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Impact of Chemical Reaction on Radiating Falkner-Skan Flow over a Wedge Moving in a Carreau Nanofluid with Convective Condition

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Abstract*— The present endeavour is to investigate the numerical analysis of the two-dimensional unsteady flow of a Falkner-Skan radiative magnetohydrodynamic flow past over a wedge in a Carreau nanofluid by considering the convective boundary condition and chemical reaction. The governing equations of the problem are altered into dimensionless form by using the transformations. The resulting system of differential equations are solved by MATLAB bvp4c solver. The effect of significant parameters has been studied and numerical results are presented in graphs and tables. The numerical results are revealed in close relation with previously published works.

Keywords*— Carreau nanofluid, Convective Boundary condition, MHD, radiation, Static/Moving wedge, chemical reaction.

I. Introduction

The fluid flow across a wedge shaped bodies are important in several engineering applications and in the area of fluid dynamics. For instance, in aerodynamics, hydrodynamics, interchanging of heat through exchangers, geothermal structures, etc. Predominantly such type of flows are often seen in improving oil recovery, ground water pollution , response of aircrafts to atmospheric explosions, geothermal fields, etc., Researchers Falkner and Skan bring a concept of an equation known as Falkner-Skan equation where a static wedge is submerged in a viscous fluid and a fluid is passed over it. This was initially proposed for a flow over a boundary with a flow wise pressure gradient. The equation and the conditions at boundary are given as: $f''' + ff' + \lambda\left(1 - f'^2\right) = 0,\ f(0) = \beta,\ \beta$ is the strength of the mass transfer at the wall, $f'(0) = \gamma,\ f'(\infty) = 1,\ \lambda = \frac{2m}{m+1}$ is a flow wise pressure gradient. The actual Falkner-Skan equation contains zero value for β *and* γ for a non-permeable wedge flow. A lot of literature regarding the Falkner-Skan wedge flow can be found in the work of Schlichting and Gersten[1] and also in Leal[2]. The wedge is triangular shaped and is used for separating two objects, one object hold in a plane and other lifting up. It converts the lateral force into a transverse splitting force. Fang and Zhang [3] presented a solution with mass transfer and wall stretching for the Falkner-Skan equation.

Then again, due to emergent demands of advanced technologies like as power station, production of chemicals and microelectronics, there is a need to launch new types of fluids for exchanging heat more effectively. Water, ethylene glycol and engine oil are regularly used base fluids for heat transfer. These fluids have low thermal conductivity when compared with the solids. The role of tiny particles of solids can enhance the thermal conductivities of such fluids.

The concept of nanofluid was initiated by Choi and Eastman [4] for the first time. The heat conductivity of the fluid can be increased by suspending nanoparticles in a base fluid. For example, copper, carbon nanotubes, CuO, aluminia, and gold are commonly used substances as nanoparticles. Yacob et al. [5] reported the Falkner-Skan flow over a wedge by considering surface heat flux in a nanofluid.

The study of fluid which is electrically conducting passed over a heated wedge with magnetic effect has many applications such as studying about plasma, controlling the boundary layer in aerodynamics, MHD power generators, cooling the nuclear reactors so forth. Several researchers (Prasad et al., [6], Imran et al., [7], Ishak et al., [8], Vol [9], El-dabe et al., [10]) fed light on the effect of MHD heat and mass transfer flow past a wedge in different circumstances for different types of fluids. Magnetic field effects on temperature and heat transfer are very interesting because few fluids also emit and absorb thermal radiation, when the fluid is a conductor of electricity. It is noteworthy to study the heat transfer due to thermal radiation as it has many uses in space study and operating at high temperatures. Abdulhameed et al., [11] reported the impact of radiation on Falkner–Skan flow over a wedge with MHD. Radiation and mass transfer effects over a moving vertical cylinder was illustrated by Suneetha and Reddy [12] and found that as radiation parameter is small, both the fluid velocity and temperature enhances harshly near the surface of the cylinder as time passes.

Researchers show much interest on the flow problems over a boundary layer considering a convective boundary condition as such flows are essential in reducing the drag friction forces and in increasing the heat transfer rate. Such problems are first proposed by Aziz [13] who studied the convective surface boundary condition over a plane surface. Bala Anki Reddy et al., [14] studied the Boundary Layer Slip with magnetic effect over an exponentially stretching surface with convective boundary condition and is observed that the opposite behaviour of the temperature profile is observed for both radiation and the Prandtl number. Suneetha and Gangadhar [15] studied the influence of radiation on stagnation point flow by considering convective boundary condition over of a Carreau Fluid and analyzed the temperature rises by rising the values of both convective and radiation parameter for cases of shrinking and stretching sheet.

Some kind of chemical reaction is observed if there is a foreign mass in air or water. Heat is produced between two species (Byron Bird R.et al. [16]) throughout a chemical reaction. Bala Anki Reddy [17] revealed that a decrement in the concentration is observed with an increment of chemical reaction parameter and solutal buoyancy parameter while studying the MHD casson flow over a stretching surface. Md Shakhaoath Khan et al., [18] numerically studied the radiating nanofluid flow along a moving wedge with chemical reaction. Bala Anki Reddy and Suneetha[19] studied the impact of chemical reaction on stagnation flow over a stretching/shrinking sheet in a micropolar fluid and noted that the mass concentration at the sheet surface decreases with homogeneous reaction and increase with heterogeneous reaction. Suneetha and Bala Anki Reddy [20] numerically studied the chemical reaction influence over a stretching cylinder embedded in a porous medium.

