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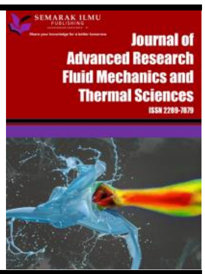

Effect of Temperature Gradient Dependent Heat Source, Secondary Velocity on Mixed Convective Flow of Nanofluid through Non-Darcy Porous Medium with Hall Currents Over an Exponentially Stretching Surface with Non-Linear Thermal Radiation

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ABSTRACT

The impact of trice request slip, non-direct warm radiation, slanted attractive field, Hall flows, compound response and dissemination on non-Darcy convective intensity and mass exchange stream of nanofluid through a permeable medium beyond a dramatically extending sheet with space temperature inclination subordinate intensity sources is well thought-out employ Runge-Kutta-Shooting strategy the conditions are assessed for various varieties. It is found that an increasing with slip parameter (A1), inclination (α), reduces f',ϕ and enhances g,θ. An opposite effect is observed with raising values of second order slip (B), the non-linearity (θ_w) in thermal radiation leads to a depreciation in the velocity components, temperature and ϕ.

1. Introduction

In the course of many automatic forming methods consisting of extrusion melt-spinning cooling of a large metallic plate in a bath makeup of plastic and rubber sheets glass blowing non-stop casting and spinning of fibers the extruded fabric problems thru a die. Motivated via the system of polymer extrusion wherein extradite emerges from a narrow slit first analyzed the double-dimensional fluid glide over a linearly surface of Stretching [2,6,15].

The existing several researchers [1,16,21,29] were investigated the influence of non-linear thermal radiation on three dimensional steady flow of a nanofluid past a non-linear stretching sheet in the presence of Soret and Dufour effects and thermal radiation, heat generation/absorption. Suguna *et al.,* [31], Bhimsen kala *et al.,* [4] have analysed the effect of thermophoresis on unsteady MHD convective heat and mass transfer flow of a viscous rotating fluid past a stretching surface with non-linear thermal radiation, thermo-diffusion in presence of heat source.

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The method of nano-fluids by utilizing a mixture of nano-particles and therefore the base liquids has been thought of by Choi [5], the rise within the heat physical phenomenon and alter in properties, for example, consistency and specific intensity in distinction with the bottom liquid is owing to occurrence of the nano-particles in the nano-fluids and warmth transfer flow of stretching sheet. It has drawn in numerous analysts to play out its designing applications by several authors [3,8-14,17, 22-29,32-37].

The effect of velocity and thermal slip, peristalsis transport and convective and boundary conditions on flow characteristics has been analysed by several authors [7,18-20].

In this examination paper, we momentarily break down the impact of second request slip, slanted attractive field, dispersal, Hall flows on the non-Darcy convective intensity and mass exchange stream of a nanofluid through a permeable medium beyond a permeable dramatically extending surface affected by attractive field. The non-direct overseeing conditions have been settled by fourth request Runge-Kutta-shooting procedure. The velocities (f′, g), temperature (θ) and nanoparticle volume fraction (ϕ), skin friction(τx,τz), Nusselt(Nu) and Sherwood(Sh), Numbers have been examined graphically and tabular for various varieties of overseeing boundaries.

2. Formulation of the Problem

The steady layer flow past a rotating stretching sheet surface in a porous medium is considered. A magnetic field of strength Ho is applied inclined at angle (α), with components (0, Ho Sin (α), Ho Cos (α)). Assuming that the plate is exponentially stretched we take the velocity $u_w(x) = c \exp(x/L)$ where c is a positive constant and having no initial rotational motion. An advetctive term and a Forchheimer quadratic drag term appear in the momentum equations due to the assumption that flow is high. The physical model of the problem with coordinate system is as shown in the Figure 1.

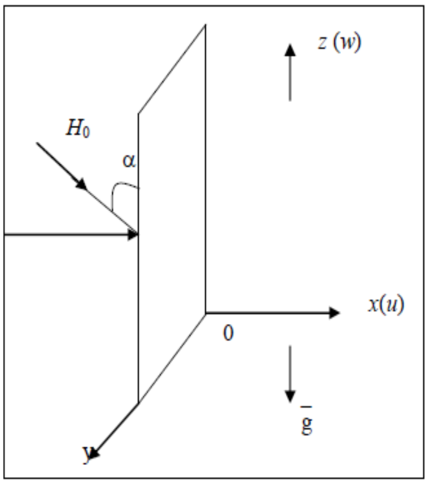

Fig. 1. Configuration of the problem

The magnetic-field (H_0) in the being there of fluid go with the flow induce the modern (Jx,0,Jz). We, pick a square Cartesian coordinate gadget O (x,y,z) among the z-axis inside the vertical path and the walls at x = zero. The instant equations are [3,26,27,33]

$$\rho(u\frac{\partial u}{\partial x}+w\frac{\partial u}{\partial z})=-\frac{\partial p}{\partial x}+\mu(\frac{\partial^2 u}{\partial x^2})+ \\ -\frac{\sigma_{nf}\mu_e H_{00}^2 Sin^2(\alpha)}{1+m^2H_0^2Sin^2(\alpha)}(u+mH_0 wSin(\alpha))-(\frac{\mu}{k})u-(\frac{b}{\sqrt{k}})u^2 \tag{1}$$

$$\rho_{nf}(u\frac{\partial w}{\partial x}+w\frac{\partial w}{\partial z})=-\frac{\partial p}{\partial z}+\mu(\frac{\partial^2 w}{\partial x^2})-\frac{\sigma\mu_e H_0^2 Sin^2(\alpha)}{1+m^2H_0^2Sin^2(\alpha)}(w-mH_0 uSin(\alpha))- \\ (\frac{\mu}{k})w-(\frac{b}{\sqrt{k}})w^2+\beta(T-T_\infty)-\beta^\bullet(C-C_{\infty o}) \tag{2}$$

The energy equation is

$$u\frac{\partial T}{\partial x}+w\frac{\partial T}{\partial z}=k_f\frac{\partial^2 T}{\partial x^2}+\frac{Q_H}{(\rho C_p)_f}\frac{\partial T}{\partial y}+\frac{\nu}{C_p}\left(\left(\frac{\partial u}{\partial x}\right)^2\left(\frac{\partial w}{\partial x}\right)^2\right)+ \\ \frac{\sigma B_0^2}{\rho(1+m^2)}(u^2+w^2)+\frac{(\rho C)_p}{(\rho C)_p}\left(D_B\frac{\partial T}{\partial x}\frac{\partial C}{\partial x}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial x}\right)^2\right)-\frac{1}{(\rho C)_f}\frac{\partial(q_R)}{\partial x} \tag{3}$$

The diffusion equation is

$$u\frac{\partial C}{\partial x}+w\frac{\partial C}{\partial z}=D_B\frac{\partial^2 C}{\partial x^2}+\frac{D_T}{T_\infty}(\frac{\partial^2 T}{\partial x^2})-k_c^{'}(C-C_\infty) \tag{4}$$

where the T, C, k_f, Cp, D1, k_{11}, β, $\beta^\bullet$, Q, q_r, q''' are temperature, concentration, thermal conductivity, heat constant, molecular, cross diffusivities, thermal coefficient, volume coefficient, heat source, heat flux of radiative, heat source of non-uniform.

where z,x,u, w, T, C, , $B(z)=B_0\exp(\frac{z}{L})$ 9 $Q_H=Q_0\exp(-\frac{z}{2L}),k_c^{'}=k_c\exp(-\frac{z}{L})$ B_0, Ω, ρ,ν and μ, $(\rho C_p)_f$, $(\rho C_p)_p$, along the x-axis and z- axis, fluid phase(T), variable glamorous field, Cartesian equals(k_f), haste factors, nano-particle volume bit,. the pervious medium, Forchheimer measure, measure of rotational stir.

