved numerically using bvp5c Matlab package. The effects of dimensionless governing parameters on the flow, heat and mass transfer was discussed and presented through graphs. Also, the skin friction coefficient and local Nusselt and Sherwood numbers are computed and discussed. Results indicate that an increase in chemical reaction parameter enhances the mass transfer rate.
Keywords: MHD, Radiation, Chemical Reaction, Nanofluid, Convection.

1. Introduction

Recently there has been an affordable amount of work carried out by scientists/researchers on radiative heat transfer in nanofluids due to their abundant applications. Particularly, the conception of radiative heat transfer is extremely employed in nanofluid solar collectors. Nanofluid transport in porous media has developed into a substantial area of research in recent years. The study of heat transfer in the presence of nanofluids is of great practical importance in engineering and sciences because many branches of science and engineering using cooling applications of nanofluids.

The mathematical modelling of radiative hydromagnetic thermal radiation processing of a nonmaterial fluid sheet extruded in porous media was discussed by Uddin et al. (2014). Radiative heat transfer of nanofluids over a nonlinearly stretching surface with thermal radiation in the presence of variable heat generation and viscous dissipation along with variable temperature is investigated by Anjali Devi and Mekala Selvaraj (2013). The study of mixed convection heat transfer over an inclined flat plate in a porous medium was discussed by Rasekh and Ganji (2013). The effect of local thermal non-equilibrium on transient MHD laminar boundary layer flow of viscous, incompressible nanofluid over a moving surface in a saturated porous media was discussed by Muthtamilselvan et al. (2014). A numericai and analytical study of the magnerohydrdynamic mixed convection flow of nanofluid over a nonlinear stretching inclined transparent plate embedded in a porous medium under the solar radiation examined by Meisam Habibi Matin and Reza Hosseini (2014). The entropy generation of magnetohydrodynamic mixed convection flow of nanofluid over a nonlinear stretching inclined transparent plate embedded in a porous medium due to solar radiation is investigated numerically by Mohammad Dehsara et al. (2013). The study of mixed convection flow over a vertical cone embedded in a porous medium saturated with nanofluid in the presence of thermal radiation was analyzed by Ali J. Chamkha et al. (2012).

The effect of the complex interactions between the electrical conductivity of the conventional base fluid and the nano particles under the influence of magnetic field in a boundary layer flow with heat transfer over a convectively heated flat surface was stated by Oluwole Daniel and Winifred Nduku (2014). The study of heat and mass transfer in copper and silver nanofluid flow over stretching sheet placed in saturated porous medium with internal heat generation or absorption was discussed by Kameswaran et al. (2013). The magnetic field, radiation and soret effect of a nanofluid flow over a moving vertical plate in porous medium was analyzed by Raju et al. (2015). The effects of aligned magnetic field, radiation and rotation on unsteady hydromagnetic free convection flow of a viscous incompressible electrically conducting fluid past an impulsively moving vertical plate in a porous medium in presence of heat sources analyzed by Sandeep et al. (2014). The heat transfer characteristics of a two dimensional steady of hydromagnetic natural convection flow of a nanofluid over a non linear stretching sheet taking in to account the effects of radiation and convective boundary conditions has been investigated numerically by Rahman and Eltayed (2012).

The heat and mass transfer in thermophoretic radiative hydromagnetic nanofluid flow over an exponentially stretching porous sheet embedded in porous medium with internal heat generation/absorption, viscous dissipation and injection effects was illustrated by Sandeep and Sulochana (2015). The mixed convection flow of magnetohydrodynamic Jeffrey nanofluid over a radially stretching surface with radiative surface is studied and convective boundary conditions through heat and mass are employed by Bilal Ashraf et al. (2015). A numerical investigation of unsteady magnetohydrodynamic mixed convective boundary layer flow of a nanofluid over an exponentially stretching sheet in porous medium is presented by Anwar et al. (2013). Very recently the researchers Raju et al. ((2015a), (2015b)) Mohankrishna et al. ((2013), (2014)), Sandeep et al. ((2012), (2013)), Ramana Reddy et al. (2014), Sugunamma et al. (2011) discussed the influence of radiation on MHD flows through different channels.

In this study we discussed the influence of radiation and chemical reaction on MHD thermosolutal nanofluid convective slip flow over a vertical plate in porous medium in presence of thermophoresis and Brownian motion effects. The governing boundary layer partial differential equations are transformed into system of ordinary differential equations by using similarity transformation and then solved numerically using bvp5c Matlab package. The effects of dimensionless governing parameters on the flow, heat and mass transfer was discussed and presented through graphs. Also, the skin friction coefficient and local Nusselt and Sherwood numbers are computed and discussed.

2. Mathematical formulation

Consider a steady, two-dimensional, incompressible flow of a nanofluid over a vertical sheet. The $\overline{x}$ -axis aligned horizontally and the $\overline{y}$ -axis is normal to it. A transverse magnetic field of strength B_0 acts normal to the bounding surface. The magnetic Reynolds number is small so that the induced magnetic field is negligible when compared to the applied magnetic field. It is further assumed that the left of the plate is heated by the convection from the hot fluid of temperature $T_f\,(>T_w>T_\infty)$ which provides a variable heat transfer coefficient $h_f(\overline{x})$. Consequently a thermal convective boundary condition arises. It is further assumed that the concentration in the left of the plate C_f is higher than that of the plate concentration C_w and free stream concentration C_∞ which provides a variable mass transfer coefficient $h_m(\overline{x})$. Chemical reaction effect along with the buoyancy forces are taken into account. The boundary layer equations as per the above assumptions are given by