The afore mentioned articles and applications in existing literature are the source of motivation to study the effects of convective boundary condition and chemical reaction on Flakner-Skan wedge flow over a static/moving wedge in a moving Carreau nanofluid. With the help of transformations, we transformed the derived governed equations as ordinary nonlinear differential equations. The mathematical solutions are determined by applying MATLAB bvp4c solver. Graphs are revealed and described for various non-dimensional governing parameters.

II. MATHEMATICAL FORMULATION

Let us examine the Falkner-Skan flow of Carreau nanofluids past a static/moving wedge with the external time dependent magnetic field and convective boundary condition. An unsteady, incompressible, two-dimensional flow is considered. It is assumed that fluid flow is instigated by a stretching wedge with the velocity $U_w(x,t)=\frac{bx^m}{1-ct}$ as well as the free stream velocity $U_e(x,t)=\frac{ax^m}{1-ct}$ where a, b, c and m are greater than zero and are constants with $0 \le m \le 1$. It is noted that $U_w(x,t)>0$ in agreement to a surface velocity of stretching wedge and $U_w(x,t)<0$ compares to surface velocity of a shrinking wedge (see Fig .1). The wedge angle is assumed to be $\Omega=\beta\pi$ an external time dependent magnetic field, denoted by $B(x)=\frac{B_0}{(1-ct)^{1/2}}$ is used perpendicular to the wedge surface. By convection, the surface below the wedge is heated from a hot fluid with temperature $T_w(x,t)$ which affords a heat transfer coefficient h_f. In addition, assumed that the ambient temperature T_∞ and ambient concentration C_∞ are smaller than the temperature $T_w(x,t)$ and concentration $C_w(x,t)$ at the surface of wedge. The thermophoresis and Brownian motion effects are considered due to the nanoparticles. The Cauchy stress tensor for the generalized Newtonian Carreau fluid (Bird et al., [21], Carreau [22], Khan and Hashim [23]) can be written as $\tau=-pI+\mu A_1 \;\; with \; \mu=\mu_\infty+(\mu_0-\mu_\infty)\left[1+(\Gamma\gamma)^2\right]^{\frac{n-1}{2}}$

$$\gamma=\sqrt{\frac{1}{2}\sum_i\sum_j\gamma_{ij}\gamma_{ji}}=\sqrt{\frac{1}{2}tr\left(A_1^2\right)} \tag{2}$$

where γ represents the shear rate, $\boldsymbol{I}$ - identity tensor, n - the power law index, p - the pressure, Γ - time material parameter, μ_0 - zero shear rate viscosity, μ_∞ - the infinite shear rate viscosity and $A_1=(gradV)+(gradV)^T$ represents the initial Rivlin-Ericksen tensor. In many physical problems, we can consider μ_∞ = 0. Thus, Eq. (1) - (2) can be reduced as

$$\mu=\mu\left[1+(\Gamma\gamma)^2\right]^{\frac{n-1}{2}} \tag{3}$$

The velocity field, temperature field and concentration fields for a two-dimensional unsteady wedge flow assumed

$$V=[u,v,0],u=u(x,y,t),v=v(x,y,t),T=T(x,y,t),C=C(x,y,t). \tag{4}$$

The governing equations for continuity, momentum, energy and species for a Carreau nanofluid with magnetic field can be written as (Khan and Azam [24] (2016))

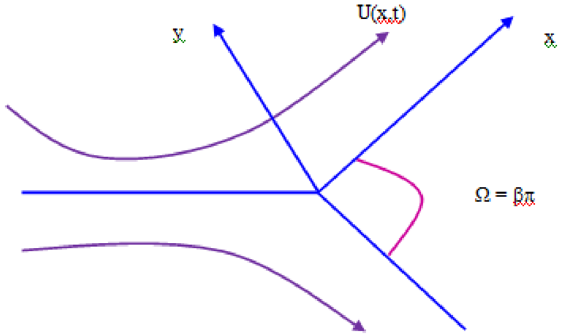

Fig.1 Physical sketch of the problem

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{5}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{\partial U_e}{\partial t}+U_e\frac{\partial U_e}{\partial x}+\nu\frac{\partial^2 u}{\partial y^2}\left(1+\Gamma^2\left(\frac{\partial u}{\partial y}\right)^2\right)^{\frac{n-1}{2}}+\nu(n-1)\Gamma^2\frac{\partial^2 u}{\partial y^2}\left(\frac{\partial u}{\partial y}\right)^2\times\left[1+\Gamma^2\left(\frac{\partial u}{\partial y}\right)^2\right]^{\frac{n-3}{2}}-\frac{\sigma B^2(t)}{\rho}(u-U_e) \tag{6}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\tau\left[D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right]+\frac{16\sigma^*}{3k^*\rho c_p}\frac{\partial}{\partial y}\left(T^3\frac{\partial T}{\partial y}\right) \tag{7}$$

