Hydromagnetic convective flow of Nanofluid through Non-Darcy Porous Medium over an Exponentially Stretching surface in the Presence of Temperature gradient dependent Heat Source under Inclined Magnetic Field and second order slip

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Abstract :. The influence of inclined magnetic field, Hall currents, chemical reaction and dissipation on non-Darcy convective heat and mass transfer flow of nanofluid through a porous medium past a exponentially stretching sheet with space temperature dependent in sources is considered employing Runge-Kutta –Shooting method the equations have been evaluated for different variations. It is observed that an increment in the inclination α reduces the linear velocity, nanoparticle volume fraction and enhances the rotational velocity ,temperature an increment in the inclination α of the magnetic field reduces the linear velocity, nanoparticle volume fraction and enhances the rotational velocity, temperature. τx,τz,Shx enhance, Nux reduces with increase in inclination of the magnetic field

Keywords : MHD, Non-Darcy Porous medium, Inclined magnetic field, Stretching surface, Temperature gradient, heat source

1. Introduction:

The fluid dynamics due to a stretching sheet are important from theoretical as well as practical point of view because of their various applications to polymer technology and metallurgy During many mechanical forming processes such as extrusion melt-spinning cooling of a large metallic plate in a bath manufacture of plastic and rubber sheets glass blowing continuous casting and spinning of fibers the extruded material issues through a die. Provoked by the process of polymer extrusion in which extradite emerges from a narrow slit first analyzed the two-dimensional fluid flow over a linearly stretching surface. The boundary layer flow due to linearly stretching sheet has been discussed Crane[1]. The boundary layer flow and heat and mass transfer due to an exponentially stretching sheet has been analyzed by Magyari and Keller[2]. The effect of external magnetic field on the flow over an exponentially shrinking sheet has been discussed by Bhattacharya and Pop[3].

The technique of nanofluids by using a mixture of nanoparticles and the base fluids has been considered by Choi[4]. The Increase in the thermal conductivity and change in properties such as viscosity and specific heat in comparison to the base fluid is due to presence of the nanoparticles in the nanofluids. It has attracted many researchers to perform its engineering applications. Keeping these applications in view several researchers [Shateyi et al[5], Ibrahim et al[6] Nandy et al[7], Khan et al[8], Njane et al[9], Goyal et al[10], Bhattacharya et al[1], Khan et al[12], Sheikhoeslam et al[13], Noghrehabad et al[14], Poornima et al[15], Malvandi et al[16], Ferdows et al[17], Hamad et al[18], Khan et al[19], Wahiduzzaman et al[20], Takhar et al[21], Sarojamma et al[22,23]] have investigated the heat transfer flow of nano-fluid past stretching sheet under varied conditions.

Recently, the effect of magnetic-permeability and Forchhemir parameters on steady flow of a nanofluids past a porous stretching surface has been discussed by Bhimsen kala et al[24].

In this paper we analyse the effect of Hall currents and rotation on the non-Darcy convective heat and mass transfer flow of a nanofluid through a porous medium past a porous exponentially stretching surface under the influence of magnetic field in presence of temperature gradient dependent heat source.The non-linear governing equations have been solved by fourth order Runge-Kutta –shooting technique. The velocity rotational velocity temperature and nanoparticle volume fraction have been discussed graphically for different variations of governing parameters. The skin friction rate of heat and mass transfer on the wall have been evaluated numerically for different variations.

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 adjective 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.

The magnetic field in the presence of fluid flow induces the current($(J_x, 0, J_z)$.We choose a rectangular cartesian co-ordinate system O(xyz) with z-axis in the vertical direction and the walls at $x = 0$.

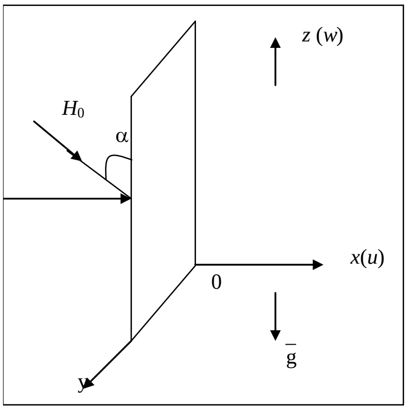

Fig. 1 : Configuration of the problem

The Momentum equations are

$$\rho(u\frac{\partial u}{\partial x}+w\frac{\partial u}{\partial z})=-\frac{\partial p}{\partial x}+\mu(\frac{\partial^2 u}{\partial x^2})-\frac{\sigma_{nf}\mu_e H_{0\,0}^2 Sin^2(\alpha)}{1+m^2H_0^2Sin^2(\alpha)}(u+mH_0wSin(\alpha))-(\frac{\mu}{k})u-(\frac{b}{\sqrt{k}})u^2 \quad (2.1)$$

$$\rho_{nf}(u\frac{\partial w}{\partial x}+w\frac{\partial w}{\partial z})=-\frac{\partial p}{\partial z}+\mu\ (\frac{\partial^2 w}{\partial x^2})--\frac{\sigma\mu_e H_0^2 Sin^2(\alpha)}{1+m^2H_0^2Sin^2(\alpha)}(w-mH_0uSin(\alpha))-$$
$$(\frac{\mu}{k})w-(\frac{b}{\sqrt{k}})w^2+\beta(T-T_\infty)-\beta^\bullet(C-C_{\infty o}) \quad (2.2)$$