The border line condition be

$$x=0,u=u_w(z)=cExp(\frac{z}{L}),+A_1^{'}\frac{\partial u}{\partial z}+B^1\frac{\partial^2 u}{\partial z^2},v=v_0,w(z,0)=0, \\ T=T_w=\ T_\infty+T_oExp(\frac{z}{L.}),C=\ C_w=\ C_\infty+C_0Exp(\frac{z}{L}) \\ x\to\infty,u\to 0,w(x,z)\to 0,T\to T_\infty,C\to C_\infty \\ \text{where, } u_w(z)=cExp(\frac{z}{L}),v_w(z)=cExp(\frac{z}{L}) \tag{5}$$

Using Roseland approximation the radiative heat flux q_r is given by

$$q_r = \frac{-4\sigma^*}{\beta_R}\frac{\partial}{\partial y}(T^{1^4}) \tag{6}$$

and expanding T^{1^4} about T_∞ by Taylor's expansion

$$T^{1^4} = 4T_\infty^3 T^1 - 3T_\infty^4$$

The non-dimensional temperature $\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}$ can be simplified as

$$T = T_\infty(1 + (\theta_w - 1)\theta) \tag{7}$$

where $\theta = \frac{T_w}{T_\infty}$ is the temperature parameter.

Introducing the non-dimensional variables as

$$\begin{aligned}&\eta = (\frac{c}{2\nu L})\exp(\frac{z}{2L})x, \psi = (2\nu Lc)^{1/2}\exp(\frac{z}{2L})f(\eta), \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \phi = \frac{C - C_\infty}{C_w - C_\infty}, u = \frac{\partial \psi}{\partial z},\\ &w = -\frac{\partial \psi}{\partial x}, w(x,z) = cExp(\frac{z}{L})g(\eta)\end{aligned} \tag{8}$$

where η, ψ, θ, ϕ - parallel, stream role, non dimensional warmth, non-dimensional nanoparticle volume part. Let try to Eq. (8) in Eq. (1), Eq. (2), Eq. (4) & Eq. (7) the governing equations bring down to

$$\begin{aligned}&f''' + f\ f'' - 2(f')^2 - \frac{M^2 Sin^2(\alpha)}{1 + m^2 Sin^2(\alpha)}(u + mwSin(\alpha)) - \\ &D^{-1}f' - fs(f')^2 + G(\theta - N\phi)\end{aligned} \tag{9}$$

$$g'' + fg - 2f'g - -\frac{M^2 Sin^2(\alpha)}{1 + m^2 Sin^2(\alpha)}(w - muSin(\alpha)) - D^{-1}g + fs(g)^2 \tag{10}$$

$$\begin{aligned}&Rd((1 + (\theta_w - 1)\theta)^3)\theta')' + \Pr(f\theta' - f'\theta) + Q\theta' + Nb\theta'\phi' + Nt(\theta')^2 + \\ &+ \Pr Ec((f'')^2 + g'^2) + \frac{\Pr EcM^2 Sin^4(\alpha)}{((1 + m^2 Sin^2(\alpha))}(f'^2 + g^2)\end{aligned} \tag{11}$$

$$\phi'' + Le(f\,\phi' - f'\,\phi) + (\frac{Nt}{Nb})\theta'' - (Le\,\gamma)\phi = 0 \tag{12}$$

and using Eq. (5) is

$$f(0) = f_w,\ f'(0) = 1 + A_1 f''(0) + Bf'''(0),$$

$$\theta(0)=1,\phi(0)=1,g(0)=0, \tag{13}$$

$$f'(\eta)\to 0,\theta(\eta)\to 0,\phi(\eta)\to 0,g(\eta)\to 0 \; as \; \eta\to\infty$$

where $fw=-v_0/\sqrt{(c\nu/2L)}$ is the wall mass transfer parameter. fw>0(vo<0) corresponds to mass suction and fw<0(vo>0) corresponds to mass injection.

The parameters occurring in Eqs. (9)-(12) are defined as follows

$$M=\frac{2\sigma B_o^2 L}{\rho_f c}e^{-\frac{x}{L}},D^{-1}=\frac{kce^{\frac{x}{L}}}{2L\nu},Fs=\frac{2bL}{\sqrt{k}},\Pr=\frac{\mu C_p}{k_f},\nu=\frac{\mu}{\rho},$$

$$Le=\frac{\nu}{D_B},Nb=D_B\frac{(\rho C)_p(C_w-C_\infty)}{(\rho C)_f},Nt=\frac{D_T}{T_\infty}\frac{(\rho C)_p(T_w-T_\infty)}{(\rho C)_f},$$

$$Q=Q_0(c\nu L/2)^{1/2},Rd=\frac{4\sigma^{\bullet}T_\infty^3}{3\beta_R k_f},\gamma=k_c(c/2L),U=cExp(z/L)$$

$$A_1=\frac{A_1'}{L}\sqrt{\frac{c}{2\nu L}}Exp(-\frac{z}{2L}),B=\frac{B'c}{2\nu L}$$

are thermo porosis, Brownian motion, radiation, first order slip, second order slip, chemical reaction parameters, fluid velocity depending exponentially upon., Prandtl, kinematic viscosity, Lewis numbers, non-uniform heat generation/absorption coefficient.

3. Method of Solution

At the present work, Runge-Kutta Fehlberg fourth-fifth (RkT-45) order system has been in work to examine the crisis defined by Eq. (9)-(12).