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2}-k_0\left(C-C_\infty\right) \tag{8}$$

along with the boundary conditions

(i) static wedge $u=0,\ v=0,\ -k\dfrac{\partial T}{\partial y}=h_f(T_w-T),\quad C=C_w(x,t)\quad at\ y=0$ (9)

$$u\to U_e\ ,T\to T_\infty, C\to C_\infty\quad as\ y\to\infty \tag{10}$$

(ii) moving wedge $u=U_w=\lambda U_e,\ v=0,\ -k\dfrac{\partial T}{\partial y}=h_f(T_w-T),\quad C=C_w(x,t)\quad at\ y=0$ (11)

$$u\to U_e\ ,T\to T_\infty, C\to C_\infty\quad as\ y\to\infty \tag{12}$$

where $\tau=\left((\rho c)_p\big/(\rho c)_f\right)$ denotes the proportion of the heat capacity of the nanoparticle to the heat capacity of the fluid, D_T - diffusion coefficient for thermophoresis , D_B the diffusion coefficient for Brownian motion , $\alpha=\left(\dfrac{k}{\rho c_p}\right)$ the thermal diffusivity, T the temperature of the fluid and C the concentration of the nanoparticle. Also, the stretching velocity $U_w(x,t)$, velocity of the free stream $U_e(x, t)$, temperature on the surface of the fluid $T_w(x, t)$, nanoparticle concentration on the surface of the fluid $C_w(x, t)$ and magnetic field $B(t)$ which is time dependent are assumed to be the form

$$U_w(x,t)=\frac{bx^m}{1-ct},\quad T_w(x,t)=T_\infty+\frac{T_0U_wx}{v(1-ct)^{1/2}},\ U_e(x,t)=\frac{ax^m}{1-ct},\quad C_w(x,t)=C_\infty+\frac{C_0U_wx}{v(1-ct)^{1/2}},\ B(t)=\frac{B_0}{(1-ct)^{1/2}}, \tag{13}$$

where T_0 and C_0 represent the initial temperature and concentration respectively.

We employ the given below similarity transformations for converting the governing equations into ordinary differential equations

$$\psi(x,y,t)=\sqrt{\frac{2\nu xU_e}{m+1}}\,f(\eta),\ \eta=\sqrt{\frac{(m+1)U_e}{2x\nu}}\,y\ ,\theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},\phi(\eta)=\frac{C-C_\infty}{C_w-C_\infty}, \tag{14}$$

where ψ denotes the stream function which satisfies the continuity equation with

$$(u,v)=\left(\frac{\partial\psi}{\partial y},-\frac{\partial\psi}{\partial x}\right).$$

Thus, the non-linear equations of momentum, energy and species are expressed as

$$\left\{1+nWe^2(f'')^2\right\}\left\{1+We^2(f'')^2\right\}^{\frac{n-3}{2}}f'''+ff''+\beta\left\{1-(f')^2\right\}-A(2-\beta)\left\{f'+\frac{\eta}{2}f''-1\right\}-Ha^2(2-\beta)\left\{f'-1\right\}=0 \tag{15}$$

$$\theta''+\Pr(f\theta'-2f'\theta)-\Pr\left(\frac{A}{2}\right)(2-\beta)\{\eta\theta'+3\theta\}+\Pr Nb\theta'\phi'+\Pr Nt(\theta')^2+\theta''Nr=0 \tag{16}$$

$$\phi''+\Pr Le(f\phi'-2f'\phi)-\Pr Le\left(\frac{A}{2}\right)(2-\beta)\{\eta\phi'+3\phi\}+\frac{Nt}{Nb}\theta''-\Pr Le Kr\phi=0 \tag{17}$$

and the boundary conditions are

$$f(0)=0,\ f'(0)=\lambda,\ \theta'(0)=-\gamma(2-\beta)^{1/2}\{1-\theta(0)\},\ \phi(0)=1, \quad (18)$$

$$f'(0)\to 1, \theta(\infty)\to 0,\ \phi(\infty)\to 0, \quad (19)$$

Where $We=\left(\sqrt{\frac{\Gamma^2(m+1)U_e^3}{2\nu x}}\right)$ is the local Weissenberg number, $A=\left(\frac{c}{ax^{m-1}}\right)$ unsteadiness parameter, $(Ha)^2=\left(\frac{\sigma B_0^2}{\rho a x^{m-1}}\right)$ Hartmann parameter, $Le=\left(\frac{\alpha}{D_B}\right)$ the Lewis number, $Nt=\left(\frac{\tau D_T(T_w-T_\infty)}{\upsilon T_\infty}\right)$ the thermophoresis parameter, $Nb=\left(\frac{\tau D_B(C_w-C_\infty)}{\upsilon}\right)$ the Browinian motion parameter, $\Pr=\frac{\upsilon}{\alpha}$ the Prandtl number, $\beta=\left(\frac{2m}{m+1}\right)$ the Wedge angle parameter, $\lambda=\left(\frac{U_w}{U_e}\right)$ the velocity ration parameter, $\gamma=\left(\frac{h_f}{k}x\operatorname{Re}^{-\frac{1}{2}}\right)$ the generalized Biot number.

In sight of physical point, the local skin friction coefficient C_f, the local Nusselt number *Nu* and the local Sherwood number *Sh* are the important characteristics of flow which are defined as

$$Cf_x=\frac{\tau_w}{\rho U_e^2}\ Nu_x=\frac{xq_w}{k(T_w-T_\infty)},\ Sh=\frac{xq_m}{D_B(C_w-C_\infty)}, \quad (20)$$

where τ_w, q_w and q_m denote the wall shear stress, wall heat flux and wall mass flux, respectively, which are defined as

$$\tau_w=\mu_0\left(\frac{\partial u}{\partial y}\right)\left(1+\Gamma^2\left(\frac{\partial u}{\partial y}\right)^2\right)^{\frac{n-1}{2}}\Bigg|_{y=0} \qquad q_w=-k\left[\frac{\partial T}{\partial y}\right]_{y=0}, q_m=-D_B\left(\frac{\partial C}{\partial y}\right)_{y=0}. \quad (21)$$

Using Eqs. (14), (20) and (21), we obtain the following non-dimensional expressions

$$(2-\beta)^{\frac{1}{2}}\operatorname{Re}^{1/2}C_f=f''(0)\left[1+We^2\left(f''(0)\right)^2\right]^{\frac{n-1}{2}},\ (2-\beta)^{\frac{1}{2}}\operatorname{Re}^{1/2}Nu=-\theta'(0),\ (2-\beta)^{\frac{1}{2}}\operatorname{Re}^{1/2}Sh=-\varphi'(0) \quad (22)$$

where $\operatorname{Re}=\left(\frac{xU_e}{\nu}\right)$ ıdicates the local Reynolds number.