The energy equation is

$$u\frac{\partial T}{\partial x}+w\frac{\partial T}{\partial z}=k_f\frac{\partial^2 T}{\partial x^2}-\frac{Q}{\rho C_p}(T-T_\infty)+\frac{\nu}{C_p}((\frac{\partial u}{\partial x})^2+(\frac{\partial w}{\partial x})^2)+$$
$$\frac{\sigma B_o^2}{\rho(1+m^2)}(u^2+w^2)+\frac{(\rho C)_p}{(\rho C)_p}(D_B\frac{\partial T}{\partial x}\frac{\partial C}{\partial x}+\frac{D_T}{T_\infty}((\frac{\partial T}{\partial xx})^2)-\frac{1}{(\rho C)_f}\frac{\partial(q_R)}{\partial x} \quad (2.3)$$

The diffusion equation is

$$u\frac{\partial C}{\partial x}+w\frac{\partial C}{\partial z}=D_B\frac{\partial^2 C}{\partial x^2}+\frac{D_T}{T_\infty}(\frac{\partial^2 T}{\partial x^2})-k_c^{'}(C-C_\infty) \quad (2.4)$$

where T,C are the temperature and concentration in the fluid. k_f is the thermal conductivity Cp is the specific heat constant pressureD_1 is molecular diffusivityk_{11} is the cross diffusivity β is the coefficient of thermal expansion $\beta^\bullet$ is the coefficient of volume expansion Q is the strength of the heat source and q_r is the radiative heat flux, q''' is the non-uniform heat source.

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, $\rho,\nu\ and\ \mu$, $(\rho C_p)_f$, $(\rho C_p)_p$, k_f are Cartesian coordinates, velocity components, along the x-axis and z-axis, temperature in the fluid phase, nanoparticle volume fraction, .variable magnetic field, the permeability of the porous medium, Forchheimer coefficient, coefficient of rotational motion, the density kinematic viscosity and dynamic viscosity of the fluid, heat capacity of the fluid, effective heat capacity of the nanoparticle material, effective thermal conductivity of the porous medium.

The boundary conditions relevant to the problem are

$$x=0,u=u_w(z)=cExp(\frac{z}{L}),+A_1^{'}\frac{\partial u}{\partial z}+B^1\frac{\partial^2 u}{\partial z^2},v=v_0,w(z,0)=0,$$
$$T=T_w=\ T_\infty+T_oExp(\frac{z}{L.}),C=\ C_w=\ C_\infty+C_0Exp(\frac{z}{L}) \quad (2.5)$$
$$x\to\infty,u\to 0,w(x,z)\to 0,T\to T_\infty,C\to C_\infty$$
$$\text{where, }\ u_w(z)=cExp(\frac{z}{L}),v_w(z)=cExp(\frac{z}{L})$$

Using Rosseland approximation and equations(2.6), the equation (2.3)reduces to

$$u\frac{\partial T}{\partial x}+w\frac{\partial T}{\partial z}=k_f\frac{\partial^2 T}{\partial x^2}+\frac{Q_H}{\rho C_p}\frac{\partial T}{\partial x}+\frac{\nu}{C_p}((\frac{\partial u}{\partial x})^2+(\frac{\partial w}{\partial x})^2)+\frac{\sigma B_o^2}{\rho(1+m^2)}(u^2+w^2)+$$
$$+\frac{(\rho C)_p}{(\rho C)_p}(D_B\frac{\partial T}{\partial x}\frac{\partial C}{\partial x}+\frac{D_T}{T_\infty}((\frac{\partial T}{\partial xx})^2)+\frac{1}{(\rho C)_f}\frac{16\sigma^\bullet T_\infty^3}{3\beta_R}\frac{\partial^2 T}{\partial x^2} \quad (2.7)$$

Introducing the non-dimensional variables as

$$\eta=(\frac{c}{2\nu L})\exp(\frac{z}{2L})x,\psi=(2\nu Lc)^{1/2}\exp(\frac{z}{2L})f(\eta),$$
$$\theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},\phi=\frac{C-C_\infty}{C_w-C_\infty},u=\frac{\partial\psi}{\partial z}, \quad (2.8)$$
$$w=-\frac{\partial\psi}{\partial x},w(x,z)=cExp(\frac{z}{L})g(\eta)$$

Where, η, ψ, θ, ϕ - similarity variable, stream function, non dimensional temperature, non-dimensional nanoparticle volume fraction. Using(2. 8) in equations(2.1, 2.2, 2.4 & 2.7) the governing equations reduces to

$$f'''+f\ f''-2(f')^2-\frac{M^2Sin^2(\alpha)}{1+m^2Sin^2(\alpha)}(u+mwSin(\alpha))- \quad (2.9)$$
$$D^{-1}f'-fs(f')^2+G(\theta-N\phi)$$

$$g''+fg-2f'g--\frac{M^2Sin^2(\alpha)}{1+m^2Sin^2(\alpha)}(w-muSin(\alpha)) \quad (2.10)$$
$$-D^{-1}g+fs(g)^2$$

$$(1+\frac{4Rd}{3})\theta''+\Pr(f\theta'-f'\theta)+Q\theta'+Nb\theta'\phi'+Nt(\theta')^2++\Pr Ec((f'')^2+g'^2)+$$
$$\frac{\Pr EcM^2Sin^4(\alpha)}{((1+m^2Sin^2(\alpha))}(f'^2+g^2) \quad (2.11)$$

$$\phi''+Le(f\phi'-f'\phi)+(\frac{Nt}{Nb})\theta''-(Le\gamma)\phi=0 \quad (2.12)$$

and the boundary conditions (2.5) are

$$f(0)=f_w,f'(0)=1+A_1f''(0)+Bf'''(0),\ \theta(0)=1,\phi(0)=1,g(0)=0,$$
$$f'(\eta)\to 0,\theta(\eta)\to 0,\phi(\eta)\to 0,g(\eta)\to 0\ as\ \eta\to\infty \quad (2.13)$$