Table 1
In the absence of convection (G=0, N=0), Chemical reaction (γ=0), $\phi(0)=1$,the analysis or findings are well have the same opinion with Bhim Sen *et al.,* [3]

Parameters				Bhim Sen *et al.,* [3] Results				Present Results			
M	K_1	fs	R	$f''(0)$	$g'(0)$	$-\theta'(0)$	$-\phi'(0)$	$f''(0)$	$g'(0)$	$-\theta'(0)$	$-\phi'(0)$
0.5	1	0.5	0.01	-0.7914	-0.0365	0.3885	1.9228	-0.7917	-0.0359	0.3879	1.9229
0.7	1	0.5	0.01	-0.6559	-0.0564	0.4532	1.9655	-0.6558	-0.0568	0.4533	1.9656
1.0	1	0.5	0.01	-0.4363	-0.0919	0.5113	2.0118	-0.4362	-0.0922	0.5114	2.0119
0.5	2	0.5	0.01	-0.6206	-0.6185	0.4646	1.9735	-0.6207	-0.6182	0.4648	1.9739
0.5	3	0.5	0.01	-0.7361	-0.0443	0.4211	1.9459	-0.7363	-0.0444	0.4217	1.9456
0.5	1	1.0	0.01	-0.5789	-0.0366	0.4351	1.9816	-0.5788	-0.0334	0.4352	1.9819
0.5	1	1.2	0.01	-0.4814	-0.0237	0.4536	2.0035	-0.4818	-0.0239	0.4538	2.0039
0.5	1	0.5	0.03	-0.8049	-0.1353	0.3526	1.9230	-0.8052	-0.1355	0.3529	1.9234
0.5	1	0.5	0.05	-0.8283	-0.2177	0.3103	1.9151	-0.8285	-0.2179	0.3109	1.9159

4. Local Skin Friction (Cf), (Cg), Local Nusselt (Nux) and Sherwood (Shx) Numbers

Cf, Cg, Nux, Shx are specified by

$$C_f = \frac{\tau_w}{0.5\rho U_w^2} = \frac{\mu(\frac{\partial u}{\partial x})_{x=0}}{0.5\rho U_w^2} \rightarrow C_f = \frac{1}{\sqrt{2R_{ez}}} f'(0) \quad , \quad C_g = -\frac{1}{\sqrt{2R_{ez}}} g'(0), R_{ez} = u_w z / \nu$$

$$Nu_x = -\frac{z(\frac{\partial T}{\partial x})_{x=0}}{T_w - T_\infty} = -\frac{\sqrt{zR_{ez}}}{L}\theta'(0) \quad , \quad Sh_x = -\frac{z(\frac{\partial C}{\partial x})_{x=0}}{C_w - C_\infty} = -\frac{\sqrt{zR_{ez}}}{L}\phi'(0)$$

5. Results and Discussion

The steady radiative electrically conducting viscous fluid past a stretching sheet under inclined magnetic field is investigated with Brownian motion, thermophoresis, heat sources, multi steps slips. Optimal approach is used due to coupled nonlinear system of governing differential equations system to get computational results. Momentum features of various intriguing parameters on entropy, velocity, concentration and temperature are deliberated through graphs. Surface drag force, temperature gradient and mass transmission rate are numerically intended versus various engineering variables. We observe this from the graphically profiles and tabular values

i. A boost in *m* rising the linear and f',g, θ, ϕ, τx smallness.τz, Nux rising, Shx rising with m$\leq$1 and smallness with higher m$\geq$1.5 on-the wall with rising in m (Figure 2).
ii. Higher the thermal radiation smaller the f',g, θ, ϕ in the flow region.τx, Nux enhances,τz smallness with Rd on η=0. Shx enhances with Rd $\leq$1.5 and reduces with Rd$\geq$3.5 (Figure 3).
iii. The velocities, temperature enhance, nanoparticle concentration reduces with higher values of Ec. τx, Nux reduce,τz,Shx enhances with increasing values of Ec on η=0 (Figure 4).
iv. The f',g, θ increase in Nb and Nt in the boundary layer. The ϕ smallness with Nb and enlarges with Nt. τx,Nux know-how a fall-down, τz rising with enlarges in Nb and Nt at the wall. Shx enhances with Nb and reducers with Nt at η=0 (Figures 5 & 6).
v. The f', ϕ smallness, g, θ enhances with first order slip (A1). τx,τz, Nux smallness, Shx enlarges on η=0 with rising A1(Figure 7).
vi. A hyping in B enlarges f', ϕ, reduces the g, θ in the flow area. τx,τz, Nux raise, Shx being down on η=0 with hyping values of B (Figure 8).
vii. A growth in the inclination (α) reduces the f', ϕ, and enlarges the g, θ.τx,τz, Shx hyping, Nux being down with hyping in α (Figure 9).
viii. An increase in (θ_w) retards the (f′) and (g), (θ) and (ϕ) in the entire flow region. The stress components τx, τx, rate of heat and mass transfer experience enhancement on the wall (η=0). Thus, the non-linearity in thermal radiation leads to an depreciation in the velocity components, temperature and ϕ (Figure 10).