III. RESULTS AND DISCUSSION

The transformed system of equations (15) - (17) with the boundary conditions (18) and (19) are solved numerically by employing a numerical procedure namely bvp4c function in Matlab. Computations are performed for different flow governing parameters namely the local Weissenberg number *We*, the unsteadiness parameter *A*, the wedge angle parameter *β*, the generalizes Biot number *γ*, the Hartmann number *Ha*, the Prandtl number *Pr*, the Lewis number *Le*, the Brownian motion parameter *Nb*, the thermophoresis parameter *Nt*, the velocity ratio parameter *λ*, and the radiation parameter *Nr*.

To prove the authenticity of the achieved numerical results, a comparison with the existing literature is conducted. The obtained results of the skin friction coefficient is comparable with those reported by Rajagopal et al. [25], Kuo [26] and Ishaq et al. [27] (Table 1). An outstanding agreement with the results of the above mentioned authors has been identified.

Table 2 is portrayed to demonstrate the impact of the unsteadiness parameter *A*, the wedge angle parameter *β*, the Hartmann number *Ha*, the velocity ratio parameter *λ*, the Radiation parameter *Nr*, the Prandlt number *Pr*, the nanoparticle concentration *Kr*, the thermophoresis parameter *Nt*, the Brownian motion parameter *Nb*, the Biot number *γ* and the local Weissenberg number *We* on the local skin-friction coefficient, Nusselt number and Sherwood number. On the basis of this table, it is noticed that the local skin friction coefficient, Nusselt number and Sherwood number enhances by enhancing the values of the unsteadiness parameter and Hartmann number. The rising values of *Nr* and *Nt* have the tendency to decline the Nusselt number and Sherwood number whereas *Nb* rises the Sherwood number. The increasing the values of the nanoparticle concentration encourage the Sherwood number but the the velocity ratio parameter declines the same.

The influence of the unsteadiness parameter *A* on the velocity profile is presented in Fig. 2. From this, it can be seen that an increment in the values of the unsteadiness parameter improves the velocity profile. For static wedge the value of *λ* is zero, and *λ* > 0 denotes the stretching wedge. The velocity and temperature distribution are plotted in Figs.3 and 4 for the impact of the wedge angle parameter *β*. The figure shows that the impact of *β* resembles as the unsteadiness parameter. Positive values of the wedge angle parameter correspond a favourable pressure gradient which grows the flow. Also,
β = 0 corresponds to wedge whose angle is zero degree (flow past a flat plate) and *β* = 0 relates to wedge angle of 90◦ C degree (stagnation point flow). The variation of the velocity profile is represented through Fig.5 for different values the local Weissenberg number *We*. The figure exhibits that the velocity graphs increase by uplifting the values of the *We*. In Fig.6, the impact of the Hartmann number *Ha* on the velocity profile is depicted. An increment in *Ha* increases velocity. The impact of the Biot number *γ* on the temperature is presented through Fig.7 for both cases. An observation of the figure makes it clear that the boundary layer thickness and the temperature are the growing function of the Biot number. The Biot number defines the ratio of internal thermal resistance of a solid to thermal resistance of a boundary layer. When *γ* = 0, the surface of the wedge is entirely isolated. It means the internal thermal resistance of the surface of the wedge is very high and there is no heat transfer from the surface of the wedge to the fluid which is away from wedge. The thermophoresis parameter *Nt* has a valuable importance for investigating the temperature distributions in nanofluid flow. The effect of the thermophoresis parameter on the temperature is elucidated through Fig. 8 for both the cases. The

figure reveals that the temperature enhance by uplifting the thermophoresis parameter. From a physical perspective, the thermophoresis force enhances with the enhancement of *Nt* which tend to shift nanoparticles from hot region to cold region and hence enhances the magnitude of the temperature. Figs. 9 -10 present the variation of the temperature and concentration contours for distinct values of the Brownian motion parameter. It is depicted that non-dimensional temperature increases by uplifting *Nb* and a decrement is observed in concentration profiles. Furthermore, boundary layer thickness is an enhancing function of *Nb*, by enhancing the Brownian motion parameter, the intensity of this disordered motion increases the kinetic energy of the nanoparticles and as a result fluid temperature increases. To illustrate the influence of Lewis number *Le* on concentration profiles, Fig.11 is presented. It is observed that the nanoparticle concentration and the boundary layer thickness diminish by rising the values of the *Le*. In fact, the mass transfer rate increases as *Le* increases. A decrement is observed in Brownian diffusion coeffcient for higher *Le* in a base fluid which result in a shorter penetration power for the concentration boundary layer thickness. The effect of *Kr* on nanoparticle concentration profile for various values of λ are shown in Fig. 12. As *Kr* increases the nanoparticle concentration decreases for the both the cases static wedge and stretching wedge. It is further observed that the fluid concentration was smaller for stretching wedge when compared with static wedge.Fig.13 reveal the impact of radiation parameter *Nr* on temperature profile for various values of λ. Rising values of *Nr* generates internal heat energy, and this helps to boosting the temperature field. It is noticed a rise in the temperature for increasing values of *Nr* for both static wedge and stretching wedge.

