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Soret and Dufour effects of electrical MHD Nanofluid with Higher order Chemical reaction

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Article Info
Volume 82
Page Number: 2250 - 2259
Publication Issue:
January-February 2020

Article History
Article Received: *14 March 2019*
Revised: *27 May 2019*
Accepted: *16 October 2019*
Publication: *16 January 2020*

Abstract:
In this study, the authors describe homogeneous chemical reactions of order 'n' of nanofluid, is discussed. Influence of some thermophysical properties of nanofluid along a stretching porous sheet is taken. The transferring temperature and concentration of nanofluid as well as higher-order chemical processing is investigated. The dimensionless Soret number and Dufour number, impacts of electric and magnetic fields on nanofluid are analyzed. The physical significance extracted from mathematical statements in terms of partial derivatives along with boundary conditions. The nonlinear governing partial mathematical derivatives converted into standard ordinary differential mathematical formulations by suitable similarity variable. These equations are evaluated by numerical method, Runge-Kutta with MATLAB 'bvp4c' iterative programming methodology to seek out results of fluid velocity, fluid temperature, fluid concentration extensively. The effects of dimensionless parameters such as the random motion of Brownian, porous, electric, mixed convection, chemical reaction and thermophoresis are verified. The dimensionless numbers such as Hartmann, Schmidt, Lewis and Prandtl, are analyzed.

Keywords:*Hartmann number, electric parameter, thermophoresis, process of chemical reaction, Brownian motion , Soret number and dimensionless Dufour number*

I. INTRODUCTION

Much attention is paid in recent years about nanofluid. Many mechanisms are urged for improvement of thermal physical phenomenon. Among these suggestions, suspension of nanoparticles within the base fluid has become a lot of engaging source. The size of (1-100nm) particles suspended in bottom fluid-like ethanol and water etc., The important application of nanofluid is cooling the substances like diesel electrical generator, nuclear systems, oil engine lasers of high-voltage, storage of thermal, drilling and water heating. Enhancing the thermal physical phenomenon of fluids with nanoparticles coined initially by Choi and Eastman [1].

Preparation of mathematical modeling is essential in analysis of homogeneous chemical processing. The movement of temperature and concentration with the effectuate of thermophoresis and reaction of chemical processing gives a high amount of performance in the output demanded by the industry. In the present trend, nanoparticles are suspended in the fluid to design chemical processing equipment, maintaining temperature and moisture in the agriculture field, food processing, cooling the machines and preventing crops from damage due to freezing, If transference of mass and heat happen at the same time in the fluid flow, then complication will arise between heat flux and driving potential. It was found that heat transfer not only by slope of heat flux, possible with slope of mass flux also. The slope of concentration field due to temperature change, Dufour, and temperature gradient due to mass flux, Soret. The application of effect of Soret

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is isotope separation, that is, light weight molecules like hydrogen and helium.

Sharma [2] analyzed the state of unsteady MHD flow where a plate is kept vertically in the medium of free and forced convection. He studied viscosity dissipation following Ohmic, source of heat, thermo-diffusion and diffusion-thermo. Shateyi [3] observed about transferring mass by a gradient of temperature, transferring heat through slop of concentration field, hall current, radiation and magnetohydrodynamics. He considered porous surface with free and forced convection.Chandra Shekar Balla[4] analyzed transferring heat by a concentration gradient, transferring concentration through temperature field gradient in free convection. He studied saturated porous fluid flow in a inclined cavity.

Rawat et al.[5] analyzed mathematical flow equations in micropolar with finite element method. He observed the impact of thermal-diffusion and diffusion-thermo in a saturated regime with porosity. Ashraf [6]considered skin friction effect at a point of zero in free and forced convection medium, transferring heat by concentration gradient and mass by temperature gradient. Kafoussias[7] obtained results about Dufour, viscosity dependent on temperature, Soret, mixed forces of free and forced in the flow. Srinivasacharya et al. [8] studied heat transfer by temperature gradient and mass transfer by temperature gradient extensively. The porous surface medium is taken vertically considering variable properties with mixed free-forced convection medium.

Mahdy [9]studied non-Newtonian flow for the effects of concentration gradient-Dufour and temperature gradient-Soret. He tested the porous surface vertically with forced combined free and forced. Crane [10] explained fluid flow about a stretching sheet. Posteinicu[11] studied Soret-temperature gradient, Dufour-concentration gradient on natural convection medium. He observed transferring heat and mass with the strength of magnetic from vertical porous surfaces. Hayat et al.[12] contributed results of Peristaltic flow about Bingham plastic with the strength of magnetic, concentration gradient due to heat flux, Dufour and temperature gradient due to mass flux, Soret.

