Heat And Mass Transfer Over A Stretching Surface In Porous Medium. Influence Of Chemical Reaction On Mhd Nanofluid Flow

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***Abstract*—The steady, laminar, mixed convection, boundary layer flow of an incompressible nanofluid past over a semi-infinite stretching surface in a nanofluid –saturated porous medium with the effects of magnetic field and chemical reaction is studied. The governing boundary layer equations (obtained with the Boussinesq approximation) are transformed into a system of nonlinear ordinary differential equations by using similarity transformation. The effects of various physical parameters are analyzed and discussed in graphical and tabular form. Comparison with published results is presented and we found an excellent agreement with it.**

Keywords— Mixed convection, boundary layer, nanofluid, magnetic field, chemical reaction.

I. INTRODUCTION

A nanofluid is a new innovation which drew the attention of most researchers in the course of last years. A nanofluid is composed of a fluid such as water and ethylene glycol and small particles of nanometric size (between 1 and 100 nm), which are generally metals (Al, Cu), oxides (AL2O3, TIO2, and CUO), carbides (SIC), nitrures (AIN, SiN) or non-metals (graphite, nanotubes of carbon).The addition of these additives allows to improve the performances of heat-transfer of basic fluids.

Choi et al. [1] found that the additions of nanoparticles to a basic fluid can double its thermal conductivity. Other experimental studies Masuda et al. [2]; Minsta et al. [3] show that the addition of a small volume fraction of nanoparticles (less than 5 %) made an increase from 10 to 50 % of thermal conductivity of basic fluids with a remarkable improvement of coefficient of heat-transfert by convection. This improvement makes nanofluids a new promising technology, improving the heat-transfert between the surfaces of exchanges and nanofluids in movement with different temperatures.

A consequence of the nanofluid-area interaction is the development of a region in the nanofluid wherein the velocity varies from its zero value at the surface to the finite value of the external flow. Because the surface and nanofluid temperatures are different, there will also be a region in the nanofluid through which the temperature of the latter will vary between the value at the wall and that the outer flow. A thermal conductivity and heat-transfer coefficient by convection enhanced which make them potentially useful in many applications. Mustafa et al. [4] studied the flow of a nanofluid near a stagnation point towards a stretching surface with the consideration of the effects of Brownian motion and thermophoresis. Alsaedi et al. [5] Analyzed stagnation point of the flow of nanofluid near a permeable stretched surface with convective boundary condition. They have found good results compared to previous ones. On the other hand, Zargartalebi et al. [6] studied the same problem but with varying thermo-physical properties. The volume fraction of the nanoparticles is assumed to be passively controlled with an isothermal exchange surface. The results show that the variation of various thermodynamic parameters induced substantial impression on the behavior of nanoparticules distribution. Khan and Pop [7]; Hassani et al. [8]; Makinde and Aziz. [9]) chose to study Boundary-layer flow of a nanofluid past a stretching sheet. it was found that the reduced Nusselt number is a decreasing function for each dimensionless parameter while the reduced Sherwood number is an increasing function for the specified values of Pr. An analysis is made by Vajravelu et al. [10] to study the heat-transfer by convection in a flow of the nanofluids (Ag-water And Cu-water) over a stretching sheet. The results indicate that The Ag-water decreases the boundary layer thickness more than that Cu-water.

The application of magnetohydrodynamics in the flow of nanofluids has received relatively an important consideration on the part of researchers. Hamad [11] examine the convective flow and heat transfer of an incompressible viscous nanofluid past a semi-infinite vertical stretching sheet in the presence of a magnetic field. It is noted that the momentum boundary layer thickness decreases while the thermal boundary layer thickness increases with increasing magnetic parameter. Kandasamy et al. [12] have studied theoretically the problem of steady MHD boundary-layer flow of a nanofluid past a vertical stretching surface in the presence of suction/injection. The boundary layer flow and heat transfer over a permeable stretching sheet due to a nanofluid with the effects of magnetic field, slip boundary condition and thermal radiation have been investigated by Wubshet and Shankar [13]. They found that the velocity profiles decreases with increasing M parameter. Ruchika et al. [14] presented the MHD boundary layer flow and heat transfer analysis of nanofluid induced by a power-law shrinking sheet. Pal and Mandal [15] investigate the magnetohydrodynamic mixed convective heat transfer induced by a non-linear stretching and shrinking sheets in the presence of thermal radiation, viscous dissipation and Ohmic heating in the medium saturated by nanofluids. MHD boundary layer flow and heat transfer towards an exponentially stretching sheet embedded in a thermally stratified medium subject to suction are presented by Mukhopadhyay [16]. It is found that the fluid velocity decreases with increasing of magnetic parameter. MHD boundary layer flow and heat transfer of a water-based nanofluid over a nonlinear stretching sheet with viscous dissipation have been investigated numerically by Mabood et al. [17]. The results show that the skin friction coefficient increases, whereas the reduced Nusselt and Sherwood numbers decrease with magnetic parameter.