TABLE 1: A comparison of the results of $-f''(0)$ for various values of the wedge angle parameter β when $We = Ha = Nr = Kr = \lambda = 0$ and $n = 1$.

β	Rajagopal et al.[25]	Kuo [26]	Ishaq et al.[27]	Present results
0.0	--	0.469600	0.4696	0.46965999
0.1	0.587035	0.587880	0.5870	0.58703521
0.3	0.774755	0.775524	0.7748	0.77475458
0.5	0.927680	0.927905	0.9277	0.92768003
1.0	1.232585	1.231289	1.2326	1.23258765

TABLE 2: Numerical values of $(2-\beta)^{1/2}\mathrm{Re}^{1/2}C_f$, $(2-\beta)^{1/2}\mathrm{Re}^{-1/2}Nu$, $(2-\beta)^{1/2}\mathrm{Re}^{-1/2}Sh$ for various values of *A*, β, *Ha*, λ, *We*, *Nr*, *Pr*, *Kr*, γ, *Nt*, *Nb* for *n*=0.5.

Parameters											$(2-\beta)^{1/2}\mathrm{Re}^{1/2}C_f$	$(2-\beta)^{1/2}\mathrm{Re}^{-1/2}Nu$	$(2-\beta)^{1/2}\mathrm{Re}^{-1/2}Sh$
A	β	*Ha*	λ	*We*	*Nr*	*Pr*	*Kr*	γ	*Nt*	*Nb*			
0.2	0.5	0.1	0.2	0.5	0.1	2.0	0.2	0.1	0.5	0.5	0.917335	0.109085	2.399855
0.0	0.5	0.1	0.2	0.5	0.1	2.0	0.2	0.1	0.5	0.5	0.831173	0.106688	2.093761
1.0	0.5	0.1	0.2	0.5	0.1	2.0	0.2	0.1	0.5	0.5	1.233662	0.113353	3.403309
2.0	0.5	0.1	0.2	0.5	0.1	2.0	0.2	0.1	0.5	0.5	1.583214	0.115423	4.368782
0.2	0.0	0.1	0.2	0.5	0.1	2.0	0.2	0.1	0.5	0.5	0.618211	0.123981	2.411091
0.2	1.0	0.1	0.2	0.5	0.1	2.0	0.2	0.1	0.5	0.5	1.156215	0.090738	2.365696
0.2	0.5	0.0	0.2	0.5	0.1	2.0	0.2	0.1	0.5	0.5	0.911382	0.109077	2.398478
0.2	0.5	0.5	0.2	0.5	0.1	2.0	0.2	0.1	0.5	0.5	1.052858	0.109256	2.429866
0.2	0.5	0.1	0.3	0.5	0.1	2.0	0.2	0.1	0.5	0.5	1.008608	0.108161	2.235388
0.2	0.5	0.1	0.4	0.5	0.1	2.0	0.2	0.1	0.5	0.5	1.169836	0.105610	1.879337
0.2	0.5	0.1	0.2	1.0	0.1	2.0	0.2	0.1	0.5	0.5	1.237989	0.103752	1.684987
0.2	0.5	0.1	0.2	2.0	0.1	2.0	0.2	0.1	0.5	0.5	1.006790	0.109184	2.417480
0.2	0.5	0.1	0.2	0.5	0.5	2.0	0.2	0.1	0.5	0.5	1.262498	0.109444	2.465450
0.2	0.5	0.1	0.2	0.5	1.0	2.0	0.2	0.1	0.5	0.5	0.917335	0.108620	2.398171
0.2	0.5	0.1	0.2	0.5	0.1	3.0	0.2	0.1	0.5	0.5	0.917335	0.107974	2.397434
0.2	0.5	0.1	0.2	0.5	0.1	4.0	0.2	0.1	0.5	0.5	0.917335	0.108487	2.901750
0.2	0.5	0.1	0.2	0.5	0.1	2.0	0.5	0.1	0.5	0.5	0.917335	0.107285	3.325351
0.2	0.5	0.1	0.2	0.5	0.1	2.0	1.5	0.1	0.5	0.5	0.917335	0.108872	2.622956
0.2	0.5	0.1	0.2	0.5	0.1	2.0	0.2	0.5	0.5	0.5	0.917335	0.108303	3.272437
0.2	0.5	0.1	0.2	0.5	0.1	2.0	0.2	1.0	0.5	0.5	0.917335	0.369312	2.388132
0.2	0.5	0.1	0.2	0.5	0.1	2.0	0.2	0.1	1.0	0.5	0.917335	0.516332	2.389718
0.2	0.5	0.1	0.2	0.5	0.1	2.0	0.2	0.1	1.5	0.5	0.917335	0.108744	2.392818
0.2	0.5	0.1	0.2	0.5	0.1	2.0	0.2	0.1	0.5	1.0	0.917335	0.108386	2.388852
0.2	0.5	0.1	0.2	0.5	0.1	2.0	0.2	0.1	0.5	1.5	0.917335	0.102877	2.420953

IV. CONCLUSIONS

In this article, the locally-similar numerical solutions have been computed for the unsteady two-dimensional Falkner-Skan flow of MHD Carreau nanofluid past a static/moving wedge affected by the thermophoresis and Brownian motions in the presence of the convective boundary condition. Radiation and chemical reaction are also considered. The time dependent non-linear partial differential equations were transformed to a set of semi-coupled non-linear ordinary differential equations and then solved numerically by utilizing numerical technique namely the bvp4c function in Matlab. The important findings of this article are listed below:

1. The parametric study indicated that the flow, temperature and concentration fields were greatly affected by the Hartmann number, wedge angle and unsteadiness parameters.
2. The velocity of the fluid was smaller for static wedge when compared to the stretching wedge. However, qualitatively quite the opposite trend was observed for the temperature and concentration fields.
3. The nanoparticle concentration and the concentration boundary layer thickness lessen by uplifting the values of the Lewis number.
4. The temperature and nanoparticle concentration boost by rising the thermophoresis parameter.
5. The temperature and thermal boundary layer thickness are the growing function of the Biot number.
6. The temperature increases by enhancing the Brownian motion parameter and a decrement is observed in concentration profiles.
7. The temperature and nanoparticle concentration enhance by uplifting the thermophoresis parameter.
8. As *Kr* increases the nanoparticle concentration decreases for the both the cases $\beta = 0$ and $\beta = 1$.
9. Rising values of thermal radiation also rises the temperature near the plate.

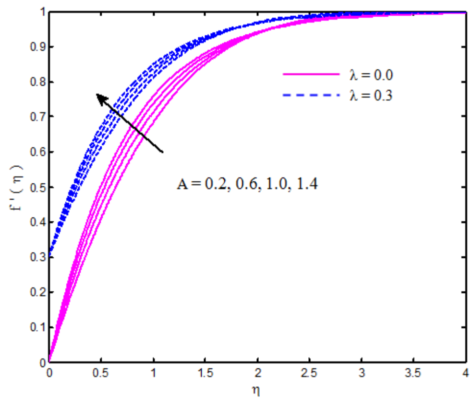

Fig. 2 Effects of *A* on the velocity profile.

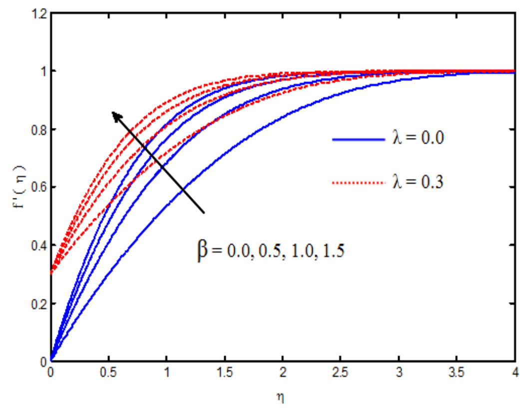

Fig. 3 Effects of β on the velocity profile.

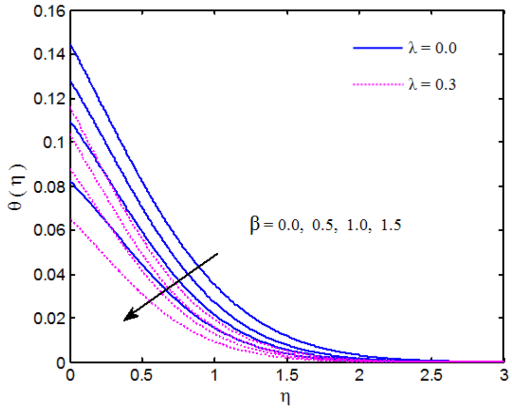

Fig.4 Effect of β on the temperature profile.

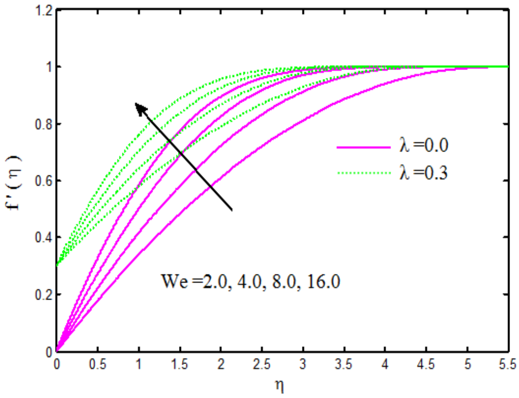

Fig. 5 Effect of the *We* on the velocity profile.

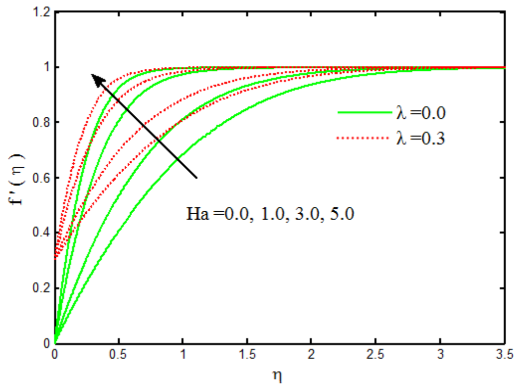

Fig. 6 Effect of *Ha* on the velocity profile.

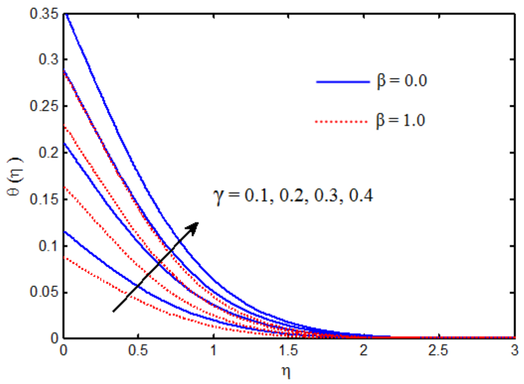

Fig.7 Effect of γ on the temperature profile.