Sheikholeslami et al.[13] concentrated on a stretched surface and analyzed deeply about Lorentz force in nanoparticles suspension of forced convection medium. Research contributions on Soret-mass transfer, Dufour-heat transfer with magnetic strength presented numerically by Hayat et al.[14] Chatterjee [15] reported about Soret-mass transfer, Dufour-heat transfer, transferring heat as well as mass in power-law governing flow. The plate is kept in a fluid at an inclined position in the medium of thermally conducting porous. Nagaraju et al.[16] investigated on rotating cylinder strengthened by magnetic in micropolar fluid flow. He resulted concentration gradient due to temperature change and temperature gradient due to mass flux, Hall as well as ion current and chemical processing. Reddy et al.[17] analyzed Soret-mass transfer, Dufour-heat transfer on micropolar with magnetic strength. The stretching sheet is taken linearly obeying non-Darcy law in the medium of porous. K.Kaladhar et al.[18] studied a couple of stress fluid flow with mixed-free and forced forces. He studied the reaction of chemical processing, Soret-mass transfer and Dufour-heat transfer. Sharma et al.[19] studied porous concentric cylinders. Natural force, homogeneous chemical porcessing and Soret-mass transfer analyzed in the governing mathematical equations.

Pal et al.[20] analyzed MHD flow obeying non-Darcy law with an unsteady condition. A stretching sheet is considered for testing the effects of Soret-Dufour, radiation as well as the reaction of chemical processing. NiranjanHari et al. [21]analyzed flow with slip condition. The reaction of chemical processing, Soret-mass transfer, Dufour-heat transfer are verified using non-dimensional parameters at a stagnation point. Many researchers contributed in the same field. [22,23].

Kishan et al.[24]discussed nanofluid obeying non-Darcy law in natural convection medium. He studied radiative nanofluid over a stretching sheet. Now, we discussed impact of the electrical field, magnetic

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field, result of thermal-diffusion and diffusion-thermo for chemical processing with high order. The electrical and magnetic parameters are dominated in the momentum and energy equations. The physical significance of the flow model is governed by nonlinear partial derivative mathematical equations. These physical phenomenon equations evaluated by using the numerical method, Runge-Kutta MATLAB software. The physical significance of the nanofluid flow are illustrated numerically in terms of graphical representation.

II. Mathematical Formulation

The fluid flow is taken as two space coordinate system, steady flow, laminar in a porous medium. The density is constant throughout the flow. A Stretching sheet is firmly surrounded with fluid where electrically conducting nano particles are considered in the governing flow. The nanofluid flow stabilized by strength of electric and magnetic fields. A linear order is assumed for the stretching elastic sheet. The value of Reynolds number, dimensionless range is assumed small. Also, hall effects and strength of induced magnetism are neglected. Based on Boussinesq approximations, the mathematical flow equation framed :

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+\frac{\sigma}{\rho}\left(E_0B_0-B_0^2u\right)-\frac{\nu}{k}u-Fu^2+g\beta_T\left(T-T_\infty\right) \qquad (2)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2}+\frac{\sigma}{\rho c_p}\left(uB_0-E_0\right)^2+\frac{D_mK_T}{c_sc_p}\frac{\partial^2 C}{\partial y^2}+\frac{(\rho c)_p}{(\rho c)_f}\left[D_B\frac{\partial N}{\partial y}\frac{\partial T}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right] \qquad (3)$$

$$u\frac{\partial N}{\partial x}+v\frac{\partial N}{\partial y}=D_B\frac{\partial^2 N}{\partial y^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2}+\frac{D_mK_T}{T_m}\frac{\partial^2 T}{\partial y^2}-\delta_n\left(N-N_\infty\right)^n \qquad (4)$$

where u denotes component of nanofluid velocity field in x- dimension and v denotes nanofluid velocity field component in the coordinates of y-dimension. ρ specifies density of fluid, ν denotes kinematic viscosity, F specifies empirical constant (Forchheimer number), k denotes thermal conductivity, g denotes gravitationa force due to acceleration, N denotes nanoparticle concentration volume fraction, coefficient of Brownian diffusion denoted by D_B , coefficient of thermal expansion denoted by β_T, and D_T denotes coefficient of thermophoretic diffusion, T defines temperature of the nanofluid, c_p defines amount of heat at constant pressure, T_w denotes stretching surface temperature and T_∞ defines temperature is taken at a distance from solid body, stretching porous sheet and K specifies permeability in porous medium.