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

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

$$\overline{u}\frac{\partial T}{\partial \overline{x}}+\overline{v}\frac{\partial T}{\partial \overline{y}}=\alpha\frac{\partial^2 T}{\partial \overline{y}^2}+\tau\left\{D_B\frac{\partial C}{\partial \overline{y}}\frac{\partial T}{\partial \overline{y}}+\left(\frac{D_T}{T_\infty}\right)\left(\frac{\partial T}{\partial \overline{y}}\right)^2\right\}-\frac{1}{(\rho c_p)_f}\frac{\partial q_r}{\partial \overline{y}}, \tag{3}$$

$$\overline{u}\frac{\partial C}{\partial \overline{x}}+\overline{v}\frac{\partial C}{\partial \overline{y}}=D_B\frac{\partial^2 C}{\partial \overline{y}^2}+\left(\frac{D_T}{T_\infty}\right)\frac{\partial^2 T}{\partial \overline{y}^2}-k_0(C-C_\infty), \tag{4}$$

The appropriate boundary conditions are

$$\overline{u}=\overline{u}_\omega+\overline{u}_{slip},\overline{v}=0,-k\frac{\partial T}{\partial \overline{y}}=h_f\left(T_f-T\right),-D_B\frac{\partial C}{\partial \overline{y}}h_m\left(C_f-C\right),\quad at\quad \overline{y}=0,$$
$$\overline{u}\to 0,\qquad T\to T_\infty,\qquad C\to C_\infty\qquad as\ \ \overline{y}\to\infty, \tag{5}$$

where $\alpha=k/\left(\rho c\right)_f$:thermal diffusivity of the fluid, $\tau=\left(\rho c\right)_p/\left(\rho c\right)_f$:ratio of heat capacity of the nano particle and fluid, K_p : Permeability of the medium, $\left(\overline{u},\overline{v}\right)$: velocity components along $\overline{x}$ and $\overline{y}$ axes, $\overline{u}_\omega=U_r\left(\overline{x}/L\right)$: velocity of the plate, L:characteristic length of the plate, $\overline{u}_{slip}=N_1\upsilon\left(\partial\overline{u}/\partial\overline{y}\right)$: linear slip velocity, ρ_f :density of the based fluid , σ :electric conductivity, μ :dynamic velocity of the base fluid, ρ_p :density of the nano particles, $\left(\rho c_p\right)_f$:effective heat capacity of the fluid, $\left(\rho C_p\right)_p$:effective heat capacity of the nano particle material, ε :porosity, D_B :Brownian diffusion coefficient, D_T : thermophoretic diffusion coefficient, and q_r :radiative heat transfer in $\overline{y}$ -direction. We consider fluid to be a gray, absorbing-emitting but non-scattering medium. We also assume that the boundary layer is optically thick and the Rosseland approximation or diffusion approximation for radiation is valid. Thus, the radiative heat flux for an optically thick boundary layer (with intensive absorption), as elaborated by Sparrow and Cess, is defined as

$q_r = -(4\sigma_1 / 3k_1)(\partial T^4 / \partial \overline{y})$, where σ_1 (=$5.67\times 10^{-8}\ W/m^2K^4$) is the Stefan-Boltzmann constant and $k_1\left(m^{-1}\right)$ is the Rosseland mean absorption coefficient. Purely analytical solutions to the partial differential boundary value problem defined by (1)-(4) are not possible. Even a numerical solution is challenging. Here we aim to transform the problem to a system of ordinary differential equations. We define the following dimensionless transformation variables:

$$\eta = \frac{\overline{y}}{\sqrt{K_p}}, \qquad \psi = U_r \frac{\overline{x}}{L}\sqrt{K_p}\, f(\eta), \qquad \theta(\eta) = \frac{T - T_\infty}{T_f - T_\infty}, \qquad \phi(\eta) = \frac{C - C_\infty}{C_f - C_\infty}, \tag{6}$$

where L is the characteristic length. From (6), we have $T = T_\infty\left\{1 + (T_r - 1)\theta\right\}$, where $T_r = T_f / T_\infty$ (the wall temperature excess ratio parameter) and hence $T^4 = T_\infty^4\{1 + (T_r - 1)\theta\}^4$. Substitution of (6) into (2)-(4) generates the following similarity equations:

$$f''' + \operatorname{Re} Da(ff'' - f'^2 - Mf') + Gr\theta + Gc\phi - f' = 0, \tag{7}$$

$$\theta'' + \operatorname{Re}\Pr Da\, f\theta' + \Pr[Nb\theta'\phi' + Nt\theta'^2] + \frac{4}{3R}\left(\left\{1 + (T_r - 1)\theta\right\}^3 \theta'\right)' = 0, \tag{8}$$

$$\phi'' + Le\operatorname{Re} Da\, f\phi' + \frac{Nt}{Nb}\theta'' - Kr\phi = 0. \tag{9}$$

The relevant boundary conditions are

$$f(0) = 0, f'(0) = 1 + af''(0), \theta'(0) = -Nc\left[1 - \theta(0)\right], \phi'(0) = -Nd\left[1 - \phi(0)\right],$$
$$f'(\infty) = \theta(\infty) = \phi(\infty) = 0, \tag{10}$$

where primes denotes differentiation with respect to η. The thermophysical dimensionless parameters arising in (5)-(8) are defined as follows: $\operatorname{Re} = U_r L / \upsilon$ is the Reynolds number, $Da = K_p / L^2$ is the Darcy number, $M = \sigma B_0^2 L / U_r \rho_f$ is the magnetic parameter, $Gr = g\beta(T_f - T_\infty)L^2 / U_r^2 x, Gc = g\beta^*(C_f - C_\infty)L^2 / U_r^2 x$ are the thermal and mass Grashof numbers, $\Pr = \upsilon / \alpha$ is the Prandtl number, $Nt = \tau D_T(T_f - T_\infty) / \upsilon T_\infty$ is the thermophoresis parameter, $Nb = \tau D_B(C_f - C_\infty) / \upsilon$ is the Brownian motion parameter, $R = kk_1 / 4\sigma_1 T_\infty^3$ is the convection-radiation parameter, $Le = \upsilon / D_B$ is the Lewis number, $a = N_1\upsilon / \sqrt{K_p}$ is the hydrodynamic (momentum) slip parameter, $Nd = h_m\sqrt{K_p} / D_B$ is the convection-diffusion parameter, $Kr = k_0 L / U_r$ is the chemical reaction parameter and $Nc = h_f\sqrt{K_p} / k$ is the convection-conduction parameter.