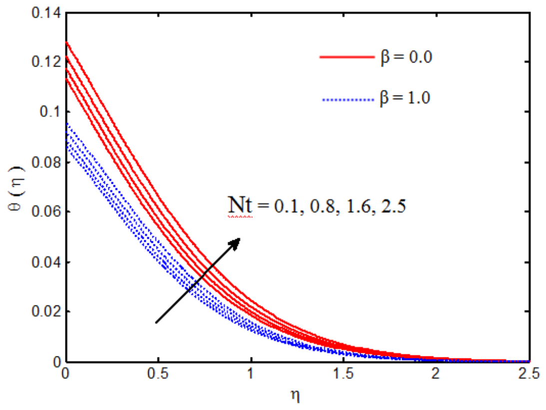

Fig.8 Effect of the *Nt* on the temperature profile.

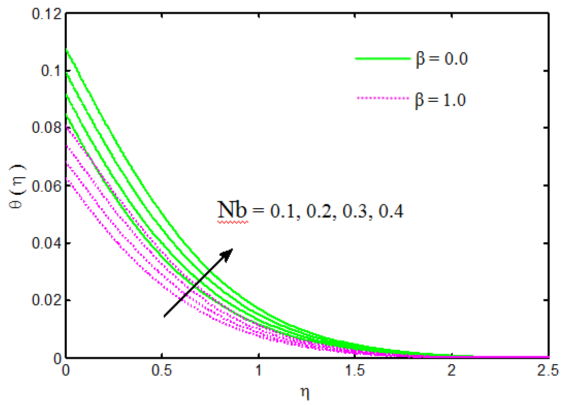

Fig.9 Effect of *Nb* on the temperature profile.

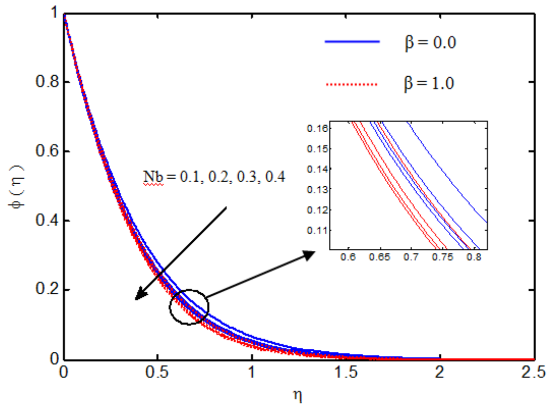

Fig.10 Effect of *Nb* on the concentration profile.

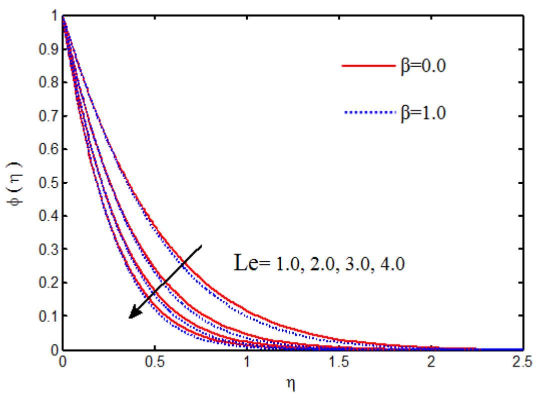

Fig. 11 Impact of *Le* on the nanoparticle concentration profile.

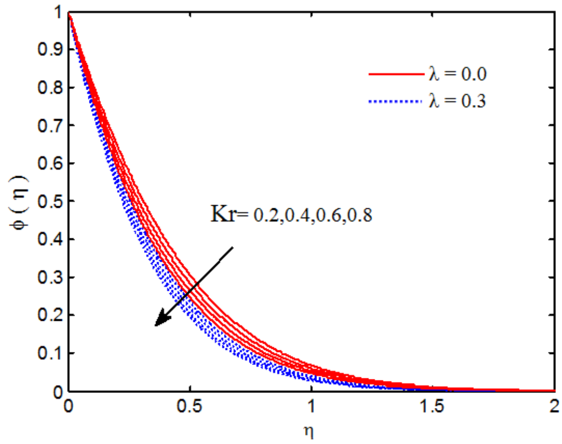

Fig.12 Impact of *Kr* on the nanoparticle concentration profile.

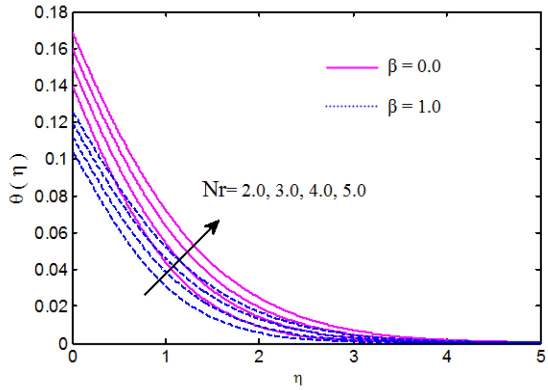

Fig.13 Effect of *Nr* on the temperature profile.