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 (2.9)-(2.12) are defined as follows

$$M=\frac{2\sigma B_o^2L}{\rho_f c}e^{-\frac{x}{L}},D^{-1}=\frac{kce^{\frac{x}{L}}}{2L\nu},Fs=\frac{2bL}{\sqrt{k}},\Pr=\frac{\mu C_p}{k_f},\nu=\frac{\mu}{\rho}$$
$$Le=\frac{\nu}{D_B},Nb=D_B\frac{(\rho C)_p(C_w-C_\infty)}{(\rho C)_f},Nt=\frac{D_T}{T_\infty}\frac{(\rho C)_p(T_w-T_\infty)}{(\rho C)_f},$$
$$Q=Q_0(c\nu L/2)^{1/2},Rd=\frac{4\sigma^\bullet T_\infty^3}{3\beta_R k_f},\gamma=k_c(c/2L),U=cExp(z/L)$$
$$A_1=\frac{A_1'}{L}\sqrt{\frac{c}{2\nu L}}Exp(-\frac{z}{2L}),B=\frac{B'c}{2\nu L}$$

are magnetic parameter, invert darcy parameter, Forchhimer parameter, Prandtl number, Kinematic viscosity, Lewis number, thermo porosis parameter, Browninan motion parameter, non-uniform heat generation/absorption coefficient, radiation parameter, chemical reaction, fluid velocity depending exponentially upon, first order slip parameter, second order slip parameter

3. Method of Solution :

In this study,an efficient numerical scheme Runge-Kutta Fehlberg fourth fifth(RkT-45) order method has been employed to investigate the problem defined by equations.(2.9)-(2.12).

4. Local Skin Friction, Local Nusselt and Sherwood Numbers:

Local skin friction(Cf),(Cg) local Nusselt number(Nux) local Sherwood number (Shx) are given by.

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

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

5. Results and Discussion

We analyse the coupled effect of inclination of magnetic field, second order slip, temperature gradient heat sources on convective heat and mass transfer flow past a exponentially stretching sheet. By using Runge-Kutta fourth order shooting technique the non linear equation have been solved. From the profiles and tabular values we observe that

- An increase in Hall parameter(m) enhances the linear and rotational velocities, reduces temperature, nanoparticle volume fraction.τx, reduces,.τz, Nux, Shx enhances on-the wall with increase in m(fig.2a-2d).
- In the presence of temperature gradient dependent heat source the linear, rotational velocities, temperature decrease while the nanoparticle volume fraction increases. τx,Nux enhances,τz, Shx reduces with increase in Q (fig. 3a-3d).
- Higher the thermal radiation (Rd) smaller the primary secondary velocities, temperature. nanoparticle concentration in the flow region.τx.τz,Shx enhances, Nux reduces with Rd on η=0(figs.4a-4d).
- The linear velocity, angular velocity, nanoparticle volume fraction increase and temperature reduced in the flow region with increase Forchheimer parameter (fs). Nux and Shx enhance on η=0 with fs(fig. 5a-5d).
- The primary velocity, nano-particle volume fraction reduces, secondary velocity, temperature enhances with first order slip (A1). τx,τz, Nux reduces, Shx enhances on η=0 with increasing A1(figs 6a-6d).
- An increase in second order slip(B) enhances linear verlocity, nanoparticle concentration, reduces the rotational velocity, temperature in the flow region. .τx,τz, Nux increases, Shx reduces on η=0 with increasing B(figs7a-7d).
- An increment in the inclination α of the magnetic field reduces the linear velocity, nanoparticle volume fraction and enhances the rotational velocity, temperature.τx, τz, Shx enhance, Nux reduces with increase in inclination of the magnetic field (fig 8a-8d).

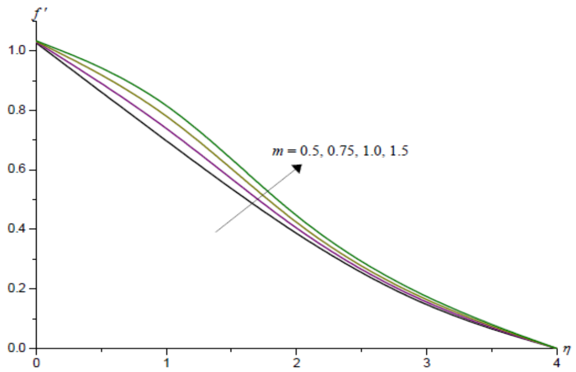

Fig.2a Variation of primary velocity(f')with m
Q=0.5,A1=0.2,α=π/4, B=-0.02, fs=0.2, Rd=0.5

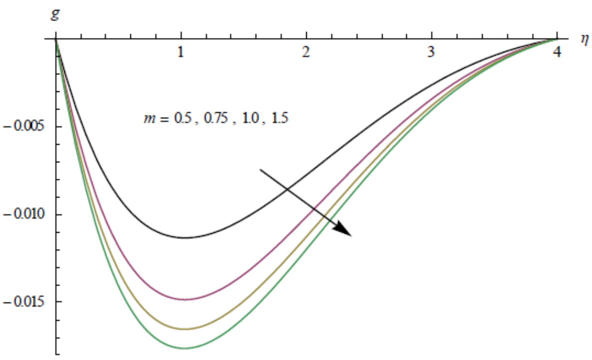

Fig.2b Variation of secondary velocity(g)with m
Q=0.5,A1=0.2,α=π/4, B=-0.02, fs=0.2, Rd=0.5