Quantities of physical interest are the local friction factor, $C_{f\overline{x}}$, the local Nusselt number, $Nu_{\overline{x}}$, and the local Sherwood number, $Sh_{\overline{x}}$. Physically, C_{fx} represents the wall shear stress, $Nu_{\overline{x}}$ defines the heat transfer rates, and $Sh_{\overline{x}}$ defines the mass transfer rates:

$$C_{fx}\operatorname{Re}_x^{-1} Da_x^{0.5} = 2f''(0), \tag{11}$$

$$Nu_{\overline{x}} Da_{\overline{x}}^{0.5} = -\left[1 + \frac{4}{3R}\left\{1 + (T_r - 1)\theta(0)\right\}^3\right]\theta'(0), \tag{12}$$

$$Sh_{\overline{x}} Da_{\overline{x}}^{0.5} = -\phi'(0), \tag{13}$$

where $Da_{\overline{x}} = K_p / \overline{x}^2$ the local Darcy is number for Darcian porous media and $\operatorname{Re}_{\overline{x}} = \overline{u}_\omega \overline{x} / \upsilon$ is the local Reynolds number.

3. Results and Discussion

The coupled ordinary differential equations (7) to (9) subject to the boundary conditions (10) are solved numerically using bvp5c Matlab Package. The results obtained shows the influences of the non dimensional governing parameters, namely magneticfield parameter M , thermal Grashof number Gr , radiation parameter R , chemical reaction parameter Kr , Darcy number Da , Reynolds number Re on velocity, temperature and concentration profiles of the flow. Also, friction factor, local Nusselt and Sherwood numbers are discussed and presented through tables. For numerical results, we considered $Nb = Nt = Kr = 0.1, a = 0.01,$

$M = \mathrm{Re} = Nc = Nd = R = Gr = Gc = 1, \mathrm{Da} = 0.5, \mathrm{T}_r = Le = 2, \mathrm{Pr} = 6.8$. These values kept as common in entire study except the varied values as shown in figures.

Figs. 1-3 show the influence of magneticfiled parameter on velocity, temperature and concentration profiles of the flow. It is clear that an increase in the magneticfield parameter decreases the velocity and increases the temperature and concentration profiles of the flow. This is due to the Lorentz's for acts opposite to the flow direction. Figs. 4and 5 depicts the effect of thermal Grashof number on temperature and concentration profiles of the flow. It is evident that with the increase in thermal Grashof number we observed depreciation in the temperature and concentration profiles of the flow. This is due to the fact that an increase in thermal Grashof number develops the buoyancy forces; these forces reduce the thermal and concentration boundary layer thickness.

Figs. 6 and 7 illustrate the effect of radiation parameter on the velocity and temperature profiles of the flow. It is observed a hike in the velocity and temperature profiles for higher values of the radiation parameter. Generally, an increase in the radiation parameter releases the heat energy to the flow, these causes to develop the momentum and thermal boundary layer thickness. Figs. 8 and 9 show the influence of Darcy number on the velocity and temperature profiles of the flow. It is evident that an increase in the Darcy parameter depreciates the velocity and temperature profiles of the flow. Physically, increase in Darcy number implies a greater permeability in the porous medium. This corresponds to a decrease in presence of solid fibers and a reduction in thermal conduction heat transfer within the medium. Figs. 10 and 11 depict the effect of Reynolds umber on velocity and temperature profiles of the flow. With the increase in Reynolds number we noticed similar type of results as we observed in the Darcy case. Generally, increasing in the Reynolds number reduces the thermal and momentum boundary layers. Fig. 12 illustrates the effect of chemical reaction parameter on the concentration profiles of the flow. It is clear that an increase in the chemical reaction parameter declines the concentration profiles of the flow.

Table 1 displays the effects of non-dimensional governing parameters on the friction factor, local Nusselt and Sherwood numbers. It is evident from the table that with the increase in chemical reaction parameter, Darcy number and Reynolds number we noticed depreciation in friction factor and increase in heat and mass transfer rate. But we observed reverse results to above with the increase in radiation parameter. An increase in thermal Grashof number enhances the friction factor, local Nusselt and Sherwood numbers. But a raise in the magneticfield parameter showed reverse action to that of thermal Grashof number.

Table 1 Variation in $f''(0), -\theta'(0)$ and $-\phi'(0)$ for different non-dimensional parameters

M	Gr	R	Kr	Da	Re	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$
1						-0.671946	0.113243	0.459785
3						-1.072453	0.105760	0.441563
5						-1.407673	0.099547	0.429298
	1					-0.671946	0.113243	0.459785
	2					-0.244855	0.121033	0.474820
	3					0.153451	0.127546	0.486553
		1				-0.671946	0.113243	0.459785
		1.5				-0.215412	0.079769	0.012102
		2				0.034071	0.061770	-0.211648
			1			-0.788091	0.106925	0.608661
			2			-0.829229	0.105392	0.665820
			3			-0.849045	0.105095	0.696850
				0.5		-0.671946	0.113243	0.459785
				1.0		-1.208970	0.190577	0.502238
				1.5		-1.617532	0.292783	0.508662
					1	-0.671946	0.113243	0.459785
					2	-1.208970	0.190577	0.502238
					3	-1.617532	0.292783	0.508662