The appropriate boundary flow conditions are

$$u=U_w(x)=bx,\quad v=0 \text{ at } y=0,\quad u=0 \text{ as } y\to\infty$$

$$T=T_w=T_\infty+A_0\left(\frac{x}{l}\right)^2 \text{ at } y=0,\ T\to T_\infty \text{ as } y\to\infty$$

$$N=N_w=N_\infty+A_0\left(\frac{x}{l}\right)^2 \text{ at } y=0,\ N\to N_\infty \text{ as } y\to\infty \qquad (5)$$

Where parameter A_0 denotes surface temperature distribution of stretching surface.
Now outline subsequent dimensionless variables for mixed convection:

$$u=bxf'(\eta),\qquad v=-\sqrt{b\nu}\,f(\eta),\qquad \eta=\sqrt{\frac{b}{\nu}},$$

$$\theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},\qquad \phi(\eta)=\frac{N-N_\infty}{N_w-N_\infty} \qquad (6)$$

where the primes indicate differentiation with relevant to η. Continuity equation (1) is verified and other governing equations along with boundary layer condition (2-5) are converted to

$$f'''+ff''+Ha^2(Er-f')-Frf'^2-Krf'+\lambda\theta=0 \qquad (7)$$

$$\theta''+\Pr f\theta'++\Pr Ha^2Ec(f'-Er)^2+Df\phi''+\Pr Nb\theta'\phi'+\Pr Nt\theta'^2=0 \qquad (8)$$

$$\phi''+Scf\phi'+\frac{Nt}{Nb}\theta''+LeSr\theta''-Sc\Gamma\phi^n=0 \qquad (9)$$

where $Kr=\nu/kb$ specifies porous parameter, $Ha^2=\sigma\beta_0^2/\rho b$ denotes Harmann number,

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$Er = E_0 / B_0 bx$ specifies local electric parameter, $Fr = Fx$ specifies local inertia coefficient, $\lambda = Gr_x / \mathrm{Re}_x^2$ defines buoyancy or mixed convection parameter, $Le = \nu / D_B$ denotes Lewis number, $\mathrm{Pr} = \mu c_p / k$ denotes Prandtl number, $(D_m k_T (T_w - T_\infty)) / \alpha T_m (N_w - N_\infty)$ is the Soret number, $(D_m k_T (N_w - N_\infty)) / (\alpha c_s c_p (T_w - T_\infty))$ specifies Dufour number, local Grashof dimensionless number denoted by $Gr_x = g\beta_T (T_w - T_\infty) x^3 / \nu^2$, $\mathrm{Re}_x = Ux / \nu$ specifies local Reynolds dimensionless number, $Nb = D_B (\rho c)_p (N_w - N_\infty) / \nu (\rho c)_f$ associated to random motion of Brownian motion , $Nt = D_T (\rho c)_p (T_w - T_\infty) / \nu T_\infty (\rho c)_f$ denotes thermophoresis dimensionless parameter and $\Gamma = \delta_n (N_w - N_\infty)^{n-1} / b$ denotes chemical reaction parameter.

The appropriate boundary conditions (5) in nondimensional form, are

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

III. NUMERICAL SOLUTION

The nonlinear governing partial derivatives mathematical formulations and boundary flow conditions are converted to non-linear coupled ODEs. We introduce R-K method of fourth- order to solve these nonlinear coupled ODEs. Given set of higher order mathematical formulations are reduced into a set of linear polynomials in the unknown functions.

$$f_1 = f, \; f_2 = f', \; f_3 = f'', \; f_4 = \theta, \; f_5 = \theta', \; f_6 = \phi, \; f_7 = \phi'$$

The flow equations (7)-(9) are transformed to following first order ODEs.

$$f_2' = f_3, \quad f_3' = -\left(f_1 f_3 + Ha^2 (Er - f_2) - F_1 f_2^2 - Krf_2 + \lambda f\right)$$
$$f_4' = f_5, \; f_5' = -\left(\mathrm{Pr}\left(f_1 f_5 + Ecf_3^2 + Ha^2 Ec (f_2 - Er)^2 + Nbf_5 f_7 + Ntf_5^2\right) + Dff_7\right)$$
$$f_6' = f_7, \; f_7' =$$
$$-\left(Scf_1 f_7 + Nt / Nb \left(-\left(\mathrm{Pr}\left(\begin{array}{l} f_1 f_5 + Ecf_3^2 + Ha^2 \\ Ec(f_2 - Er)^2 + \\ Nbf_5 f_7 + Ntf_5^2 \end{array}\right)\right) + LeSrf_5 - Sc\Gamma f_6^n\right)\right)$$

MATLAB bvp4c programming applied to get approximate solutions to present physical significance of non-dimensional parameters.