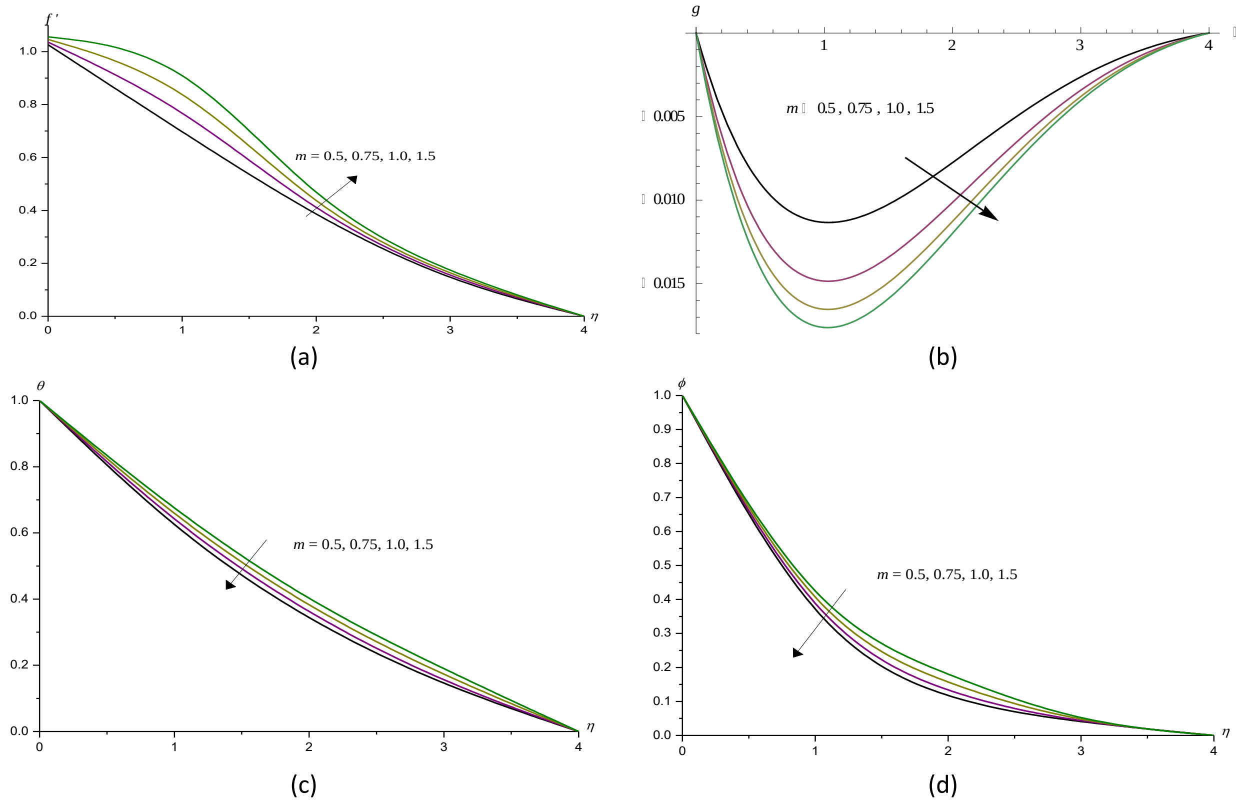

Fig. 2. Variation of (a) primary velocity (f’) (b) secondary velocity (g) (c) temperature (θ) (d) nanoconcentration (ϕ) with *m*. $\alpha=\pi/4, \theta_w=1.05$, A1=0.2, B=-0.02, Nb=0.1, Nt=0.1, Rd=0.5, Ec=0.01

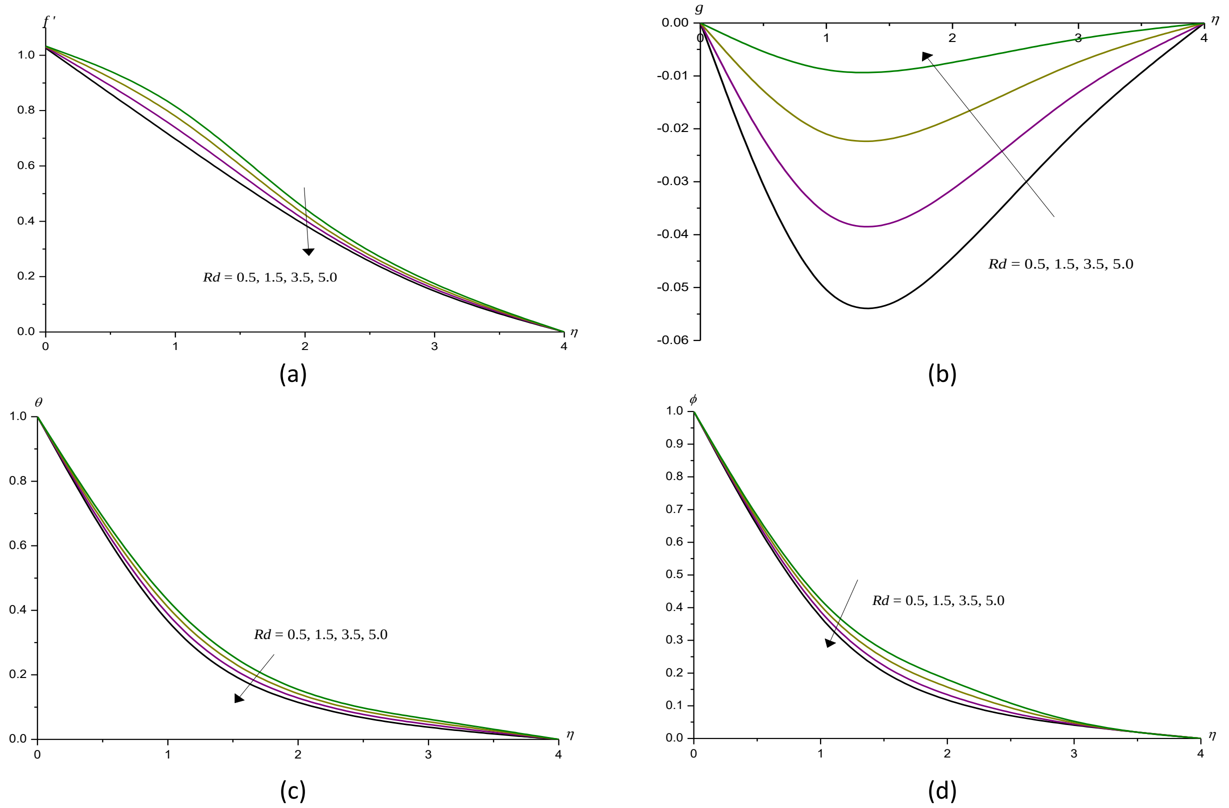

Fig. 3. Variation of (a) primary velocity (f’) (b) secondary velocity (g) (c) temperature (θ) (d) nanoconcentration (ϕ) with Rd. m=0.5, $\alpha=\pi/4, \theta_w=1.05$, A1=0.2, B=-0.02, Nb=0.1, Nt=0.1, Ec=0.01