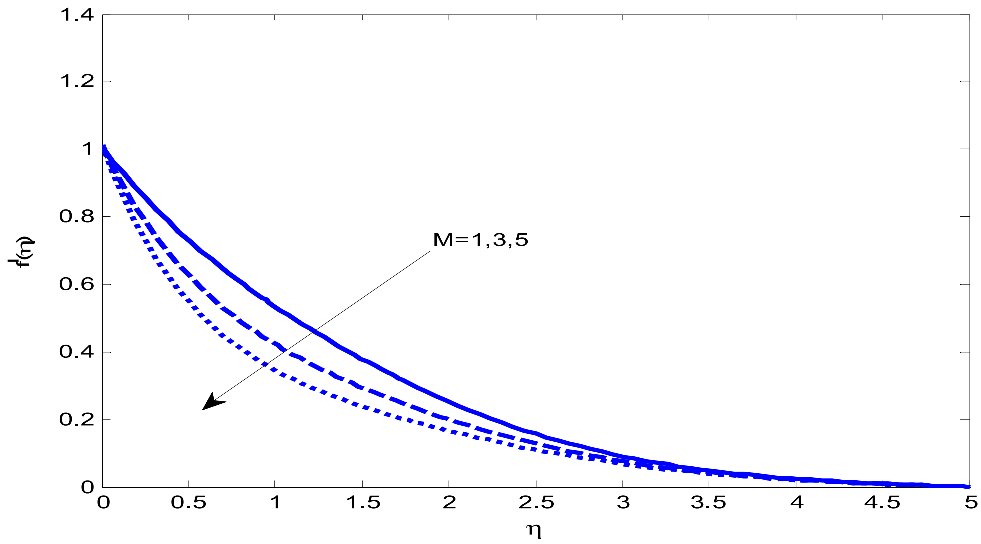

Fig.1 Velocity profiles for different values of

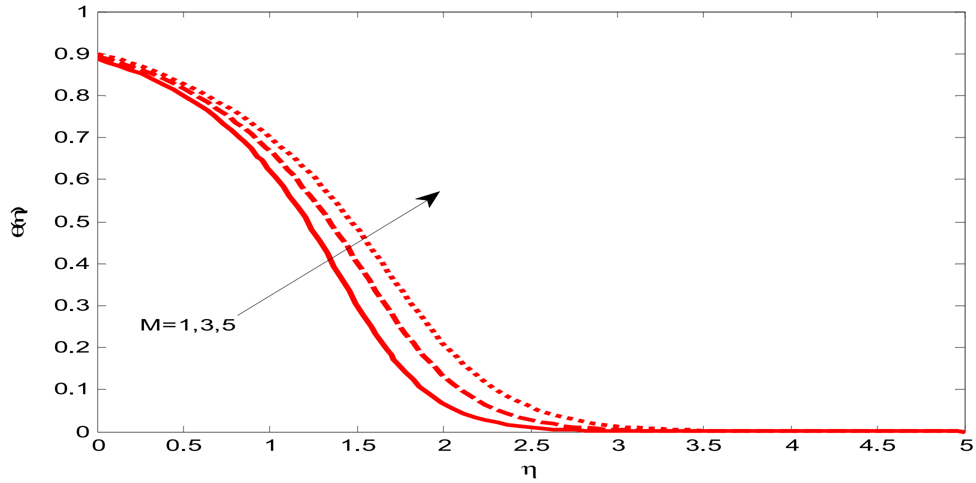

Fig.2 Temperature profiles for different values of

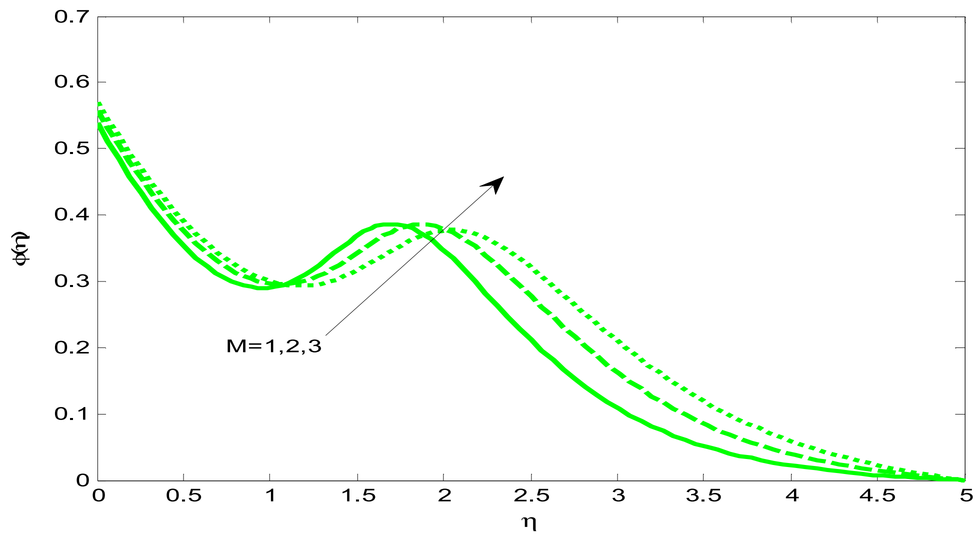

Fig.3 Concentration profiles for different values of

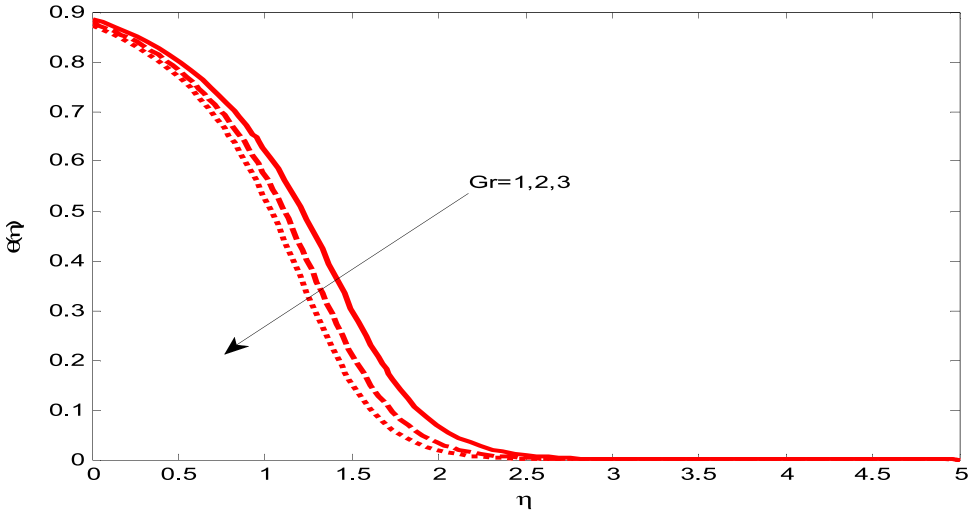

Fig.4 Temperature profiles for different values of

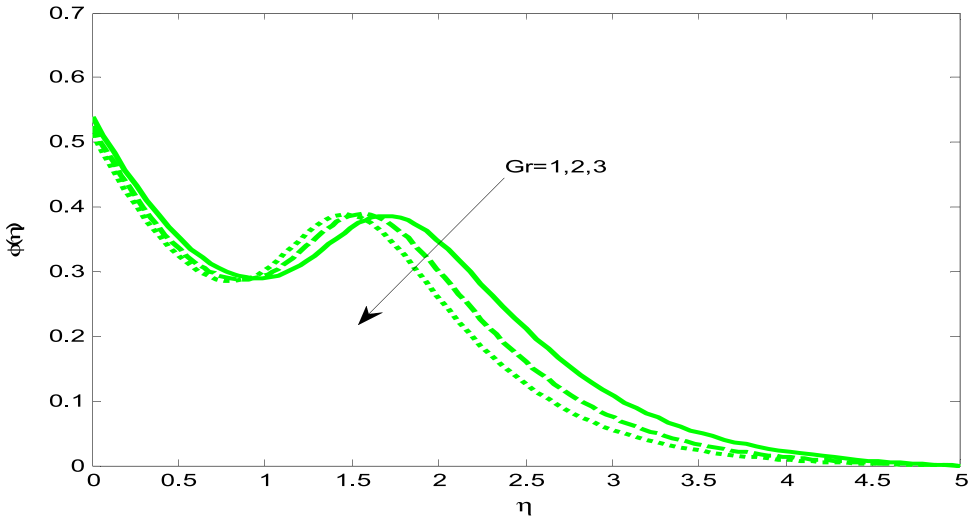

Fig.5 Concentration profiles for different values of

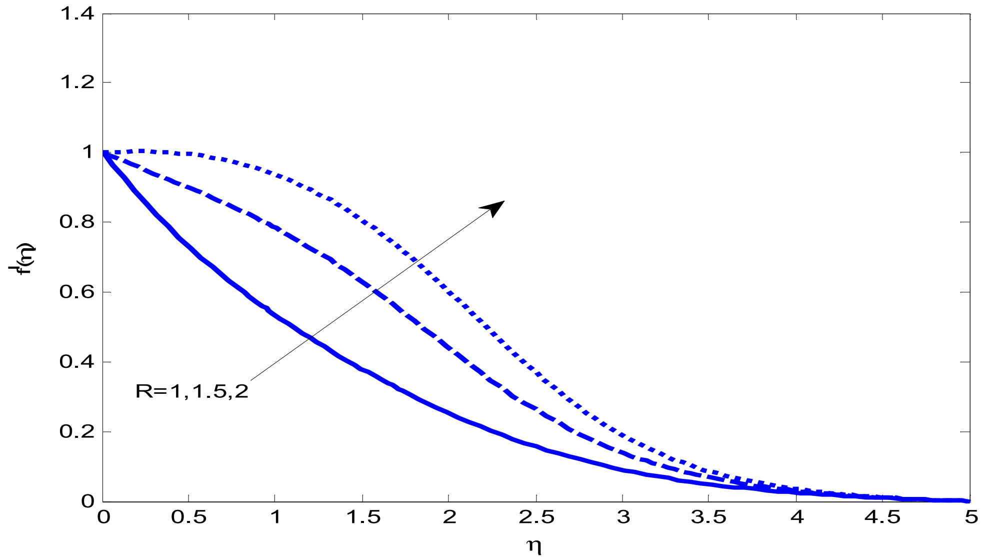

Fig.6 Velocity profiles for different values of

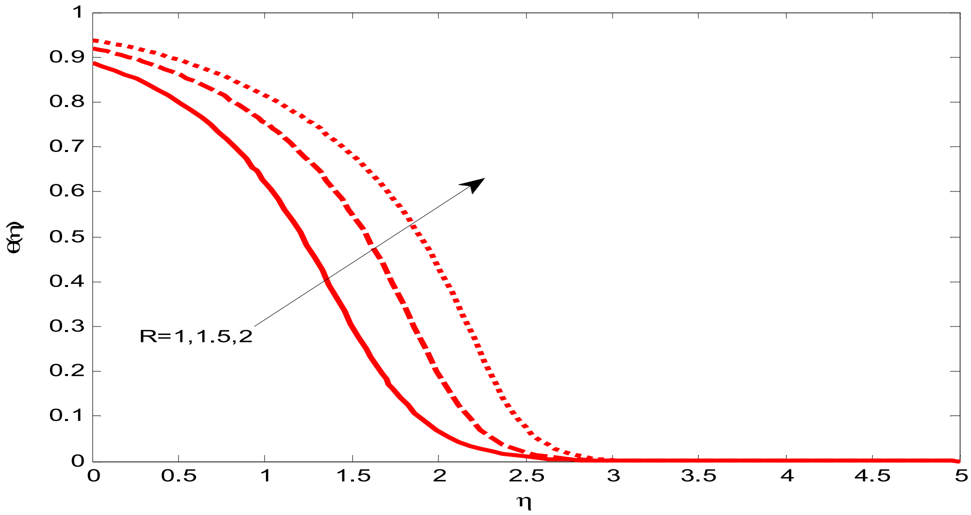

Fig.7 Temperature profiles for different values of

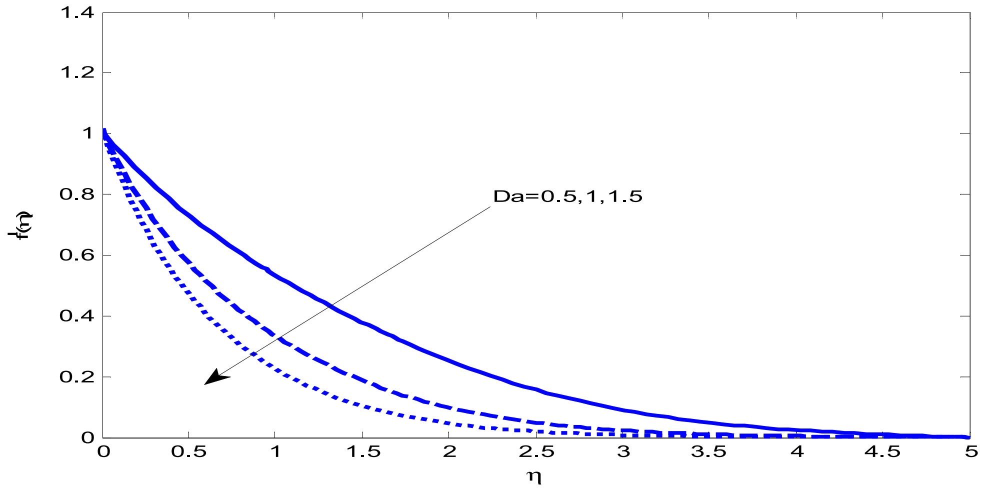

Fig.8 Velocity profiles for different values of

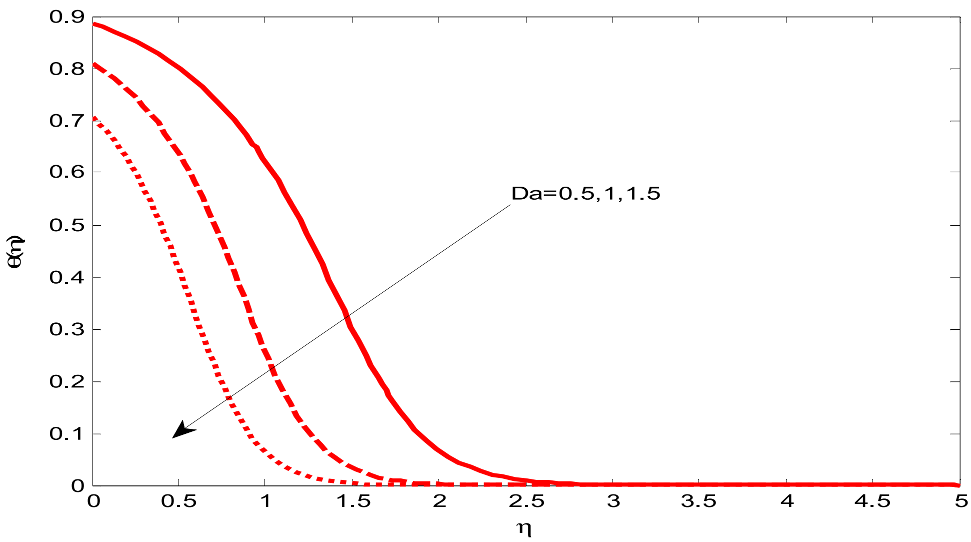

Fig.9 Temperature profiles for different values of

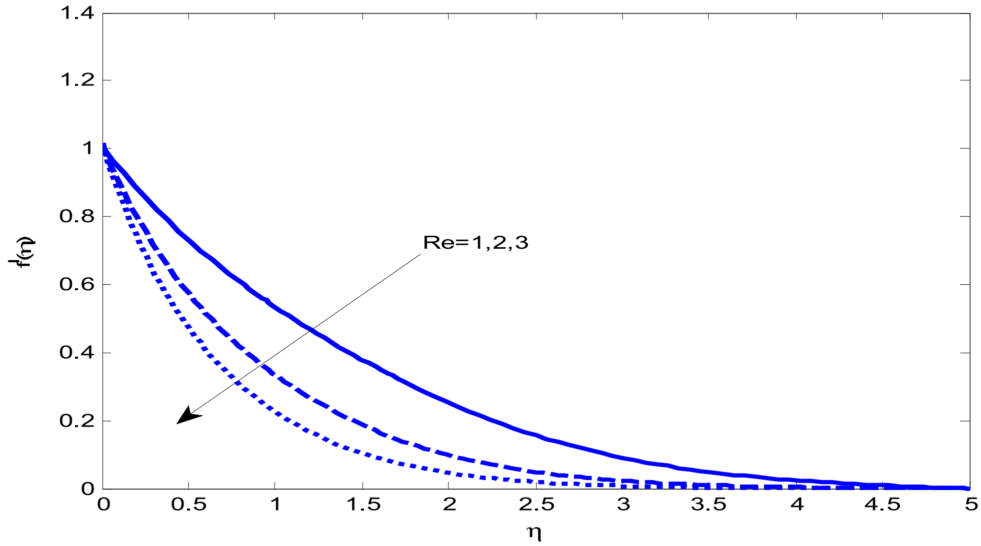

Fig.10 Velocity profiles for different values of

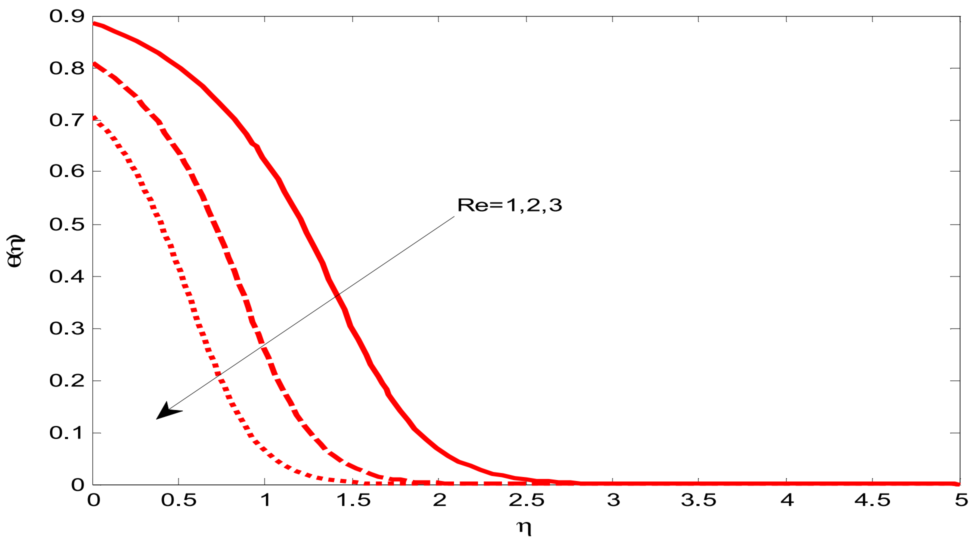

Fig.11 Temperature profiles for different values of

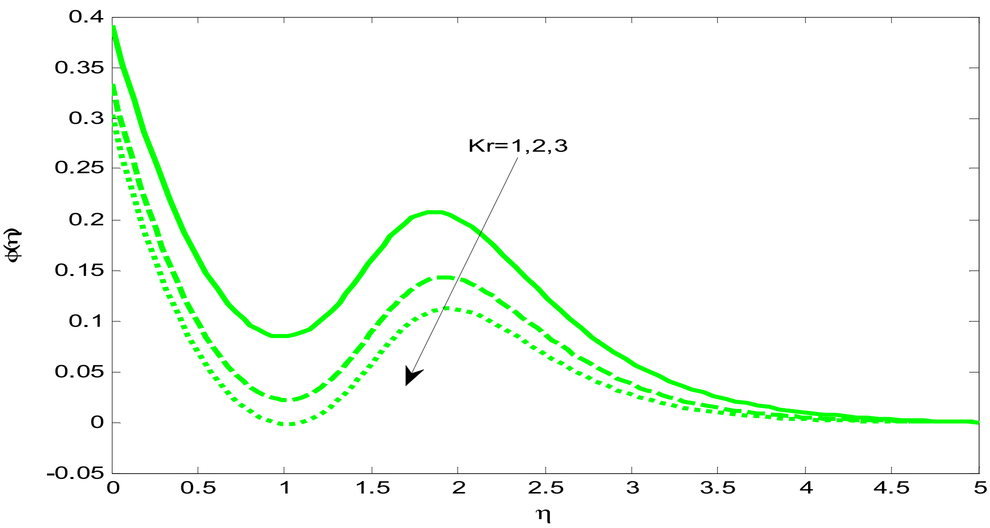