IV. RESULTSAND DISCUSSION

The nanofluid flow equations (7)-(9) are numerically integrated by employing Runge-Kutta method (10) are locally similar and solved by a numerical method using R-K method. The coupled mathematical nonlinear partial derivatives changed into ODEs by applying suitable similarity flow transformation. MATLAB-bvp4c software is applied for computation. The physical significance parametric study are obtained graphically in figures 1 to 10 and discussed. Now, the following dimensionless default parameter are valued in computation.

$$Ha = 0.5, \; Kr = 0.5, \; Er = 0.1, \; \lambda = 0.3, \; Nt = 1, \; Nb = 1, \; \mathrm{Pr} = 0.7,$$
$$Sc = 1, \; Sr = 0.1, Df = 0.1, \; \delta = 0.3, n = 1 \; \text{and} \; Le = 1$$

Figure 1 is plotted to view the changes for several values of the Hartmann parameter. As expected enhancing values of Ha diminishes nanofluid velocity monotonously. The standard reason behind this physical phenomenon is that Lorentz force, a resistive force. Due to Lorentz force, nanofluid flow is becoming slow. It is witnessed that temperature fluid and volume fraction of nanoparticle interaction reduce with enhance of magnetic strength.

Figure 2 renders effects of electric dimensionless parameter on nanofluid velocity, nanofluid temperatureand volume fraction of nanoparticle interaction. The resistive Lorentz force interaction in nanoparticles develops more with the strength of electric field. Thus body forces are accelerated, leads to boundary layers of fluid velocity and fluid temperature thickness in the governing flow. It is noteworthy that opposite trend is followed in the volume fraction of nanoparticle interaction.Thefluid becomes more heated due to thermophoretic force generated by temperature gradient. Consequently, both nanofluid temperature and nanofluid concentration enhance with the increase of thermophoresis factor, which is displayed in figure 3.Figure4 viewed temperature gradient develops by an increment of Brownian motion dimensionless factor. This causes enhancement in nanofluid motion randomly. The reason is a collision between the fluid particles and their random motions. Hence more heat is produced, thus temperature-θ profile increases. But opposite trend is seen in the fluid concentration.Figure 5 emphasizes dimensionless number mixed convection parameter on velocity flow, temperature flow and concentration flow. The physical behaviors of both gradients of thermal and concentration, witnessed that with enhance of mixed convection parameter, velocity profile increases. They act as a pressure gradient which enhances the nanofluid velocity. But volume fraction of nanoparticle boundary layer diminishes when mixed convection parameter increased.Figure 6 is plotted to view the changes for several values of the thermal-diffusion and diffusion-thermo, dimensionless number. Nanofluid Velocity field and temperature field profiles enhance with an increment of Soret number and Dufour number. The concentration profile near the boundary layer declines but the high movement is seen at a far distance from the fluid boundary layer.Figure 7 illustrates chemical reaction on the volume fraction of nanoparticle interaction. It is observed that with the enhance of chemical process parameter, nanofluid concentration profile diminishes. The reason is combined results of random motion of particle deposited due to thermophoresis and Brownian in fluid flow.Figure 8 examines impact of dimensionless Sc on concentration field. It is found that increment of Schmidt number, volume fraction of nanoparticle concentration profile diminishes. The reason is Lewis number characterizes the impact of dependency of diffusion on Brownian motion in the nanofluid governing flow.