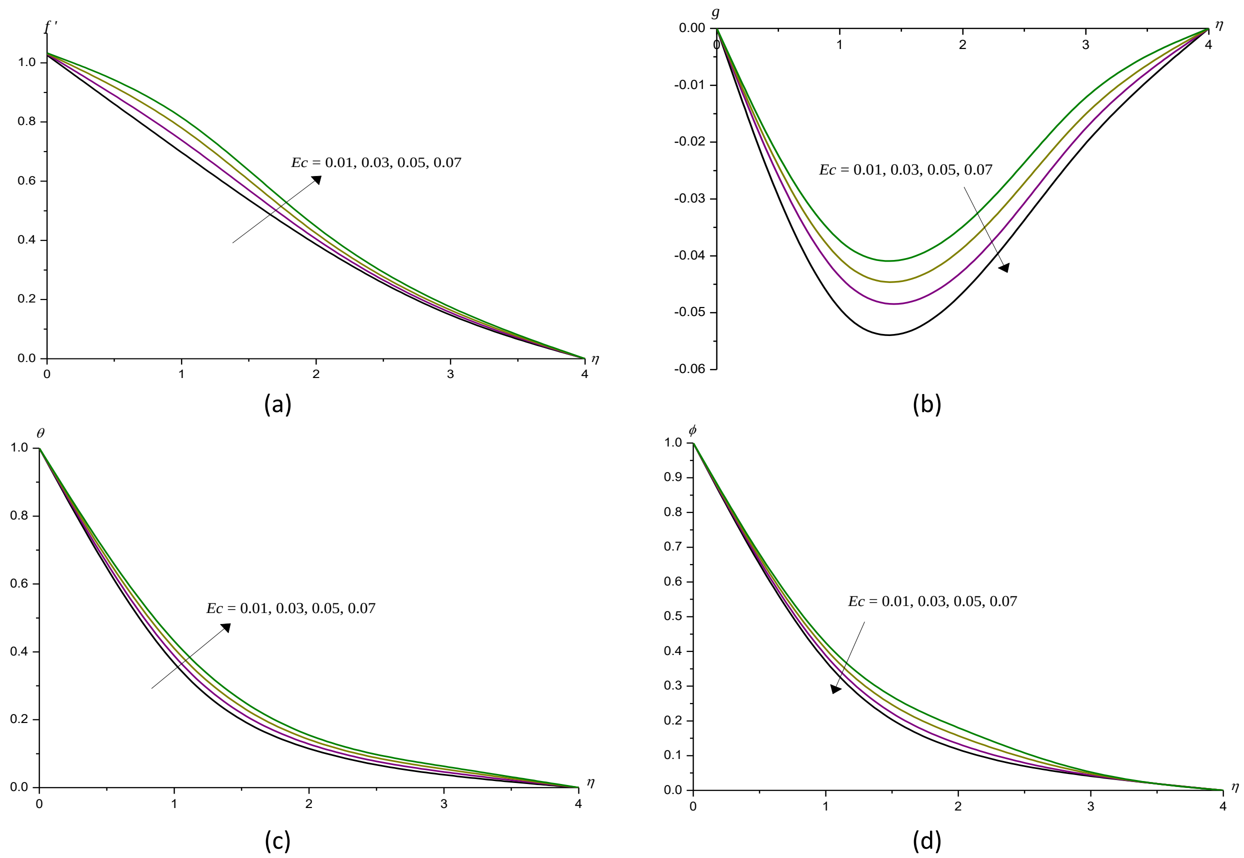

Fig. 4. Variation of (a) primary velocity (f’) (b) secondary velocity (g) (c)temperature (θ) (d) nanoconcentration (ϕ) with Ec. m=0.5, $\alpha=\pi/4$, $\theta_w=1.05$, A1=0.2, B=-0.02, Nb=0.1, Nt=0.1, Rd=0.5

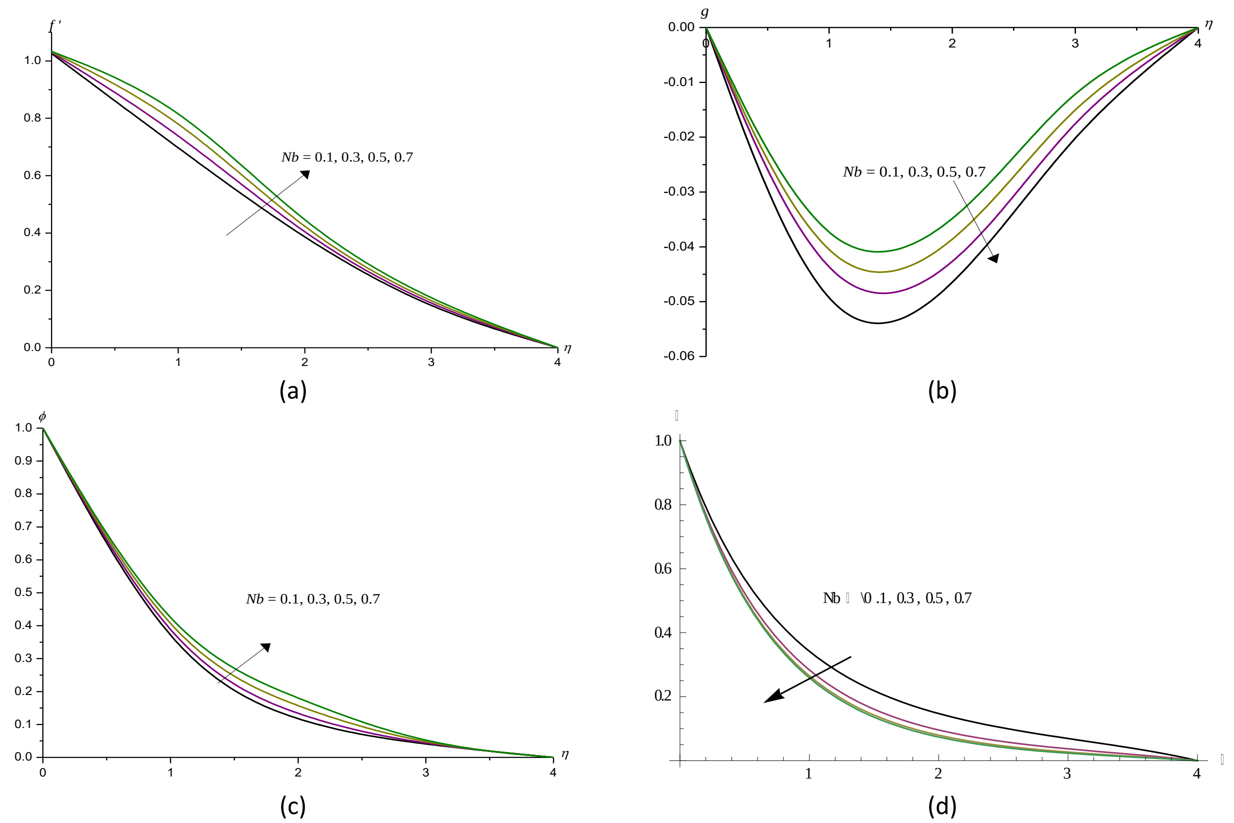

Fig. 5. Variation of (a) primary velocity(f’) (b) secondary velocity(g) (c) temperature (θ) (d) nanoconcentration (ϕ) with *Nb*. m=0.5, $\alpha=\pi/4$, $\theta_w=1.05$, A1=0.2, B=-0.02, Nt=0.1, Rd=0.5, Ec=0.01