The combination of heat and mass transfer in the presence of a chemical reaction is a growing need in the chemical industries such as nuclear reactor safety and combustion systems, solar collectors. Patil et al. [18] studied the effects of chemical reaction on mixed convection flow of a polar fluid through a porous medium in the presence of internal heat generation. The effects of chemical reactions on unsteady MHD free convection and mass transfer for flow past a hot vertical porous plate with heat generation absorption through porous medium was studied by Singh and Kumar [19] . It noted that temperature, velocity skin-friction coefficient increase and Nusselt number decreases for generative chemical reactions (ɣ<0). However, destructive chemical reactions (ɣ>0) have opposite effect on temperature, velocity, skin-friction coefficient and Nusselt number.

The objective of this paper is to study the interaction in nanofluids in the presence of MHD and chemical reaction.

II. MATHEMATICAL ANALYSIS

Consider steady, laminar, MHD mixed convection, boundary layer flow of an incompressible nanofluid past over a semi-infinite stretching surface in a nanofluid –saturated porous medium as displayed in Fig. 1. Introducing the Cartesian coordinate system, the x-axis measures the distance along the plate, and the y-axis measures the distance normally into the fluid. The surface of plate is maintained at uniform temperature, concentration and nanoparticle volume fraction Tw, Cw and ϕw , respectively, and these values are assumed to be greater than the ambient temperature, concentration and nanoparticle volume fraction, T∞ ,C∞, and ϕ∞ respectively. The Oberbeck–Boussinesq approximation is employed. Homogeneity and local thermal equilibrium in the porous medium are assumed. We consider a porous medium whose porosity is denoted by ε and permeability by k. The Darcy velocity is denoted by ω.

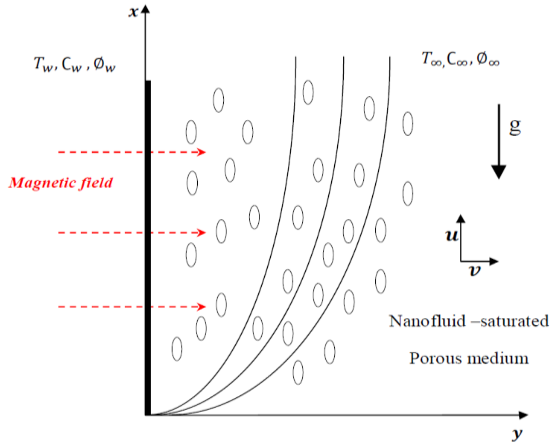

Fig. 1. *Physical model and coordinate system.*

In-line with these assumptions, the governing equations describing the conservation of mass, momentum, energy and concentration can be written as follows:

$$\nabla \cdot \omega = 0 \; (1)$$

$$\frac{\rho_f}{\varepsilon}\frac{\partial \omega}{\partial t} = -\nabla p - \frac{\mu}{k}\omega - \delta B_0^2 u \; (2)$$

$$+g\left[\emptyset \rho_p + (1-\emptyset)\left\{\rho_f\begin{pmatrix}1-\beta_T(T-T_\infty)\\ -\beta_c(C-C_\infty)\end{pmatrix}\right\}\right]$$

$$(\rho c)_m \frac{\partial T}{\partial t} + (\rho c)_f \omega . \nabla T = \; (3)$$

$$k_m \nabla^2 T + \varepsilon(\rho c)_p\left[D_B \nabla C \cdot \nabla T + \left({}^{D_T}/_{T_\infty}\right)\nabla T \cdot \nabla T\right]$$

$$\frac{\partial C}{\partial t} + \frac{1}{\varepsilon}\omega . \nabla \emptyset = D_B \nabla^2 C + \left({}^{D_T}/_{T_\infty}\right)\nabla^2 T \; (4)$$

$$\frac{\partial C}{\partial t} + \frac{1}{\varepsilon}\omega \cdot \nabla C = D_m \nabla^2 C - k(C - C_w) \; (5)$$

Here $\rho_{f,\mu,}\beta_T$ and β_c are the density, viscosity, volumetric volume expansion coefficient of fluid and the analogous solutal coefficient respectively while ρ_p is the density of the particles, δ and B_0 are the electrical conductivity and induced magnetic field, $\omega = (u, v)$is the two-dimensional velocity vector. The gravitational acceleration is denoted by g. Eqs .(1)-(4) are based on the earlier model of Nield and Kuznetsov [20] ,with a modification included MHD .we have introduced the effective heat capacity $(\rho c)_m$,and the effective thermal conductivity k_m of the porous medium. The coefficients that appear in Eqs . (3) and (4) are the Brownian diffusion coefficient D_B and the thermophoretic diffusion coefficient D_T ,D_m , k_1 and n are is the mass diffusivity, a dimensional chemical reaction parameter and order of the chemical reaction. The flow is assumed to be slow so that a forchheimer quadratic drag term and an advective term do not appear in the momentum equation.

boundary conditions are taken to be

$$v = 0, T = T_{w,} C = C_w, \emptyset = \emptyset_w \text{ at } y = 0 \; (6a)$$

$$u = v = 0, T \to T_\infty, C \to C_\infty, \emptyset \to \emptyset_\infty \text{ at } y \to \infty \ (6b)$$