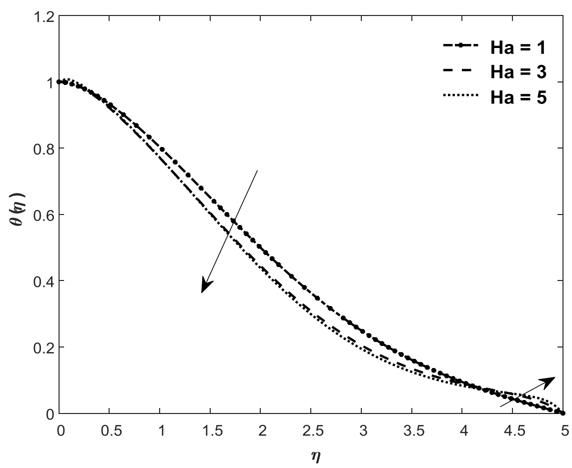

Fig. 1 Impact of Hartmann number for nanofluid velocity and temperature fields

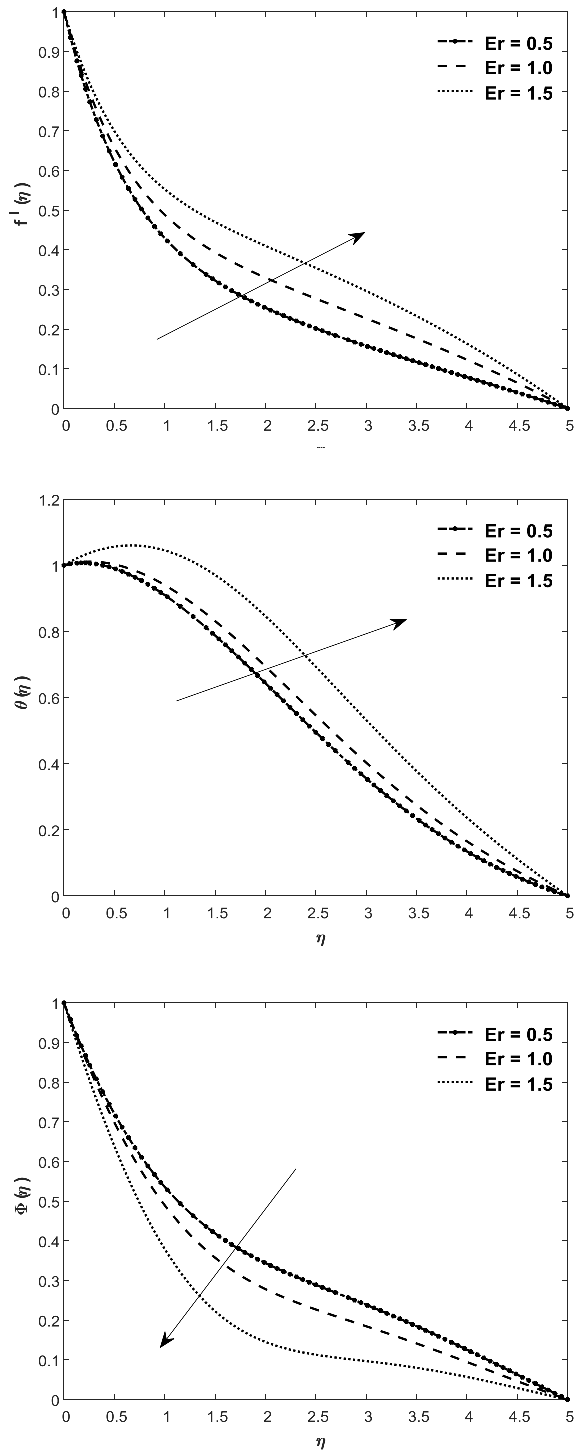

Fig. 2 Impact of Electric parameter Er for fields f', θ, ϕ

Fig. 9 revealed that the impact of Prandtl number on fluid concentration. The volume fraction of nanoparticle interaction decreases near the boundary layer but increases far away from it. Since Prandtl number correlates the momentum and thermal equations, increasing Prandtl number lower thermal diffusivity caused. This result made nanoparticle

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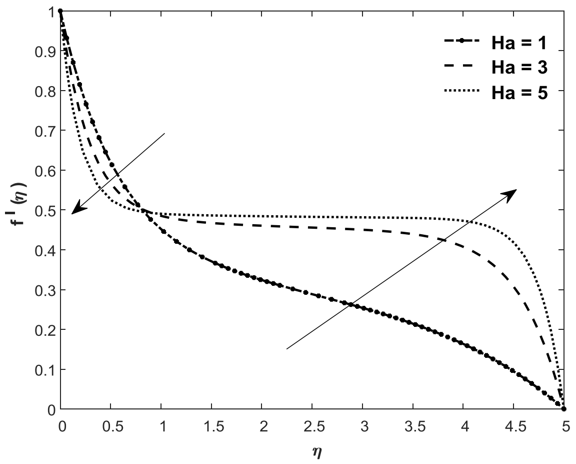
volume fraction concentration- ϕ profile to decrease. From fig. 10 demonstrates the nanoparticle volume fraction interaction on chemical processing with different orders. Interestingly, observed that the volume fraction of nanoparticle suppresses when homogeneous chemical processing with higher order enhances.