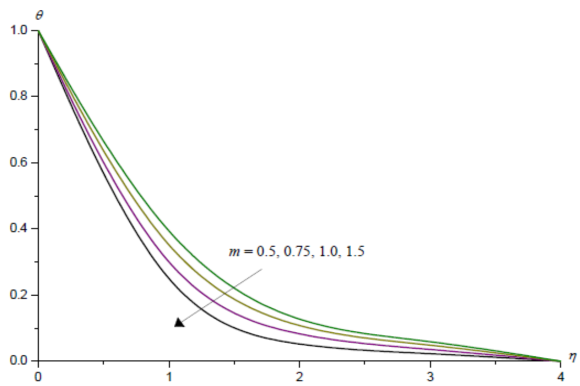

Fig.2c Variation of temperature(θ)with m
Q=0.5,A1=0.2,α=π/4, B=-0.02, fs=0.2, Rd=0.5

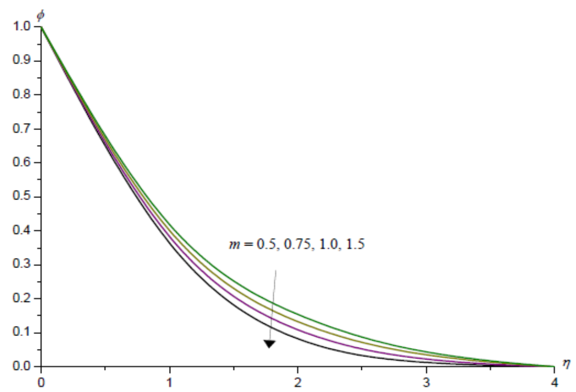

Fig.2d Variation of nanoconcentration(ϕ)with m
Q=0.5,A1=0.2,α=π/4, B=-0.02, fs=0.2, Rd=0.5

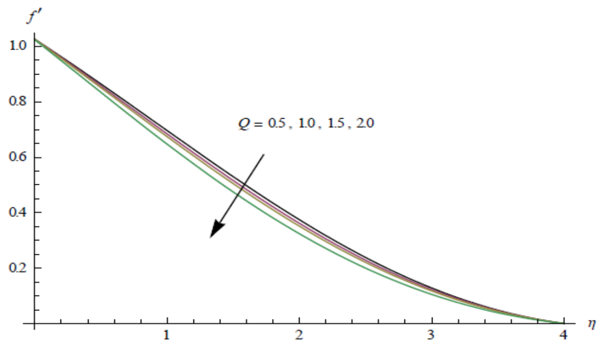

fig.3a Variation of primary velocity(f`)with Q
M=0.5,A1=0.2,α=π/4, B=-0.02, fs=0.2, Rd=0.5

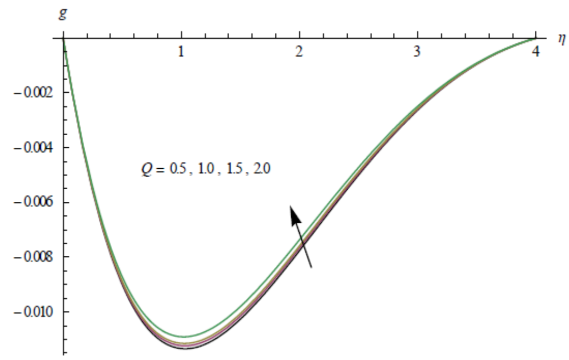

Fig.3b Variation of secondary velocity(g)with Q
M=0.5,A1=0.2,α=π/4, B=-0.02, fs=0.2, Rd=0.5

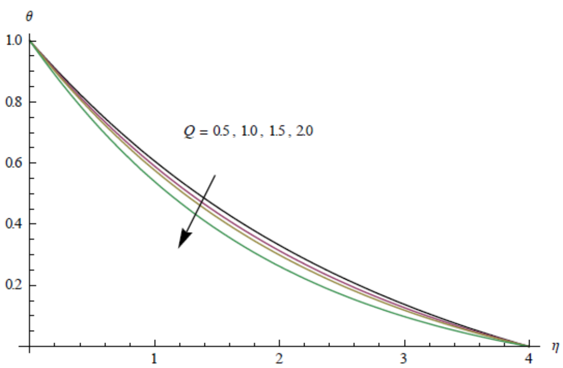

Fig.3c Variation of temperature(θ)with Q
M=0.5,A1=0.2,α=π/4, B=-0.02, fs=0.2, Rd=0.5

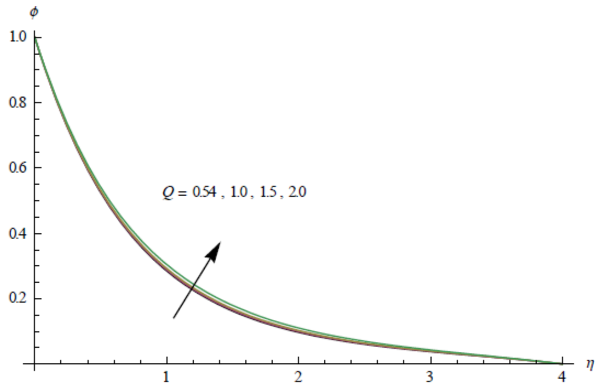

Fig.3d Variation of nanoconcentration(ϕ)with Q
M=0.5,A1=0.2,α=π/4, B=-0.02, fs=0.2, Rd=0.5