Using the Boussinesq approximation with an assumption that the nanoparticle concentration is dilute, the governing equations for this problem can be written as follows:

$$0 = \nabla p - \frac{\mu}{k}\omega - \delta B_0^2$$

$$+g\begin{bmatrix} -(\rho_p - \rho_{f\infty})(\emptyset - \emptyset_\infty) \\ +(1-\emptyset_\infty)\rho_{f\infty}\{\beta_T(T - T_\infty) + \beta_c(C - C_\infty)\} \end{bmatrix} \ (7)$$

We now make the standard boundary layer approximation, based on a scale analysis, and write the governing equations as follows:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \ (8)$$

$$\frac{\partial p}{\partial x} = -\frac{\mu}{k} - \delta B_0^2 u + g[(1-\emptyset_\infty)\rho_{f\infty}\beta_T(T - T_\infty)$$

$$+\beta_c(C - C_\infty) - (\rho_p - \rho_{f\infty})(\emptyset - \emptyset_\infty)] \ (9)$$

$$\frac{\partial p}{\partial y} = 0 \ (10)$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha_m \nabla^2 T$$

$$+\tau\left[D_B\frac{\partial C}{\partial y}.\frac{\partial T}{\partial y} + \left({}^{D_T}/_{T_\infty}\right)\left(\frac{\partial T}{\partial y}\right)^2\right] \ (11)$$

$$\frac{1}{\varepsilon}\left(u\frac{\partial \emptyset}{\partial x} + v\frac{\partial \emptyset}{\partial y}\right) = D_B\frac{\partial^2 \emptyset}{\partial y^2} + \left({}^{D_T}/_{T_\infty}\right)\frac{\partial^2 T}{\partial y^2} \ (12)$$

$$\frac{1}{\varepsilon}\left(u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y}\right) = D_m\frac{\partial^2 C}{\partial y^2} - k(C - C_\infty)^n \ (13)$$

where:

$$\alpha_m = \frac{k_m}{(\rho c)_f}, \tau = \frac{\varepsilon(\rho c)_P}{(\rho c)_f} \ (14)$$

We can eliminate p from Eqs. (9) and (10) by cross-differentiation. At the same time we can introduce a stream function Ψ defined by the Cauchy-Riemann equation:

$$u = \frac{\partial \Psi}{\partial y}, v = -\frac{\partial \Psi}{\partial x} \ (15)$$

The Eq. (8) is satisfied identically so the following four coupled similarity equations become:

$$\frac{\partial^2 \Psi}{\partial y^2} = \left(1 + \frac{\delta B_0^2}{\mu}\right)\left[\frac{(1-\emptyset_\infty)\rho_\infty kg}{\mu}\left(\beta_T\frac{\partial T}{\partial y} + \beta_c\frac{\partial C}{\partial y}\right) - \frac{(\rho_p - \rho_{f\infty})gk}{\mu}\frac{\partial \emptyset}{\partial y}\right] \ (16)$$

$$\frac{\partial \Psi}{\partial y}\frac{\partial T}{\partial x} - \frac{\partial \Psi}{\partial x}\frac{\partial T}{\partial y} = \alpha_m \nabla^2 T$$

$$+\tau\left[D_B\frac{\partial \emptyset}{\partial y}\cdot\frac{\partial T}{\partial y} + \left({}^{D_T}/_{T_\infty}\right)\left(\frac{\partial T}{\partial y}\right)^2\right] \ (17)$$

$$\frac{1}{\varepsilon}\left(\frac{\partial \Psi}{\partial y}\cdot\frac{\partial \emptyset}{\partial x} - \frac{\partial \Psi}{\partial x}\cdot\frac{\partial \emptyset}{\partial y}\right) = D_B\frac{\partial^2 \emptyset}{\partial y^2} + \left({}^{D_T}/_{T_\infty}\right)\frac{\partial^2 T}{\partial y^2} \ (18)$$

$$\frac{1}{\varepsilon}\left(\frac{\partial \Psi}{\partial y}\cdot\frac{\partial C}{\partial x} - \frac{\partial \Psi}{\partial x}\cdot\frac{\partial C}{\partial y}\right) = D_m\frac{\partial^2 C}{y^2} - k(C - C_\infty)^n \ (19)$$

The system of equations can be simplified by introducing the following similarity transformations:

$$\eta = \frac{y}{x}pe_x^{1/2}, f(\eta) = \frac{\Psi}{\alpha_m pe_x^{1/2}}, \theta(\eta) = \frac{T - T_\infty}{T_\omega - T_\infty},$$

$$\varphi(\eta) = \frac{C - C_\infty}{C_\omega - C_\infty}, S(\eta) = \frac{\emptyset - \emptyset_\infty}{\emptyset_\omega - \emptyset_\infty} \ (20)$$