Fig.12 Concentration profiles for different values of

4. Conclusions

This study presents the effects of radiation and chemical reaction on MHD thermosolutal nanofluid convective slip flow over a vertical plate in porous medium in presence of thermophoresis and Brownian motion effects. The governing boundary layer partial differential equations are transformed into system of ordinary differential equations by using similarity transformation and then solved numerically using bvp5c Matlab package. The effects of dimensionless governing parameters on the flow, heat and mass transfer was discussed and presented through graphs. Also, the skin friction coefficient and local Nusselt and Sherwood numbers are computed and discussed. The conclusions of the present study are made as follows:

- An increase in magneticfiled parameter reduces the friction factor and heat and mass transfer rate.
- Darcy number have tendency to enhance the heat and mass transfer rate.
- A raise in the chemical reaction parameter reduces the friction factor and enhance the mass transfer rate.
- An increase in the radiation parameter enhances the momentum and thermal boundary layer thickness.

References

Ali J. Chamkha., Abbasbandy, S., Rashad, A.M., and Vajravelu, K. (2012). Radiation effects on mixed convection about a cone embedded in a porous medium filled with a nanofluid, *Meccanica Springer Science Business Media B.V,* 48, 275-285.

Ali J. Chamkha., Rashad, A.M., and Eisa Al-Meshiei. (2011). Melting Effect on Unsteady Hydromagnetic Flow of a Nanofluid Past a Stretching Sheet, *International Journal of Chemical Reactor Engineering,* 9.

Anjali Devi, S.P., and Mekala Selvaraj. (2013). Thermal radiation effects of hydromagnetic flow of nanofluid over a nonlinearly stretching sheet in the existence of variable heat generation and viscous dissipation, *International Journal of Science and Research (IJSR),* 4, 935-943.

Anwar Be´g, O., Khan, M.S., Ifsana Karim., Md. M. Alam., and Fedows, M. (2014). Explicit numerical study of steady hydromagnetic mixed convective nanofluid flow from an exponentially stretching sheet in porous media, *Applied Nanoscience,* 4, 943-957.

Bilal Ashraf, M., Hayat, T., Alsaedi, A., and Shehzad, S.A. (2015). Convective heat and mass transfer in MHD mixed convection flow of Jeffrey nanofluid over a radially stretching surface with thermal radiation, *Journal of Central south university springer.* 22, 1114- 1123.

Haibin Cheng., Pan Zhang., Qingjie Zgang., Jianfeng Wu., Yawen Dai., Wei Hu and Norman M.Wereley. (2014). Effects of surface modification on the stability of suspension and thermal conductivity enhancement of composite fe nanofluids, *IEEE Transactions on Magnetics,* 50(11).

Kameswaran, P.K., Makukula, Z.G., Sibanda, P., and Motsa, S.S. (2014). A new algorithm for internal heat generation in nanofluid flow due to a stretching sheet in a porous medium, *International Journal of Numerical Methods for Heat & Fluid Flow,* 24, 1020-1043.

Meisam Habibi Matin., and Reza Hosseini. (2014). Solar radiation assisted mixed convection MHD flow of nanofluids over an inclined transparent plate embedded in a porous medium, *Journal of Mechanical Science and Technology,* 28(9), 3885-3893.