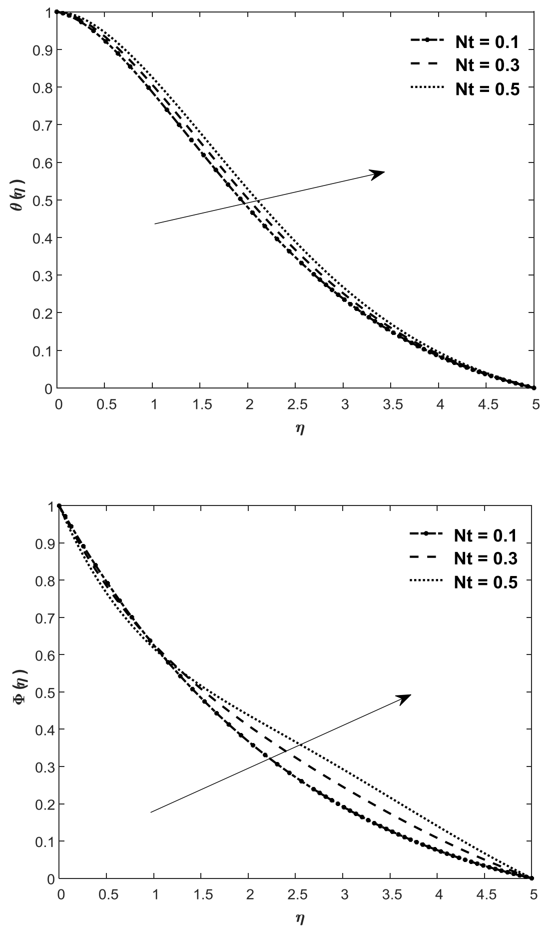


Fig. 3: Effects of Thermophoresis Nt for θ field and ϕ fields

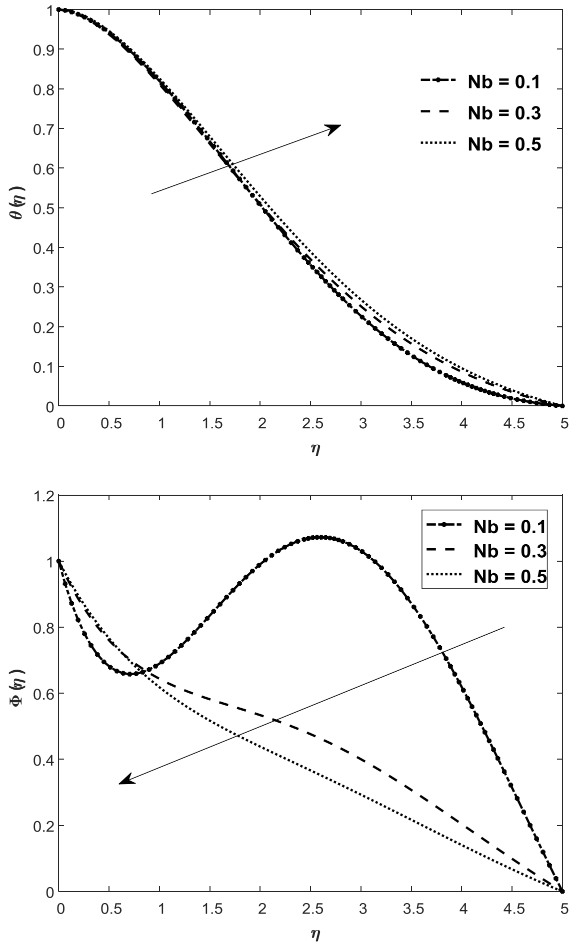
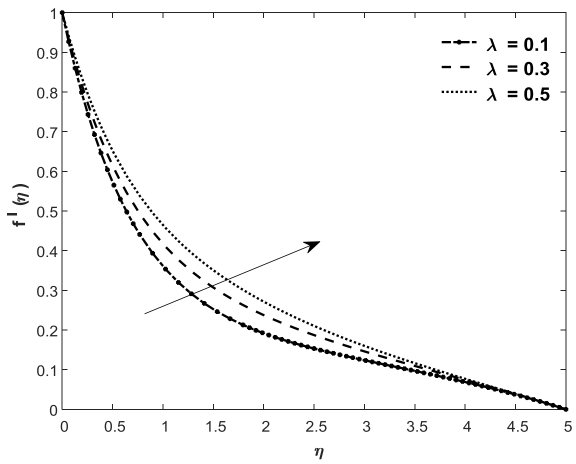