The governing equations (Eqs.(16)-(19)) can be reduced to:

$$f'' = \frac{Ra_x}{pe_x}[\theta' + Nc\varphi' - NrS'] \cdot \frac{1}{(1+M)} \ (21)$$

$$\theta'' + \frac{1}{2}f\theta' + NbS'\theta' + Nt(\theta')^2 = 0 \ (22)$$

$$S'' + \frac{1}{2}LefS' + \frac{Nt}{Nb}\theta'' = 0 \ (23)$$

$$\frac{1}{Le_m}\varphi'' + \frac{1}{2}f\varphi' - \gamma\varphi^n = 0 \ (24)$$

The transformed boundary conditions are:

$$\eta = 0, f = 0, \theta = 1, \emptyset = 1, \varphi = 1 \ (25a)$$

$$\eta \to \infty, f' = 1, \theta = 0, \emptyset = 0, \varphi = 0, (25b)$$

Where primes denote differentiation with respect to η, The involved physical parameters are defined as:

$$Nr = \frac{(\rho_p - \rho_{f\infty})(\emptyset_\omega - \emptyset_\infty)}{\rho_{f\infty}\beta_T(T_\omega - T_\infty)(1-\emptyset_\infty)},$$

$$Nb = \frac{\varepsilon(\rho c)_p D_B(\emptyset_\omega - \emptyset_\infty)}{(\rho c)_f \alpha_m},$$

$$Nt = \frac{\varepsilon(\rho c)_p D_T(T_\omega - T_\infty)}{(\rho c)_f \alpha_m T_\infty},$$

$$Nc = \frac{\beta_c(C_\omega - C_\infty)}{\beta_T(T_\omega - T_\infty)}, (26)$$

$$Ra_x = \frac{(1-\emptyset_\infty)\rho_{f\infty}kg\beta_T(T_\omega - T_\infty)x}{\mu\alpha_m},$$

$$Pe_x = \frac{U_\infty x}{\alpha_m}, Le = \frac{\alpha_m}{\varepsilon D_B},$$

$$Le_m = \frac{\alpha_m}{\varepsilon D_m}, M = \frac{\delta B_0^2 k}{\mu},$$

$$\gamma = \frac{\varepsilon k x^2 (C_w - C_\infty)^{n-1}}{\alpha_m Pe_x}$$

Where Nr, Nb, Nt, Nc, Rax, Pex, Le, Lem, M and γ present the buoyancy ratio parameter, the Brownian motion parameter, the thermophoresis parameter, the regular double-diffusive buoyancy ratio, the local Darcy-rayleigh number, the local Peclet number, nanofluid Lewis number, modified Lewis number, magnetic parameter and dimensionless chemical reaction parameter. We note that porosity (ε) is absorbed into the Nb, Nt, Le amd Lem parameters and therefore it is not explicitly simulated in this study.

The physical quantities of interest are the local Nusselt number (Nux) and the local Sherwood number (Shx) which are defined as:

$$\mathrm{Nu_x} = \frac{\mathrm{xq_w}}{\mathrm{k(T_w - T_\infty)}}, \mathrm{Sh_x} = \frac{\mathrm{xq_m}}{\mathrm{D_m(\emptyset_\omega - \emptyset_\infty)}} \quad (27)$$

Where , $\mathrm{q_\omega}$ and $\mathrm{q_m}$ are the heat flux and the mass flux at the surface, respectively. Using (20) we obtain dimensionless version of these key design quantities:

$$(\mathrm{pe_x})^{-1/2}\mathrm{Nu_x} = -\theta'(0), (\mathrm{pe_x})^{-1/2}\mathrm{Sh_x} = -S'(0).$$

Here $(\mathrm{pe_x})^{-1/2}\mathrm{Nu_x}$ and $(\mathrm{pe_x})^{-1/2}\mathrm{Sh_x}$ are identified as the reduced Nusselt number and reduced Sherwood number which are represented by $-\theta'(0)$ and $-S'(0)$, respectively.

Results And Discussion

In this paper, steady, laminar, MHD mixed convection, boundary layer flow of an incompressible nanofluid past over a semi-infinite stretching surface in a nanofluid –saturated porous medium. The results obtained shows the influences of the non dimensional governing parameters, namely Magnetic field parameter M, Mixed parameter coefficient Rax/Pex, Thermophoresis parameter Nt, Brownian motion parameter Nb, buoyancy ratio parameter Nr, regular buoyancy ratio parameter Nc, nanofluid Lewis number parameter Le, modified Lewis number parameter Lem, order of the chemical reaction parameter n and dimensionless chemical reaction parameter on velocity, temperature, concentration and nanoparticle volume fraction.

Fig.2 depicts the influence of buoyancy ratio parameter on the velocity, temperature, nanoparticle volume fraction and concentration of the nanofluid with $(\gamma = 0.5)$ or without $(\gamma = 0.0)$ chemecal reaction. In the absence of chemical reaction, it is seen that the velocity decreases and the temperature, nanoparticle volume fraction and concentration of the nanofluid increase with increase of nanoparticle buoyancy ratio Nr. For $\gamma = 0.5$ one can observe that the velocity and concentration decrease. In this case, there are no significant changes in the temperature and nanoparticule volume fraction of nanofluid.