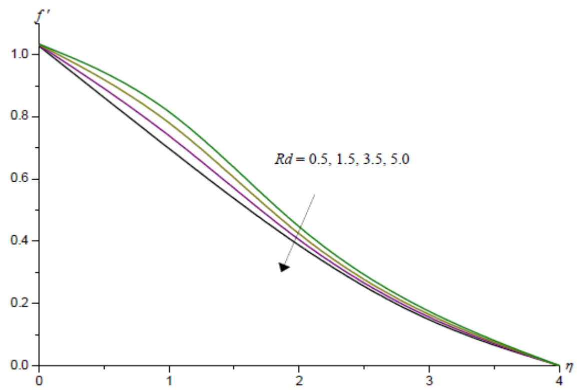

Fig.4a Variation of primary velocity(f`)with Rd
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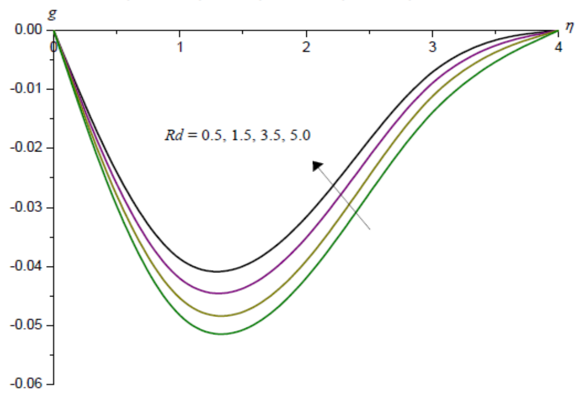

Fig.4b Variation of secondary velocity(g)with Rd
M=0.5,A1=0.2,α=π/4, B=-0.02, fs=0.2, Q=0.5

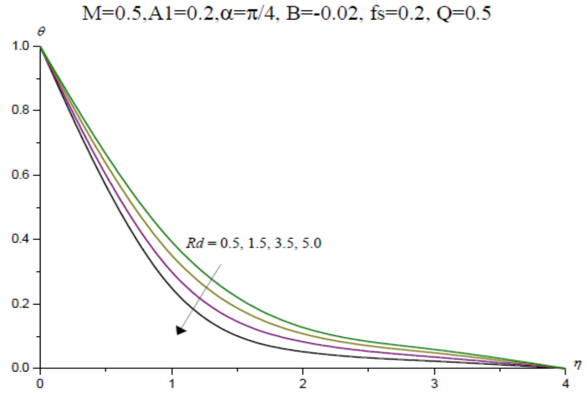

Fig.4c Variation of temperature(θ)with Rd
M=0.5,A1=0.2,α=π/4, B=-0.02, fs=0.2, Q=0.5

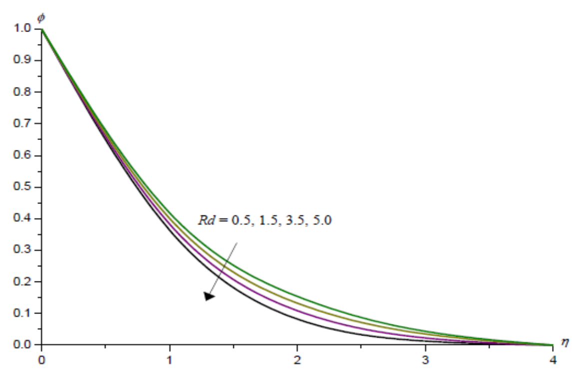

Fig.4d Variation of nanoconcentration(ϕ)with Rd
M=0.5,A1=0.2,α=π/4, B=-0.02, fs=0.2, Q=0.5

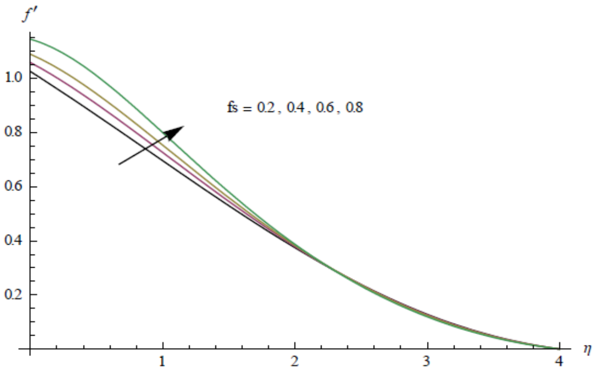

Fig.5a Variation of primary velocity(f')with fs
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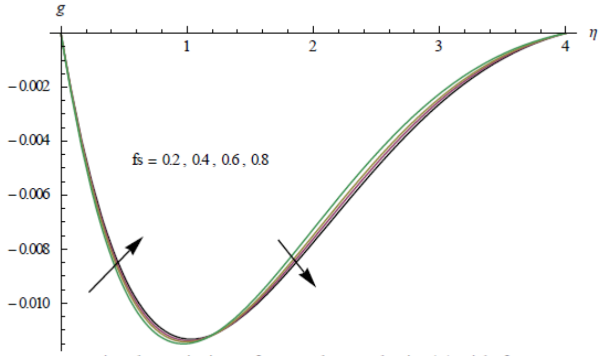