Fig. 4: Impacts of Brownian motion Nb forFields θ, ϕ



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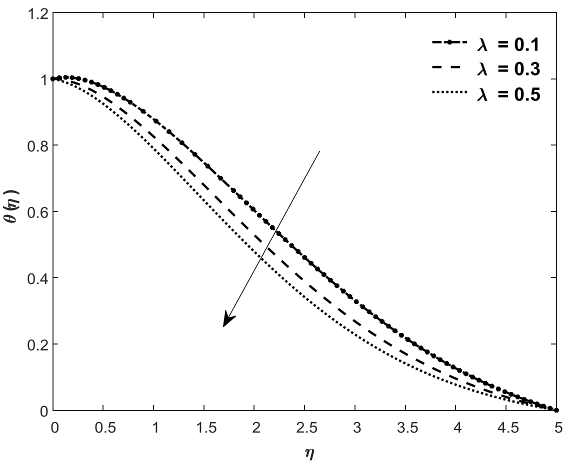


Fig. 5: Effects of mixed convection parameter λ forvelocity and temperature fields

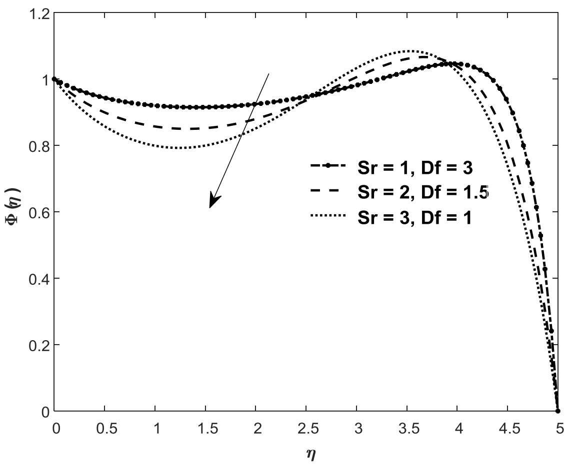
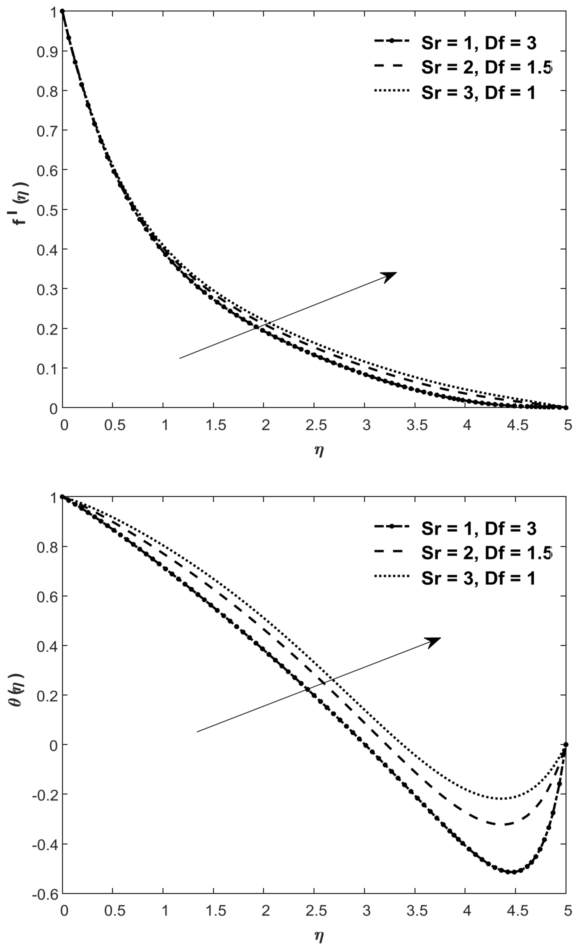