Mohammad Dehsara., Nemat Dalir., and Mohammad Reza Heirani Nobari. (2014). Numerical analysis of entropy generation in nanofluid flow over a transparent plate in porous medium in presence of solar radiation, viscous dissipation and variable magnetic field, *Journal of Mechanical Science and Technology,* 28(5), 1819-1831.

Uddin, M.J., Osman Anwar Bég., and Ahmad Izani Md. Ismail. (2014). Mathematical Modelling of Radiative Hydromagnetic Thermosolutal Nanofluid Convection Slip Flow in Saturated Porous Media, *Hindawi Publishing Corporation Mathematical Problems in Engineering.*2014, 1-11.

Mohan Krishna P, Sugunamma V and Sandeep N (2013). Magnetic field and chemical reaction effects on convective flow of a dusty viscous fluid, *Communications in Applied Sciences.* 1, 161-187.

Mohan Krishna P, Sugunamma V, Sandeep N (2014). 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*, Vol 25, pp39-52.

Muthtamilselvan, M., Prakash, D., and Deog-Hee Hoh. (2014). Effect of thermal non- equilibrium on transient hydromagnetic flow over a moving surface in a nanofluid saturated porous media, *Journal of Mechanical Science and Technology,* 28(9), 3709- 3718.

Nadeem, S., Arshad Riaz., Ellahi, R., and Noreen Sher Akbar. (2013). Mathematical model for the peristaltic flow of nanofluid through eccentric tubes comprising porous medium, *Applied Nanoscience,* 4, 733-743.

Noor, N.F.M., Rizwan Ul Haq., Nadeem, S., and Hashim, I. (2015). Mixed convection stagnation flow of a micropolar nanofluid along a vertically stretching surface with slip effects, *Springer Science+Business Media Dordrecht.*

Oluwole Daniel MAKINDE., and Winifred Nduku MUTUKU. (2014). Hydromagnetic Thermal Boundary Layer of Nanofluids Over a Convectivity Heated Flat with Viscous Dissipation and Ohmic Heating, *U.P.B. Sci. Bull., Series A,* 76, 181-192.

Rahman, M.M., and Eltayeb, I.A. (2012). Radiative heat transfer in a hydromagnetic nanofluid past a non-linear stretching surface with convective boundary condition, *Springer Science+Business Media Dordrech,* 48, 601-615.

Raju, C S K., Jayachandra Babu, M., Sandeep, N., Sugunamma, V., and Ramana Reddy, J.V. (2015). Radiation and Soret Effects of MHD Nanofluid Flow over a Moving Vertical Moving Plate in Porous Medium, *Chemical and Process Engineering Research*, 30, 9- 23.

Raju, C.S.K., Sandeep, N., Babu, M.J., Sugunamma, V.(2015a). Radiation and Chemical Reaction Effects on Thermophoretic MHD Flow over an Aligned Isothermal Permeable Surface with Heat Source, Chemical and Process Engineering Research, 31, 27-42.

Raju, C.S.K, Sandeep, N., Sulochana, C., Sugunamma, V., Jayachandra Babu, M. (2015b). Radiation, Inclined Magnetic field and Cross-Diffusion effects on flow over a stretching surface. Journal of Nigerian Mathematical Society (In Press)

Ramana Reddy, J.V., Sugunamma, V., Mohan Krishna, P., Sandeep, N. (2014) . Aligned magneticfield, Radiation and chemical reaction effects on unsteady dusty viscous flow with heat generation/absorption, *Chemical and process eng. Research*, 27, 37- 53.

Rama Subba Reddy Gorla., Ali Chamkha., and Rashad., A.M. (2010). Mixied Convective Boundary Layer Flow Over a Vertical Wedge Embedded in a Porous Medium Saturated with a Nanofluid, *Thermal Issues in Emerging Technologies, ThEta3, Cairo, Egypt*, 445-451.

Rana, G.C., and Chand, R. (2015). Stability analysis of double-diffusive convection of Rivlin-Ericksen elastic-viscous nanofluid saturating a porous medium: a revised model, *Forschung im Ingenieurwesen*, 79, 87-95.

Rasekh, A., and Ganji, D.D. (2013). Analytic Approximate Solutions of Mixed Convection about an Inclined Flat Plate Embedded in a Porous Medium Filled with Nanofluids, *International Journal for Computational Methods in Engineering Science and Mechanics*, 14(5), 440-451.

Sandeep N, Reddy A.V.B, Sugunamma V, (2012). 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, 1-9.

Sandeep, N., Sugunamma, V., Mohankrishna, P. (2013). 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, 36-43.

Sandeep Naramgari., and Sulochana, C. (2015). Dual solutions of radiative MHD nanofluid flow over an exponentially stretching sheet with heat generation/absorption, *Applied Nanoscience*, 5 (In press).

Sandeep Naramgari., Sugunamma Vangala., and Mohankrishna Penem. (2014). Aligned Magnetic Field, Radiation and Rotation Effects on Unsteady Hydromagnetic Free Convection Flow Past an Impulsively Moving Vertical Plate in a Porous Medium, *Hindawi Publishing Corporation International Journal of Engineering Mathematics.*

Sugunamma, V. and Sandeep, N. (2011) .Unsteady hydrmagnetic free convection flow of a dissipative and radiating fluid past a vertical plate through porous media with constant heat flux. *International journal of mathematics and computer applications research*. 1, 37-50.

Tariq Hussain., Sabir Ali Shehzad., Tasawar Hayat., Ahmed Alsaedi., and Fallesh Al- Solamy. (2014). Radiative Hydromagnetic Flow of Jeffery Nanofluid by an Exponentially Stretching Sheet, *plosone.org*, 9, 1-9.

Venkateswarlu, B., and Satya Narayana, P.V. (2015). Chemical reaction and radiation absorption effects on the flow and heat transfer of a nanofluid in a rotating system, *Applied Nanoscience,* 5, 351-360.