Fig.5b Variation of secondary velocity(g)with fs
M=0.5,A1=0.2,α=π/4, B=-0.02, Rd=0.5, Q=0.5

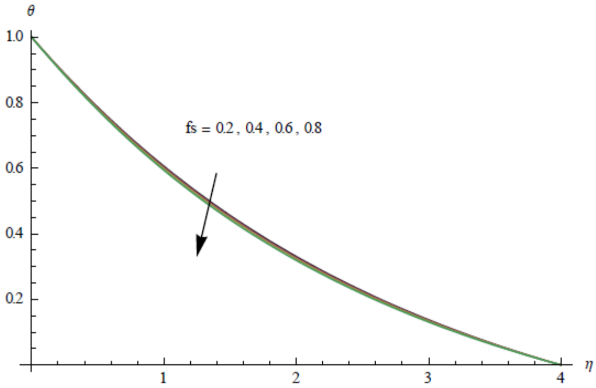

Fig.5c Variation of temperature(θ)with fs
M=0.5,A1=0.2,α=π/4, B=-0.02, Rd=0.5, Q=0.5

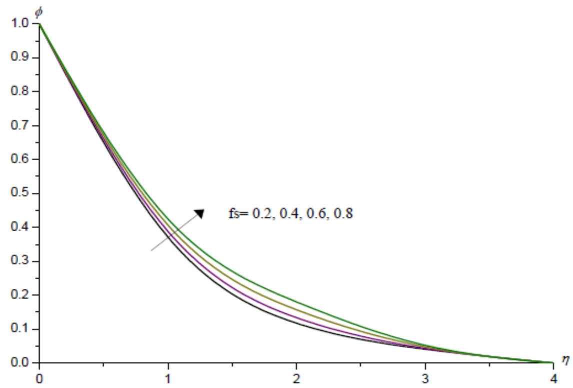

Fig.5d Variation of nanoconcentration(ϕ)with fs
M=0.5,A1=0.2,α=π/4, B=-0.02, Rd=0.5, Q=0.5

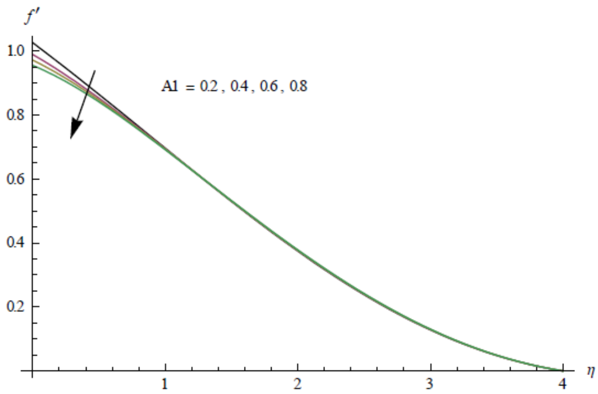

Fig.6a Variation of primary velocity(f')with A1
M=0.5,fs=0.2,α=π/4, B=-0.02, Rd=0.5, Q=0.5

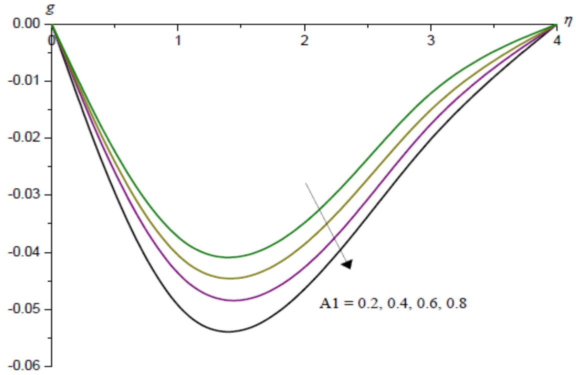

Fig.6b Variation of secondary velocity(g)with A1
M=0.5,fs=0.2,α=π/4, B=-0.02, Rd=0.5, Q=0.5

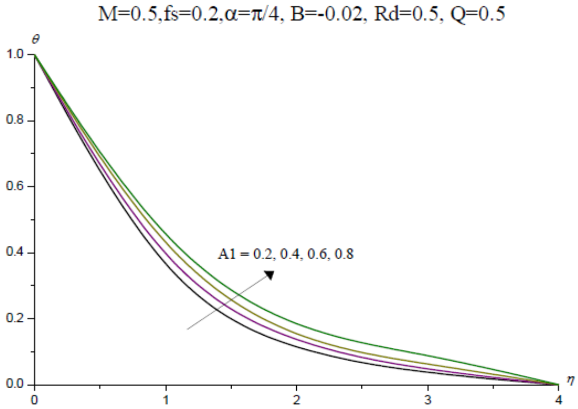

Fig.6c Variation of temperature(θ)with A1
M=0.5,fs=0.2,α=π/4, B=-0.02, Rd=0.5, Q=0.5

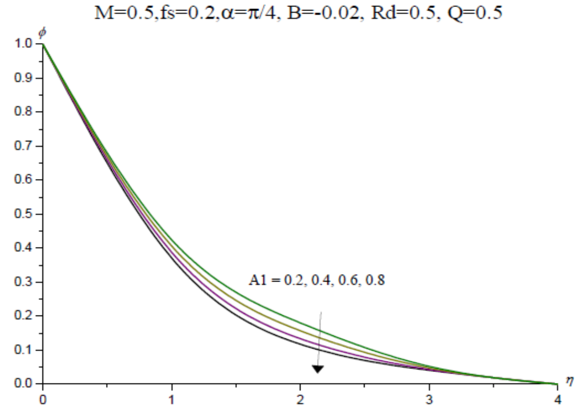

Fig.6d Variation of nanoconcentration(ϕ)with A1
M=0.5,fs=0.2,α=π/4, B=-0.02, Rd=0.5, Q=0.5