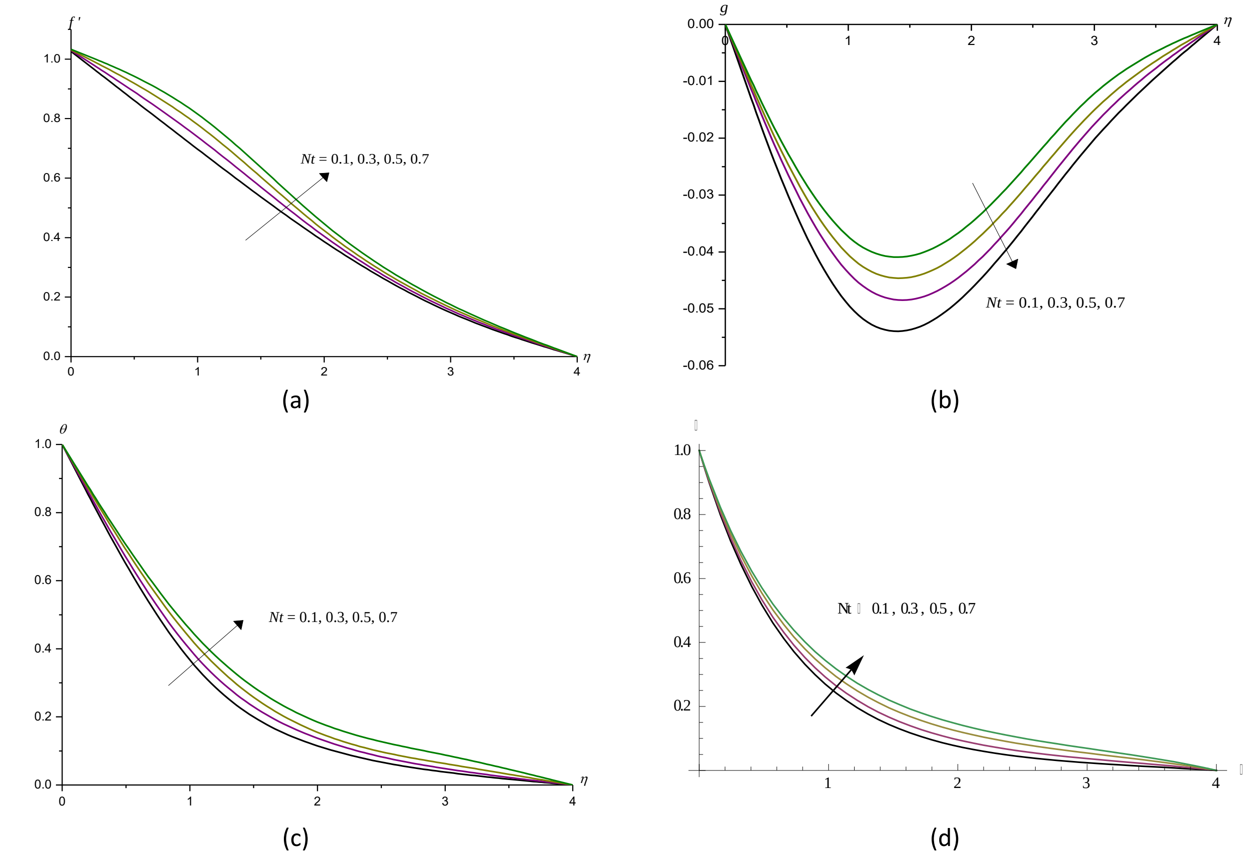

Fig. 6. Variation of (a) primary velocity (f') (b) secondary velocity (g) (c)temperature (θ) (d) nanoconcentration (ϕ) with *Nt*. m=0.5, $\alpha=\pi/4$,θ_w=1.05, A1=0.2, B=-0.02, Nb=0.1, Rd=0.5, Ec=0.01

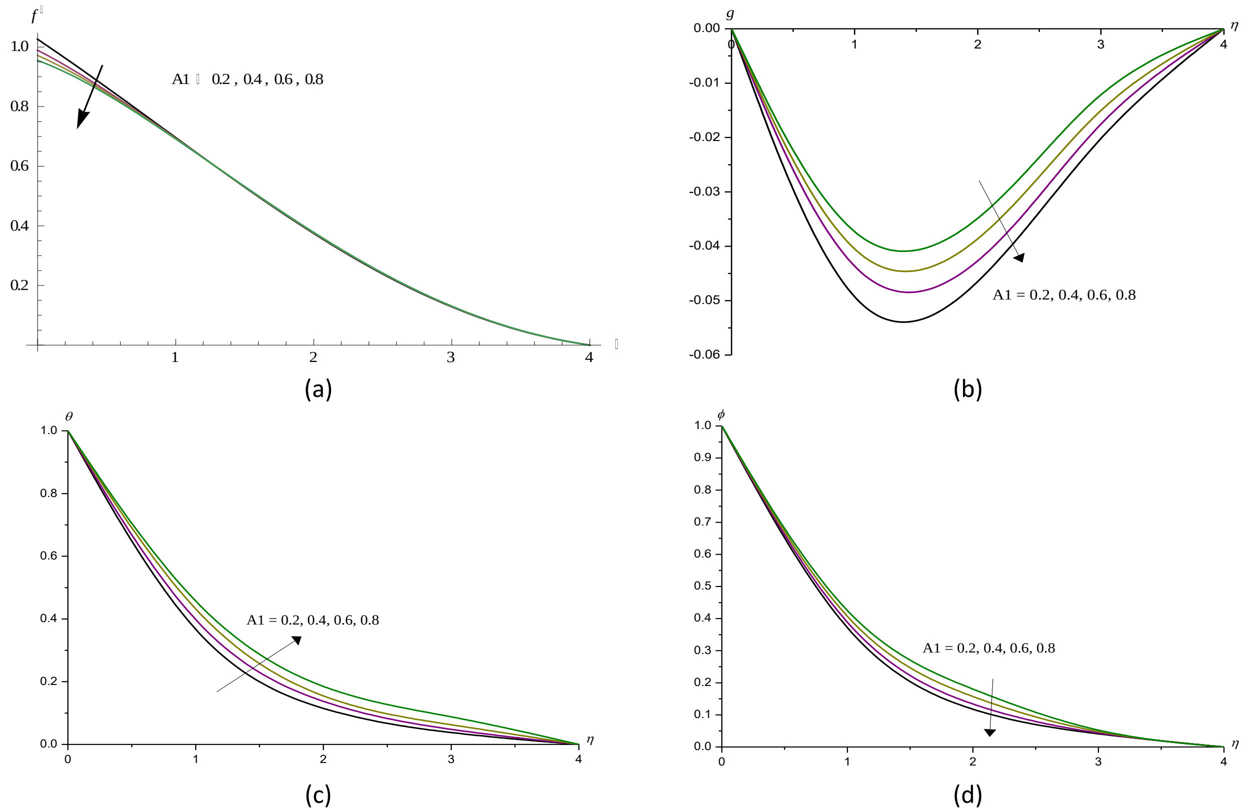

Fig. 7. Variation of (a) primary velocity (f') (b) secondary velocity (g) (c)temperature (θ) (d) nanoconcentration (ϕ) with A1. m=0.5, $\alpha=\pi/4$,θ_w=1.05, B=-0.02, Nb=0.1, Nt=0.1, Rd=0.5, Ec=0.01