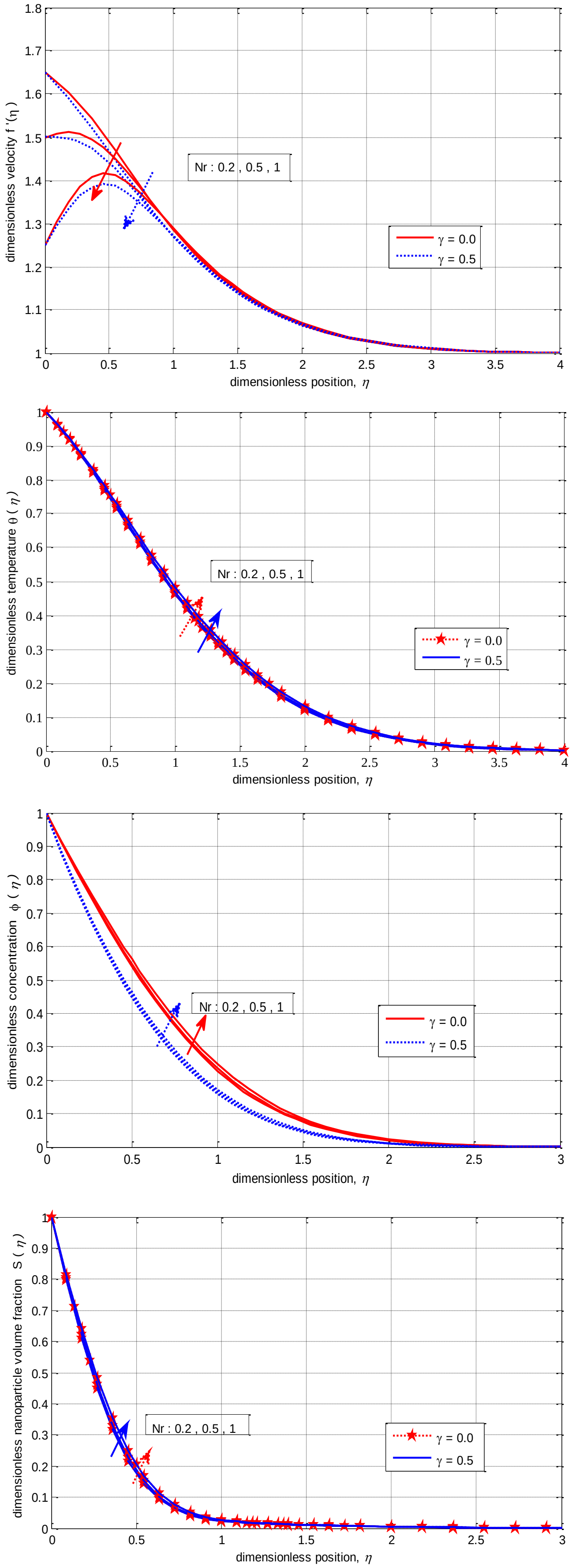

Fig. 2. *Effects of Nr on a velocity, b temperature, c concentration and d nanoparticle volume fraction profiles M = 1, Rax/Pex = 1, Nb = 0.5, Nt = 0.2, Nc = 0.5, Le = 10, Lem =2, n = 1.*

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The effect of the regular buoyancy ratio on velocity, temperature, nanoparticle volume fraction and concentration of the nanofluid is shown in Fig. 3. It is seen that if $\gamma = 0.0$ the velocity increase but the temperature, nanoparticle volume fraction and concentration decrease with increase of regular buoyancy ratio parameter. This is attributed to the increased velocity near the wall when Nc increases and hence enhances both heat and mass transfer processes. We can note that the presence of chemical reaction decrease the velocity and concentration of nanoparticle.