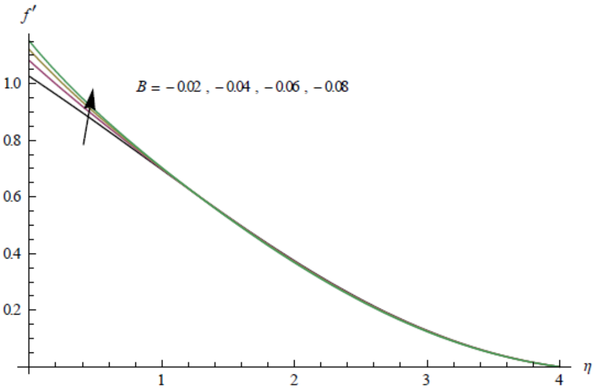

Fig.7a Variation of primary velocity(f')with B
M=0.5,fs=0.2,α=π/4, A1=-0.2, Rd=0.5, Q=0.5

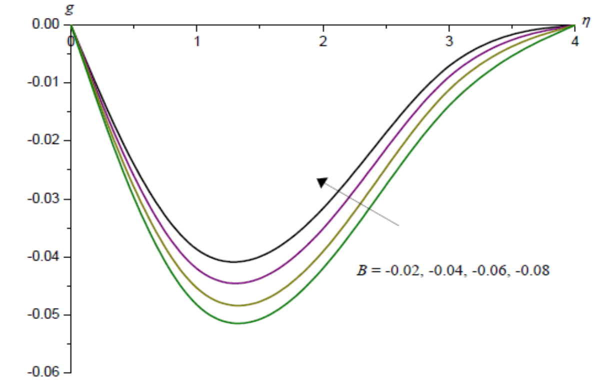

Fig.7b Variation of secondary velocity (g)with G
M=0.5,fs=0.2,α=π/4, A1=-0.2, Rd=0.5, Q=0.5

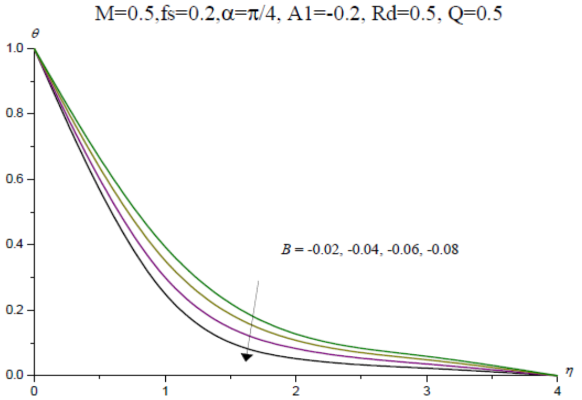

Fig.7c Variation of temperature(θ)with B
M=0.5,fs=0.2,α=π/4, A1=-0.2, Rd=0.5, Q=0.5

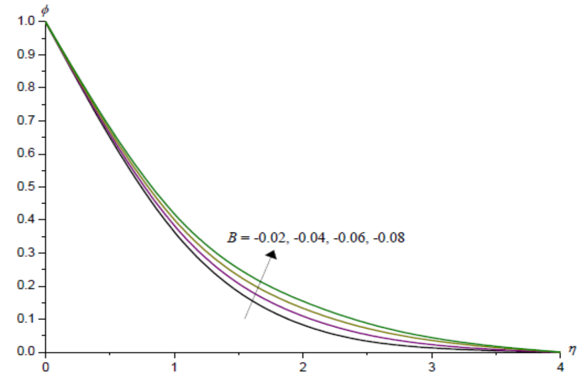

Fig.7d Variation of nanoconcentration(ϕ)with B
M=0.5,fs=0.2,α=π/4, A1=-0.2, Rd=0.5, Q=0.5

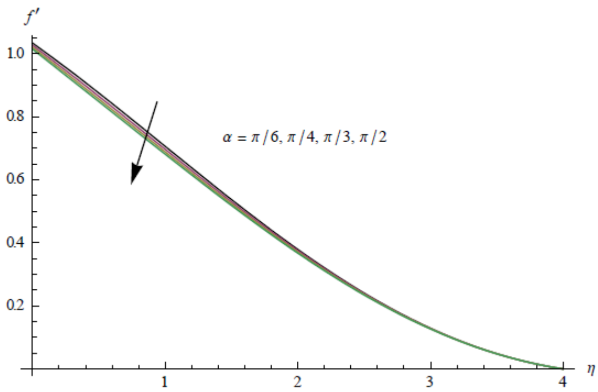

Fig.8a Variation of primary velocity(f')with α
M=0.5,fs=0.2,B=-0.02, A1=-0.2, Rd=0.5, Q=0.5