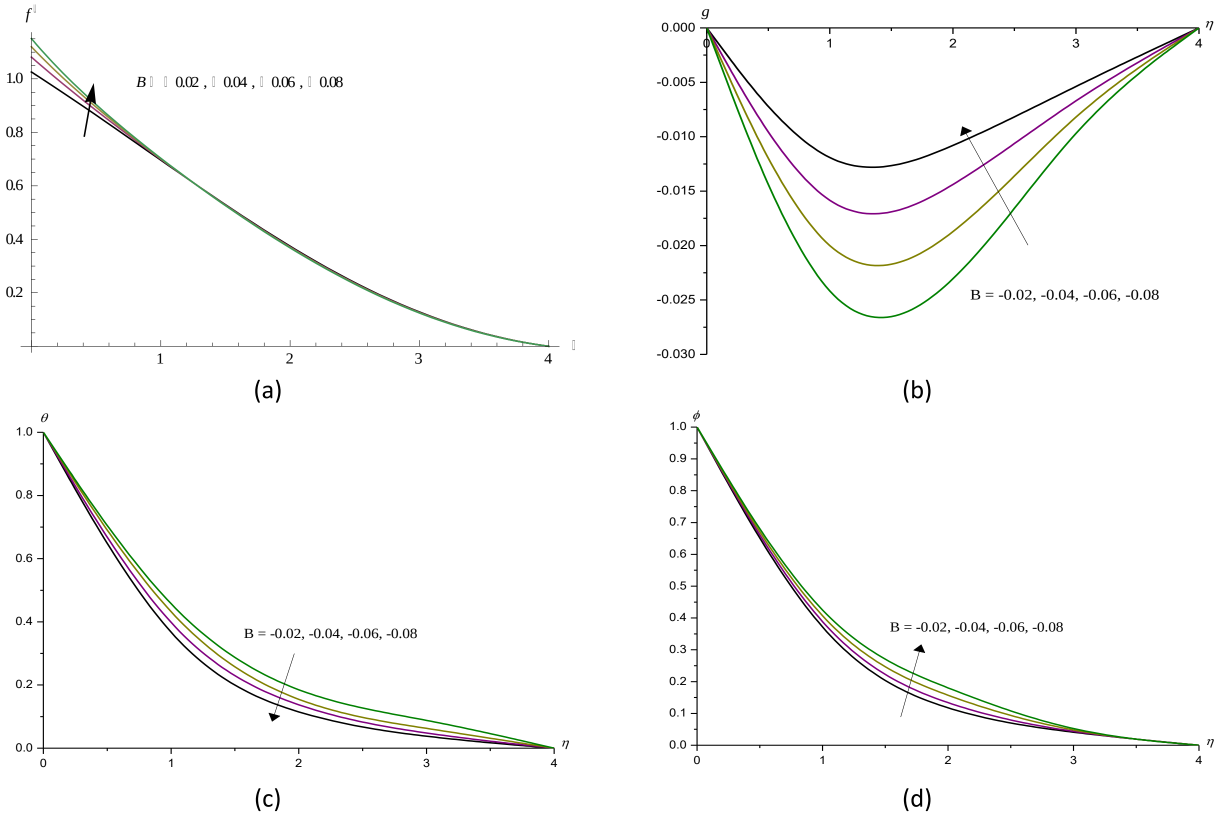

Fig. 8. Variation of (a) primary velocity (f’) (b) secondary velocity (g) (c)temperature (θ) (d) nanoconcentration (ϕ) with B. m=0.5, α=π/4,θ_w=1.05, A1=0.2, Nb=0.1, Nt=0.1, Rd=0.5, Ec=0.01

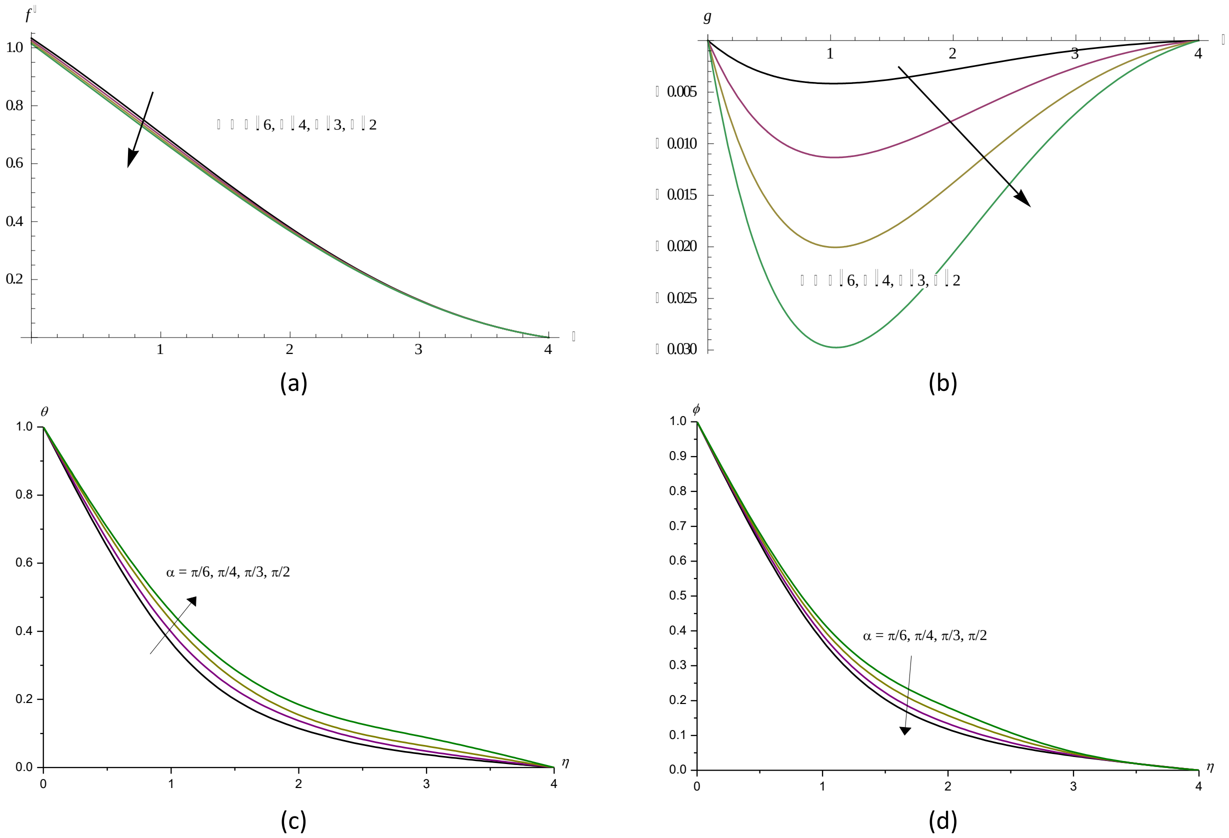

Fig. 9. Variation of (a) primary velocity (f’) (b) secondary velocity (g) (c)temperature (θ) (d) nanoconcentration (ϕ) with α. m=0.5, θ_w=1.05, A1=0.2, B=-0.02, Nb=0.1, Nt=0.1, Rd=0.5, Ec=0.01