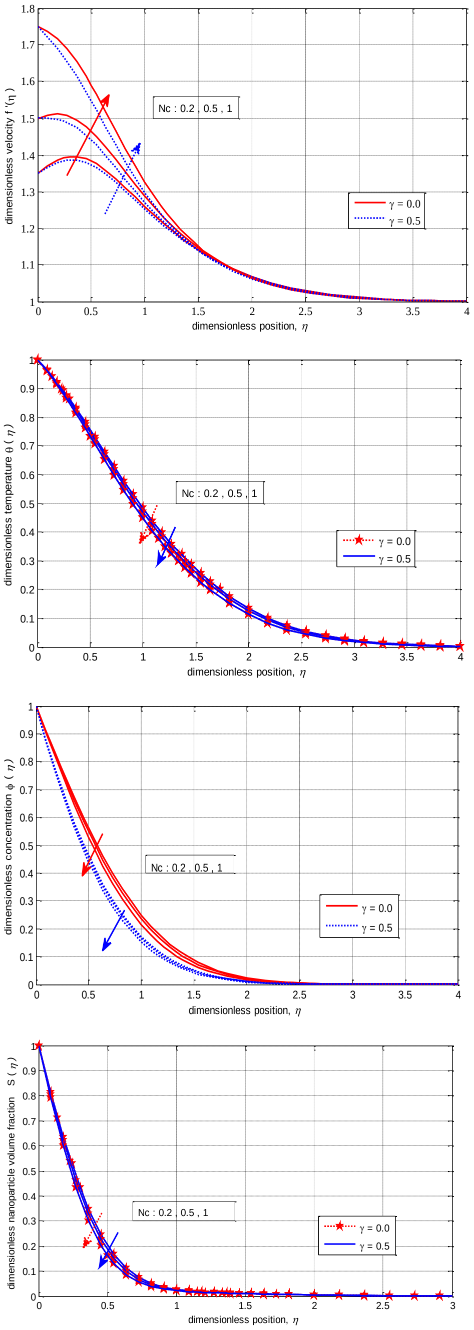
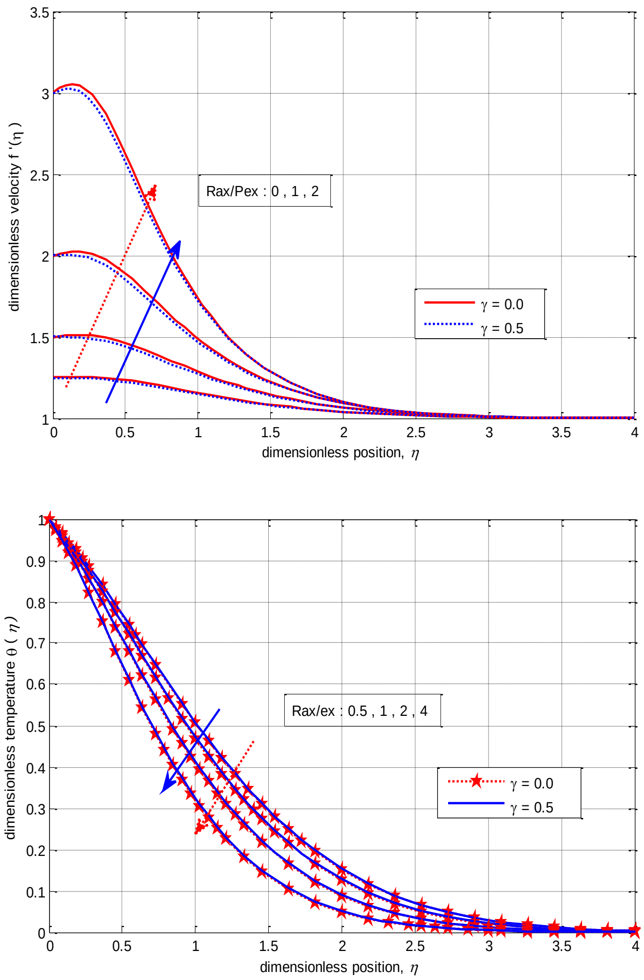


Fig. 3. *Effects of Nc on a velocity, b temperature, c concentration and d nanoparticle volume fraction profiles M = 1, Rax/Pex = 1, Nb = 0.5, Nt = 0.2, Nr = 0.5, Le = 10, Lem =2, n = 1.*

Influence of Mixed convection parameter can be seen in Fig. 4. It is clear that with an increase in Rax/Pex parameter increases the velocity and decrease temperature, nanoparticle volume fraction and concentration. We can also not that the increases of dimensionless chemical reaction parameter leads to decrease in velocity and concentration of nanofluid with no significant changes in the temperature and nanoparticule volume fraction of nanofluid.

The effect of, modified Lewis number parameter on the velocity, temperature and concentration profiles is plotted in Figs.5. With the increase in the modified Lewis number parameter both velocity and concentration decrease, but the temperature profile increase not very sensitive. This behavior may be due to the fact that increasing Le number implies that mass dispersion is less pronounced than heat dispersion and for this particular system this results in larger concentration gradient near the wall when Le number is larger. We can also not that with increases of modified Lewis number parameter no significant changes in the nanoparticule volume fraction of nanofluid. , it is seen that the presence of chemical reaction affect only the velocity and concentration profiles whose decrease if $\gamma = 0.5$.



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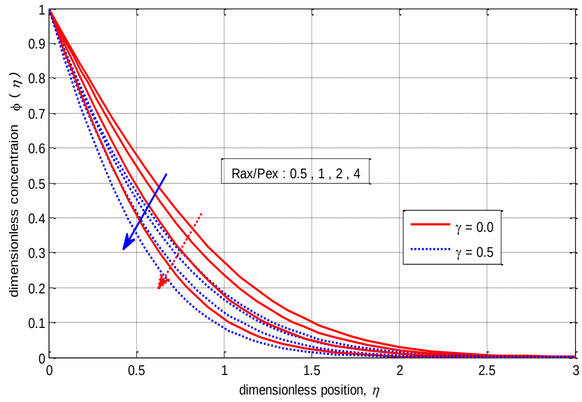