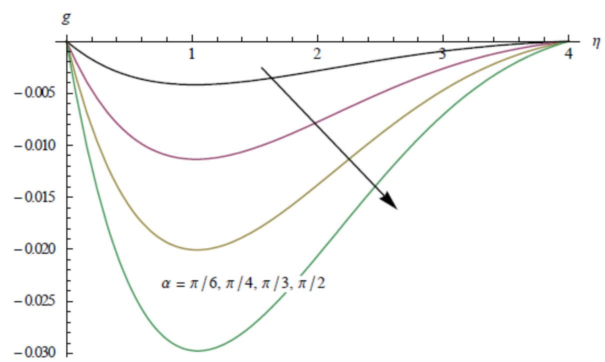

Fig.8b Variation of secondary velocity(g)with α
M=0.5,fs=0.2,B=-0.02, A1=-0.2, Rd=0.5, Q=0.5

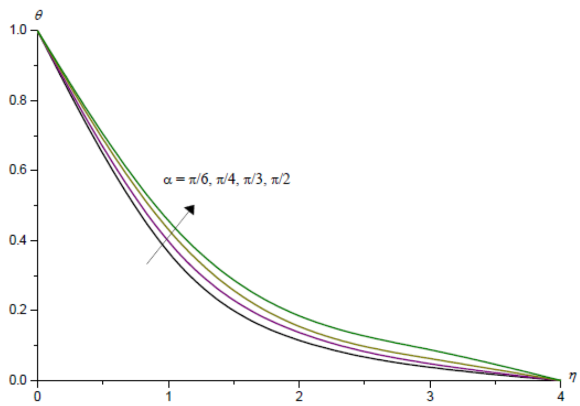

Fig.8c Variation of temperature(θ)with α
M=0.5,fs=0.2,B=-0.02, A1=-0.2, Rd=0.5, Q=0.5

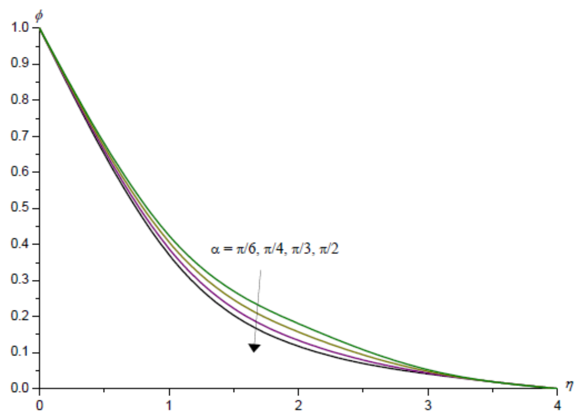

Fig.8d Variation of nanoconcentration(ϕ)with α
M=0.5,fs=0.2,B=-0.02, A1=-0.2, Rd=0.5, Q=0.5

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	1.3216	A1	0.2	-0.312705	-0.0276558	0.46342	1.32443
	0.75	-0.309231	-0.0363373	0.46389	1.32422		0.4	-0.237347	-0.0273414	0.461206	1.32584
	1.0	-0.306324	-0.04056	0.464285	1.32405		0.6	-0.202093	-0.0271917	0.460153	1.32651
	1.5	-0.302299	-0.0433759	0.464834	1.32381		0.8	-0.16867	-0.0270483	0.459144	1.32715
Q	0.5	-0.312662	-0.0276563	0.463098	1.3216	B	-0.02	-0.312705	-0.0276558	0.46342	1.32443
	1.5	-0.327999	-0.0274943	0.490695	1.31147		-0.04	-0.427909	-0.0281228	0.466712	1.32233
	-0.5	-0.340373	-0.0273625	0.513333	1.30039		-0.06	-0.508969	-0.0284421	0.468965	1.32089
	-1.5	-0.374862	-0.0269896	0.579235	1.26664		-0.08	-0.57426	-0.0286941	0.470744	1.31975
Rd	0.5	-0.312662	-0.0276563	0.463098	1.3216	α	π□6	-0.299872	-0.0102802	0.465186	1.32365
	1.5	-0.313003	-0.0276509	0.464979	1.32311		π□4	-0.312705	-0.0276558	0.46342	1.32443
	3.5	-0.313163	-0.0276484	0.465763	1.32246		π□3	-0.323802	-0.0484559	0.461881	1.32511
	5.0	-0.3133	-0.0276462	0.466405	1.32194		π□2	-0.333363	-0.0713248	0.46054	1.32571
fs	0.2	-0.312705	-0.0276558	0.46342	1.32443						
	0.4	-0.260927	-0.028252	0.469651	1.32138						
	0.6	-0.214642	-0.028785	0.475255	1.3186						
	0.8	-0.134921	-0.0297034	0.484968	1.31371						

6. Conclusions:

The effect inclined magnetic field on non-darcy convective heat transfer flow of electrically conducting fluid past exponentially stitching sheet in the presence of temperature gradient dependent heat source is discussed by employing Rnge-kutta shooting technique. It is observed that an increment in the inclination α of the magnetic field reduces the linear velocity, nanoparticle volume fraction and enhances the rotational velocity, temperature. τx, τz, Shx enhance, Nux reduces with increase in inclination of the magnetic field. Hall parameter enhances the linear and rotational velocities, reduces temperature, nanoparticle volume fraction.τx, reduces, τz, Nux, Shx enhances on-the wall with increase in m. Also we noticed that, in the presence of temperature gradient dependent heat source the linear, rotational velocities, temperature decrease while the nanoparticle volume fraction increases. τx,Nux enhances,τz, Shx reduces with increase in Q. In view of the other, the primary velocity, nano-particle volume fraction reduces, secondary velocity, temperature enhances with first order slip (A1). τx,τz, Nux reduces, Shx enhances on η=0 with increasing A1.

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