Fig. 6 Impacts of Soret and DufourSr and Df on f', θ, ϕ



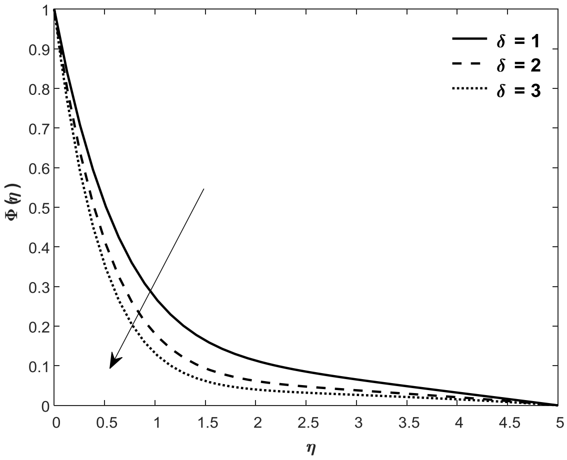


Fig. 7: Impact of chemical reaction δ for ϕ field

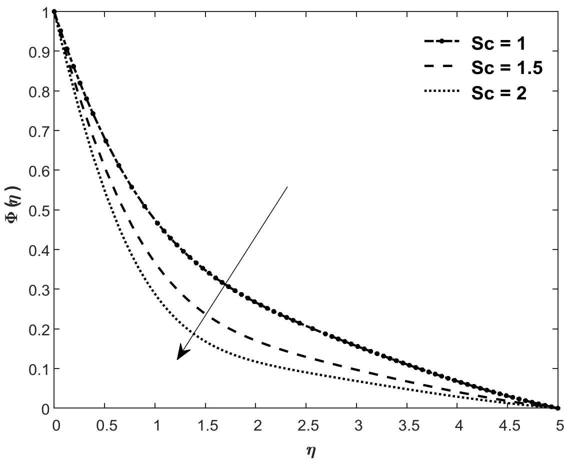


Fig. 8: Effects of Sc for ϕ field

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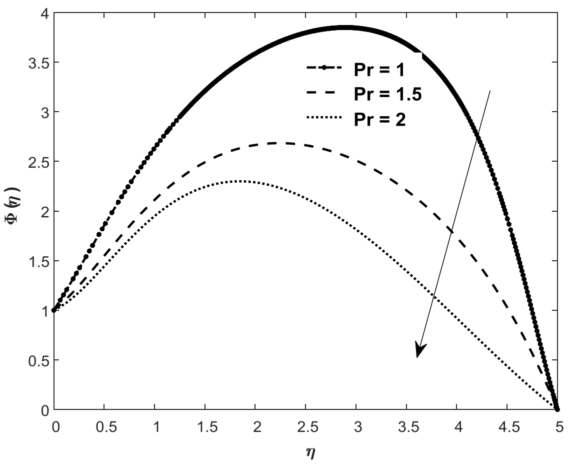

Fig. 9: Effects of Prandtl number Pr for ϕ

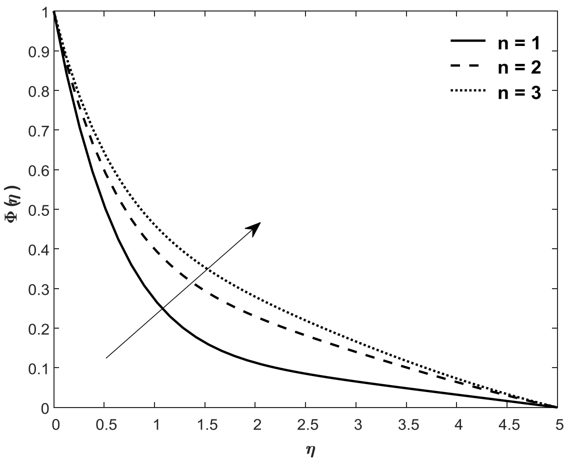

Fig. 10: Effects of n for ϕ field

V. CONCLUSION

This research study, combined impacts electrical and magnetic strength for higher order homogeneous chemical processing . A porous sheet with stretching surrounded by nanofluid flow are analyzed. The geomentrical model for numerical study, considering dimensionless parameters like Hartmann, porous , electric, mixed convection, thermophoresis, Brownian motion , Prandtl , Schmidt Soret-Dufour and homogeneous chemical reaction. The physical signifance of these parameters, approximate solutions are obtained numerically by employing R-K method numerically and presented graphically with aid of MATLAB software bvp4c.

The important points are concluded:

- The significant velocity profile is achieved for increment of mixed convection parameter, electric parameter, and soret number and dufour number whereas velocity profile is suppressed by Hartmann number.
- Hartmann number, electric parameter, thermophoresis, and soret number and dufour number enhance heat in fluid flow due to that temperature profile increases whereas opposite trend is followed in mixed convection parameter.
- Volume fraction of nanoparticle profile develops with enhance of Hartmann number, soret and dufour, thermophoresis parameter and order of homogeneous chemical processing parameter. Declining trend is observed in nanoparticle volume fraction profile for the parameters such as electric parameter, Brownian motion parameter, Schmidt, Prandtl and homogeneous chemical processing factor.

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