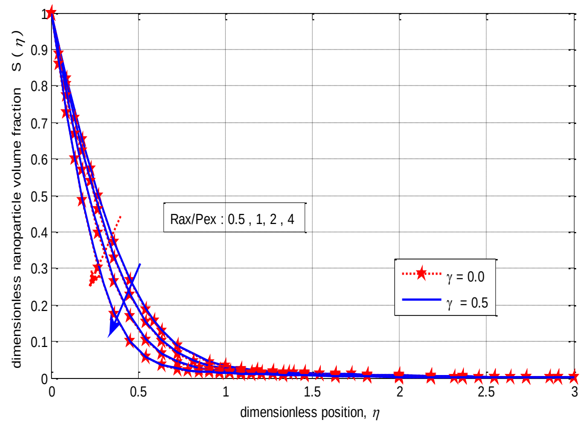
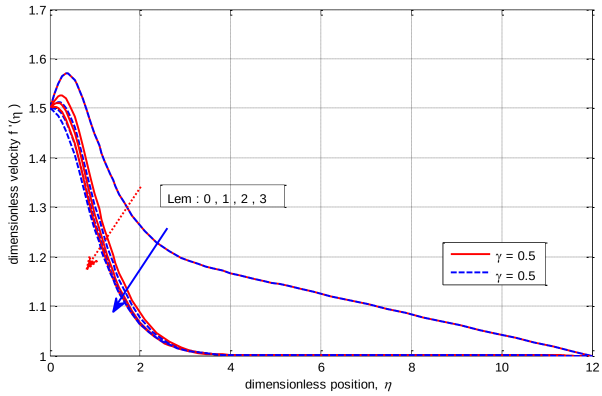
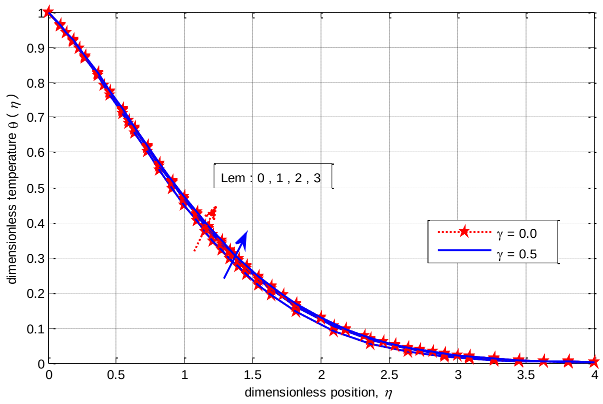


Fig. 4. *Effects of Rax/Pex on a velocity, b temperature, c nanoparticle volume fraction and d concentration profiles. M = 1, Nb = 0.5, Nt = 0.2, Nc = 0.5,Nr = 0.5, Le = 10, Lem =2, n = 1.*





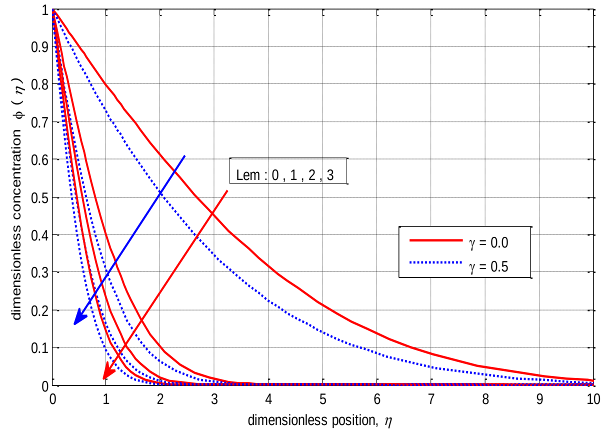
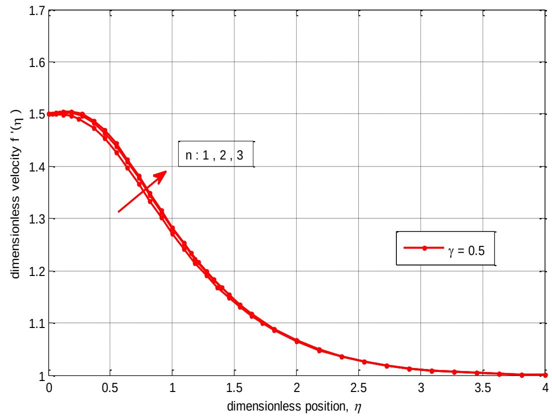


Fig. 5. *Effects of Lem on a velocity, b temperature and c concentration profiles for M = 1, Rax/Pex = 1, Nb = 0.5, Nt = 0.2, Nr = 0.5, Nc = 0.5, Le =10, n = 1.*

Figure 6: is prepared to study the effect of order of the chemical reaction parameter n on velocity and concentration. It is seen that the increase in n lead to increase only the velocity and concentration but it has no effect on the temperature and nanoparticule volume fraction.



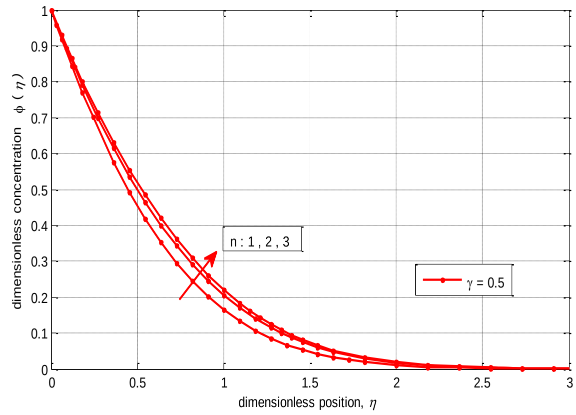


Fig. 6. *Effects of n on a velocity and b concentrate on profiles for M = 1, Rax/Pex = 1, Nb = 0.5, Nt = 0.2, Nr = 0.5, Nc = 0.5, Le =10, Lem = 2.*

In order to test the accuracy of our results, the obtained results is compared with the results of Puneet et al. [21] for local Nusselt number $Nu_x/Pe_x^{1/2} = -\theta'(0)$ and reduced Sherwood number $Sh_x/Pe_x^{1/2} = -S'(0)$ Neglecting the effects of M, Nc, Lem, n and γ. We notice that the comparison shows an excellent agreement, as presented in Table 1.