REFERENCES

1. H. Schlichting and K. Gersten, Boundary Layer Theory, Eighth revised Ed., Berlin: Springer-Verlag, 2000.
2. L.G., Leal, Advanced Transport Phenomena: Fluid Mechanics and convective Transport Processes, New York: Cambridge University Press, 2007.
3. T. Fang and J. Zhang, “An exact analytical solution of the falkner- skan equation with mass transfer and wall stretching,” *Int. J. Non-Linear Mech.*, vol. 43, pp. 1000–1006, *2008*. (http://dx.doi.org/10.1016/j.ijnonlinmec.2008.05.006.)
4. S.U.S. Choi and J.A., “Eastman, enhancing thermal conductivity of fluids with nanoparticles,” *ASME Pub. Fed*, vol. 231, pp. 99–106, 1995.
5. N.A. Yacob, A. Ishaq, R. Nazar, and I. Pop, “Falkner-skan problem for a static and moving wedge with prescribed surface heat flux in a nanofluid,” *Int. Commun. Heat Mass Transf*, vol. 38, pp. 149–153, 2011.
6. K.V. Prasad, P.S. Datti, and K. Vajravelu, “MHD mixed convection flow over a permeable non-isothermal wedge,” *Journal of King Saud University Scienc*, vol. 25, pp. 313–324, 2013.
7. Imran Ullah, Ilyas khan, and Sharidan Shafie, “hydromagnetic falkner-skan flow of casson fluid past a moving wedge with heat transfer,” *Alexandria Engineering Journa*, vol. 55, pp. 2139–2148, 2016.
8. A. Ishaq, R. Nazar, and I. Pop, “Moving wedge and flat plate in a micropolar fluid,” *Int. J. Eng. Sci*, vol. 44, pp. 1225−1236, 2006.
9. ME. Vol, “Effect of the magnetic field on forced convection flow along a wedge with variable viscosity,” *Mech. Mech. Eng*, vol.7, pp. 107–117, 2004.
10. N.T. El-dabe, A.Y. Ghaly, R.R. Rizkallah, and K.M. Ewis, “Numerical solution of MHD boundary layer flow of non-newtonian casson fluid on a moving wedge with heat and mass transfer and induced magnetic field,” *J. Appl. Math. Phys*, vol.3, pp. 649-663, 2015.
11. M. Abdulhameed, H .Saleh, I .Hashim, and R. Roslan, “Radiation effects on two-dimensional MHD falkner–skan wedge flow,” *Appl Mech Mater*, vol. 773–774, pp. 368–372, 2015.

12. S .Suneetha, and N.Bhaskar Reddy, "Radiation and mass transfer effects on mhd free convection flow past a moving vertical cylinder embedded in porous medium," *Journal of Naval Architecture and Marine Engineering*, vol.7, no.1, pp. 1-10, 2010. (ISSN: 1813-8535)
13. A. Aziz, "A similarity solution for laminar thermal boundary layer over a flat plate with a convective surface boundary condition," *Commun. Nonlinear Sci. Numer. Simulat*, vol. 4, pp.1064-1068, 2009.
14. P. Bala Anki Reddy, "Magnetohydrodynamic flow of a casson fluid over an exponentially inclined permeable stretching surface with thermal radiation and chemical reaction," *Ain Shams Engineering Journal*, vol. 7, no. 2, pp. 593-602, 2016.
15. S. Suneetha and K. Gangadhar, "Thermal radiation effect on mhd stagnation point flow of a carreau fluid with convective boundary condition," *Open Science Journal of Mathematics and Application*, vol. 3, no. 5, pp. 121-127, 2015.
16. R.Byron Bird, Warren E Stewart, and N. Edwin Lightfoot., *Transport phenomena.* John Wiley and Sons, New York. 1992.
17. P. Bala Anki Reddy, "Magnetohydrodynamic flow of a casson fluid over an exponentially inclined permeable stretching surface with thermal radiation and chemical reaction," *Ain Shams Engineering Journal*, vol. 7, pp. 593–602, 2016.
18. Shakhaoath Khan Md, Ifsana Karim, Sirajul Islam Md, and Mohammad Wahiduzzaman, "MHD boundary layer radiative, heat generating and chemical reacting flow past a wedge moving in a nanofluid," *Nano Convergence*, vol. 1,no. 1, 20, 2014.
19. P. Bala Anki Reddy and S. Suneetha, "effects of homogeneous-heterogeneous chemical reaction and slip velocity on mhd stagnation flow of a micropolar fluid over a permeable stretching/shrinking surface embedded in a porous medium," *Frontiers in Heat and Mass Transfer*, vol. 8, no. 24, 2017. (DOI: 10.5098/hmt.8.24)
20. S. Suneetha, and P .Bala Anki Reddy, "Impact of chemical reaction over a stretching cylinder embedded in a porous medium with lorentz forces," *Research Journal of Pharmacy and Technology*, vol. 9, no. 12, pp. 2415-2421, 2016. DOI No: 10.5958/0974-360X.2016.00482.0
21. R. Byron Bird, Warren E. Stewart, and N. Edwin Lightfoot, *Transport phenomena*, New York: John Wiley and Sons, 1992.
22. P.J. Carreau, "Rheological equations from molecular network theories. *Trans. Soc. Rheol,* vol. 116, pp. 99−127, 1972.
23. Khan M. Hashim, "Boundary layer flow and heat transfer to carreau fluid over a nonlinear stretching sheet," *AIP Adv*, vol. 5, 107203, 2015.
24. M, Khan and M. Azam, "Unsteady boundary layer flow of carreau fuid over a permeable stretching surface," *Results Phys*, vol. 6, pp.1168−1174, 2016.
25. K.R. Rajagopal, A.S. Gupta, and Na TY, "A note on the falkner-skan flows of a non- newtonian fluid," *Int. J. Non-Linear Mechanics*, vol. 18, no. 4, pp. 313−320, 1982.
26. B.L. Kuo, "Application of the differential transformation method to the solutions of falkner-skan wedge flow," *Acta Mechanica*, vol. 164, pp. 161−174, 2003.
27. A. Ishaq, NazarR, and I. Pop, "Moving wedge and flat plate in a micropolar fluid," *Int. J. Eng.* Sci, vol. 44, pp. 1225−1236, 2006.