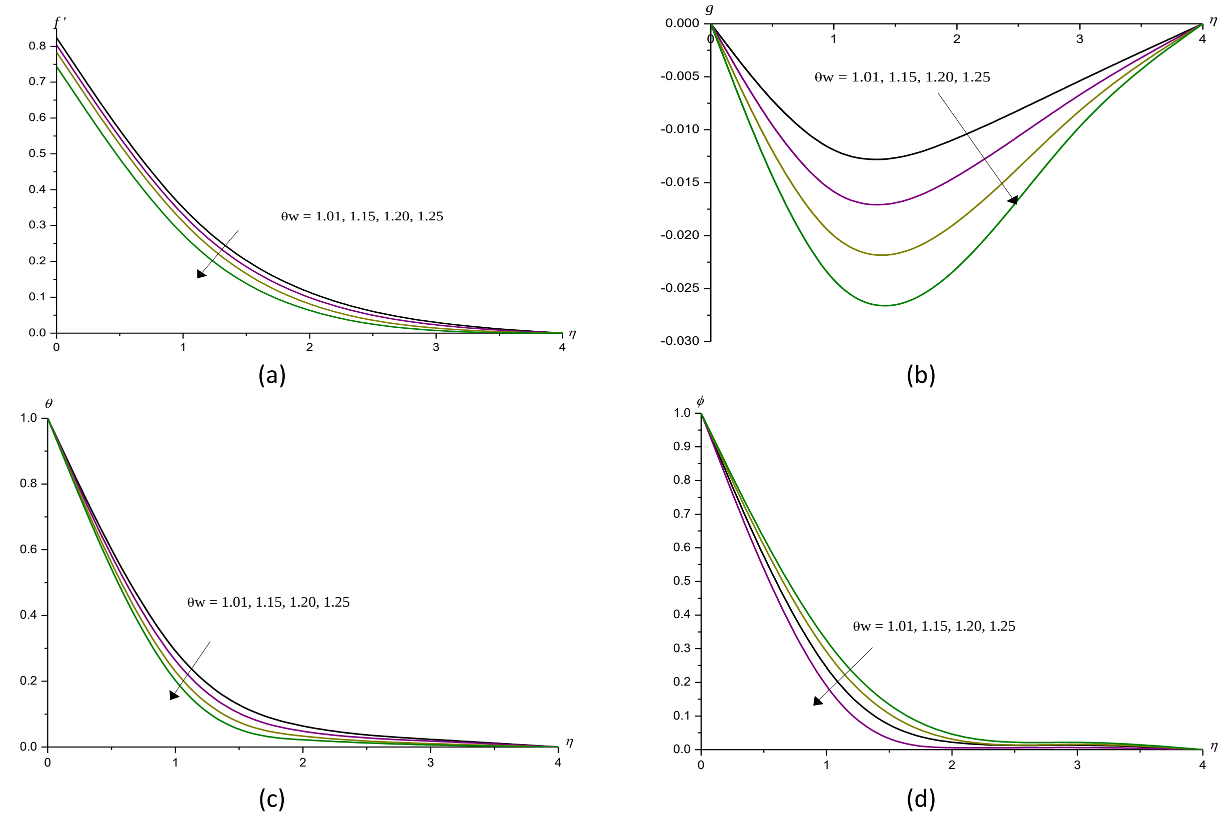

Fig. 10. Variation of (a) primary velocity (f') (b) secondary velocity (g) (c)temperature (θ) (d) nanoconcentration (ϕ) with θ_w. m=0.5, α=π/4, A1=0.2, B=-0.02, Nb=0.1, Nt=0.1, Rd=0.5, Ec=0.01

Table 2
Skin Friction (τ_x,τ_z), Nusslet number (Nu) and Sherwood Number (Sh) at η = 0

Parameter		τx(0)	τz(0)	Nu(0)	Sh(0)	Parameter		τx(0)	τz(0)	Nu(0)	Sh(0)
m	0.5	-0.312662	-0.0276563	0.463098	1.32176	Nt	0.1	-0.313399	-0.0276488	0.468906	1.3738
	0.75	-0.309231	-0.0363373	0.463897	1.32422		0.3	-0.312705	-0.0276558	0.46342	1.32443
	1	-0.306324	-0.0405677	0.464285	1.32405		0.5	-0.311641	-0.0276665	0.456115	1.2621
	1.5	-0.302299	-0.0433759	0.464834	1.32381		0.7	-0.310608	-0.0276767	0.449911	1.21224
Rd	0.5	-0.312662	-0.0276563	0.463098	1.32176	Nb	0.1	-0.320166	-0.0275903	0.471782	1.18584
	1.5	-0.313003	-0.0276509	0.464979	1.32311		0.3	-0.312705	-0.0276558	0.463426	1.32443
	3.5	-0.313163	-0.0276484	0.465763	1.32246		0.5	-0.307548	-0.0276988	0.451397	1.36808
	5	-0.313366	-0.0276462	0.466405	1.32194		0.7	-0.303898	-0.0277279	0.441103	1.38367
Ec	0.01	-0.312662	-0.0276563	0.463098	1.32167	A1	0.2	-0.312705	-0.0276558	0.463426	1.32443
	0.03	-0.311744	-0.0276649	0.461566	1.32542		0.4	-0.237347	-0.0273414	0.461206	1.32584
	0.05	-0.310805	-0.0276737	0.459628	1.32638		0.6	-0.202093	-0.0271917	0.460153	1.32651
	0.07	-0.310121	-0.0276801	0.458266	1.32708		0.8	-0.16867	-0.0270483	0.459144	1.32715
θ_w	1.05	-0.913873	-0.0427366	0.164262	1.32443	B	-0.02	-0.312705	-0.0276558	0.463426	1.32443
	1.15	-0.916258	-0.0442699	0.164292	1.32456		-0.04	-0.427909	-0.0281228	0.466712	1.32233
	1.20	-0.916369	-0.0442643	0.164326	1.32466		-0.06	-0.508969	-0.0284421	0.468965	1.32089
	1.25	-0.916392	-0.0442614	0.164426	1.32478		-0.08	-0.57426	-0.0286941	0.470744	1.31975
α	π/6	-0.299872	-0.0102802	0.465186	1.32365						
	π/4	-0.312705	-0.0276558	0.463423	1.32443						
	π/3	-0.323802	-0.0484559	0.461881	1.32511						
	π/2	-0.333363	-0.0713248	0.460545	1.32571						

6. Conclusions

The inclined magnetic field, secondary velocity, Hall Effect, temperature parameter on flow characteristics has been analysed by solving nonlinear, coupled governing equations by Runge-Kutta Fehlberg shooting method.
It has been observed that, increase in hall parameter accelerates velocity components, reduces temperature and nano-concentration. An increase in secondary velocity and inclined magnetic field, reduces linear velocity, nano-concentration, enhances secondary velocity and temperature. The velocity components, temperature and nano-concentration depreciate with increase in temperature parameter. The nonlinearity thermal radiation leads to a reduction flow characteristic.

It is hoped that the findings of this paper will be helpful for further research work in heat and mass transfer problem.

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