TABLE I. COMPARISON OF RESULT FOR THE REDUCED NUSSELT NUMBER AND SHERWOOD NUMBER WHILE NT = 0.5; NR=0.5; AND A=$\pi/6$.

		$Nu_x/Pe_x^{1/2}$ = -ϴ'(0)				$Sh_x/Pe_x^{1/2}$ =-S'(0)			
		Nb=0.5		Nb=1.0		Nb=0.5		Nb=1.0	
Le	Ra_x/Pe_x	Puneet [21]	Present study	Puneet [21]	Present study	Puneet [21]	Present study	Puneet [21]	Present study
5	0.3	0.3331	0.3300	0.2179	0.2224	1.3424	1.3465	1.3856	1.3895
	0.5	0.3453	0.3421	0.2260	0.2311	1.3952	1.3998	1.4439	1.4480
	1	0.3742	0.3708	0.2559	0.2516	1.5194	1.5250	1.5803	1.5850
15	0.3	0.3169	0.3123	0.1982	0.2012	2.3935	2.4031	2.4089	2.4173
	0.5	0.3300	0.3252	0.2066	0.2098	2.4992	2.5094	2.5187	2.5273
	1	0.3609	0.3554	0.2366	0.2299	2.7461	2.7575	2.7741	2.7835

The variation of the dimensionless heet transfer rates $(Nu_x/Pe_x^{1/2})$ and mass transfer rates $Sh_x/Pe_x^{1/2}$ for different values of the parameters M, n, Nc and Lem by fixing other governing parameters are displayed in Table 2 and 3. It is possible to see that as Magnetic field parameter increase, the heat transfer rate (local Nusselt number) and mass transfer rates (Sherwood number) are decreasing. We can also note that as order of the chemical reaction parameter increase, the heat transfer rate and the mass transfer rates is increasing.

TABLE II. COMPUTATION SHOWING THE VALUES LOCAL NUSSELT NUMBER $-\theta'(0)$ AT NR = 0.5, RAX/PEX = 1, NT = 0.2, NB = 0.5 ,M=1, LE = 10 AND Γ = 0.5 FOR DIFFERENT VALUES OF LEM, , N AND NC

	$Nu_x/Pe_x^{1/2} = -\theta'(0)$								
L_{em}	Nc=0.2			Nc=0.5			Nc=1		
	n=1	n=2	n=3	n=1	n=2	n=3	n=1	n=2	n=3
0	0.3962	0.3962	0.3962	0.4165	0.4165	0.4165	0.4484	0.4484	0.4484
1	0.3904	0.3909	0.3911	0.4025	0.4037	0.4041	0.4221	0.4242	0.4250
2	0.3889	0.3894	0.3895	0.3988	0.4000	0.4004	0.4149	0.4170	0.4178
3	0.3880	0.3885	0.3887	0.3967	0.3978	0.3982	0.4108	0.4128	0.4135

TABLE III. COMPUTATION SHOWING THE VALUES LOCAL SHERWOOD NUMBER $-S'(0)$ AT NR = 0.5, RAX/PEX = 1, NT = 0.2, NB = 0.5, M =1,LE = 10 AND Γ = 0.5 FOR DIFFERENT VALUES OF LEM, , N AND NC.

	$Sh_x/Pe_x^{1/2}$= - S'(0)								
L_{em}	Nc=0.2			Nc=0.5			Nc=1		
	n=1	n=2	n=3	n=1	n=2	n=3	n=1	n=2	n=3
0	2.1104	2.1104	2.1104	2.2196	2.2196	2.2196	2.3908	2.3908	2.3908
1	2.0980	2.0993	2.0999	2.1904	2.1935	2.1949	2.3375	2.3428	2.3453
2	2.0932	2.0949	2.0957	2.1790	2.1829	2.1847	2.3162	2.3230	2.3261
3	2.0899	2.0918	2.0927	2.1711	2.1755	2.1774	2.3011	2.3089	2.3123

CONCLUSION

In this study, magneto-hydrodynamic, mixed convection, boundary layer flow of nanofluid over a semi-infinite stretching surface in porous medium is studied. Effects of different parameters on the velocity, temperature, concentration and nanoparticle volume fraction profiles are investigated. The main results of present study are given below:

- It has been found that increasing the order of reaction n, increases the velocity and concentration.
- As order of the chemical reaction parameter increase, the local Nusselt number local Sherwood number is increasing.
- An increase in magnetic parameter M decreases both the local Nusselt number and local Sherwood number.

- The effect of chemical reaction is to decrease the velocity and concentration profile.

- The regular buoyancy ratio Nc increases the velocity and reduces the temperature concentration and nanoparticles volume fraction profiles.

- With an increase in mixed convection parameter Rax/Pex increases the velocity and decrease temperature, nanoparticle volume fraction and concentration.

- The increases of mixed convection parameter increase the velocity and decrease the temperature, concentration and nanoparticles volume fraction.

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