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Effect of Chemical Reaction, Non Uniform Heat Source on Convective Heat and Mass Transfer Flow Past a Stretching Sheet in a Rotating Fluid

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Abstract
In this chapter, we study the combined influence of radiation and radiation absorption on convective heat and mass transfer flow of a viscous electrically conducting rotating fluid past a stretching sheet. The equations governing the flow of heat and mass transfer have been solved by Galerkin finite element analysis with three nodded line segments. The velocity, temperature and concentration have been analysed for different values of M, m, R, N, Rd, Sc and Q_1. The rate of heat and mass transfer on the plate has been evaluated numerically for different variations
Keywords: Chemical reaction, Non-uniform heat source, rotation, Hall effect..

1. INTRODUCTION

The hydromagnetic flow and heat transfer problems have become important industrially. To be more specific, it may be pointed out that many metallurgical processes involve the cooling of continuous strips or filaments by drawing them through a quiescent fluid and that in the process of drawing, these strips are sometimes stretched. Mention may be made of drawing, annealing and tinning of copper wires. In all the cases the properties of the final product depend to a great extent on the rate of cooling. By drawing such strips in an electrically conducting fluid subjected to magnetic fluid, the rate of cooling can be controlled and a final product of desired characteristics can be achieved. Another interesting application of hydromagnetics to metallurgy lies in the purification of molten metals from nonmetallic inclusions by the application of a magnetic field. The study of heat and mass transfer is necessary for the determining the quantity of the final product. However, there are fluids, which react chemically with some other ingredients present in them. The effect of a chemical reaction on the flow past an impulsively started infinite vertical plate with uniform heat flux was studied by Anderson et. al. [1], have studied the diffusion of a chemical reactive species from a linearly stretching sheet. Raptis et. al. [15], have studied the viscous flow over a non-linearly stretched sheet in the presence of a chemical reaction and magnetic field.

Suction or injection of a stretched surface was studied by Erickson et.al. [5], and Fox et.al. [6] for uniform velocity and temperature and investigates its effects on the heat and mass transfer in the boundary layer. The study of heat generation or absorption in moving fluids is important in the problems dealing with chemical reactions and these concerned with dissociating distribution. Consequently, the practice deposition rate in nuclear reactors, electronic chips and semi conductor waves. Vajravelu and Hadjinicolaou [22] have studied the heat characteristics in the laminar boundary layer of a viscous fluid over a stretching sheet with viscous dissipation or frictional heating and internal heat generation. Mohebujjaman et.al. [11] have studied the MHD heat transfer mixed convection flow along a vertical stretching sheet in presence of magnetic field with heat generation. Biliana et.al. [3] have analyzed the numerical solution of the boundary layer flow over an exponentially stretching sheet with thermal radiation. Jat et.al. [8] have studied the MHD flow and heat transfer over a stretching sheet.

Samadh et. al. [18] have studied MHD heat and mass transfer free convection flow along a vertical stretching sheet in the presence of magnetic field with heat generation. Seddeek [19] have studied the heat and mass transfer on a stretching sheet with a magnetic field in a visco-elastic fluid flow through a porous medium with heat source or sink. Veena et.al. [23] have discussed the non-similar solutions for heat and mass transfer flow in an electrically conducting visco-elastic fluid over a stretching sheet embedded in a porous medium. Hsiao [7] has analysed the heat and mass transfer for electrical conducting mixed convection with radiation effect for visco-elastic fluid past a stretching sheet. Shit [20] has studied Hall effects on MHD free convective flow on mass transfer over a stretching sheet. Raghavendra Rao [13] has discussed the effect of chemical reaction, Hall effects on the convective heat and mass transfer flow past a stretching sheet. Recently, Sreerangavani et al [21] has discussed the effect of Hall currents, thermal radiation and radiation absorption on mixed convective heat and mass transfer flow past a stretching sheet. Sarojamma et al [16] have discussed the influence of hall currents on cross diffusive convection in a MHD boundary layer flow on stretching sheet in porous medium with heat generation.

The motion of rotation fluids enclosed with in a body or vice versa, was given by Green span, discussed these problems relating to the boundary layers and their interaction in rotating flows and gave so many examples relating to such interaction. The rotating viscous flow equation yields a layer known as Eckman boundary layer after the Swedish oceanographer Eckman who discovered it. Attempts to observe the structure of the Eckman layer in the surface layers of the sea have been successful. Eckman layers are easy to produce and observe in the laboratory. Such boundary layers or similar ones are required to connect principally geotropic flow in the interior of the fluid to the horizontal boundaries where conditions like a prescribed horizontal stress or no slip on a solid bottom are given. In a similar way other kinds of various boundaries have been studies so as to connect geotropic flow to vertical boundaries (for example a vertical well along which the depth varies) on which boundary conditions consistent with geotropic flow are given. Mahendra Mohan [10] has discussed the free and forced convections in rotating Hydromagnetic viscous fluid between two finitely conduction parallel plates maintained at constant temperature gradients. In view of many scientific and engineering applications of fluids flow through porous media. Rao et.al. [12] made an investigation of the combined free and forced convective effects on an unsteady Hydro magnetic viscous incompressible flow in a rotating porous channel. This analysis has been extended to porous boundaries by Sarojamma and Krishna [17]. An initial value investigation of the hydro magnetic and convective flow of a viscous electrically conducting fluid through a porous medium in a rotating channel has been made by Krishna et.al. [9]. The fluid was subjected to an external uniform magnetic field perpendicular to the plane of the disk. The effects of uniform suction or injection through the disk on the unsteady MHD flow were also considered. Circar and Mukherjee [4] have analyzed the effect of mass transfer and rotation on flow past a porous plate in a porous medium with variable suction in a slip flow regime. Balasubramanyam [2] has investigated convective heat and mass transfer flow in horizontal rotating fluid under different conditions.

In this paper, we study the combined influence of radiation and radiation absrption on convective heat and mass transfer flow of a viscous electrically conducting rotating fluid past a stretching sheet. The equations governing the flow of heat and mass transfer have been solved by Galerkin finite element analysis with three nodded line segments. The velocity, temperature and concentration have been analysed for different values of M, m, R, N, Rd, Sc and Q_1. The rate of heat and mass transfer on the plate has been evaluated numerically for different variations.

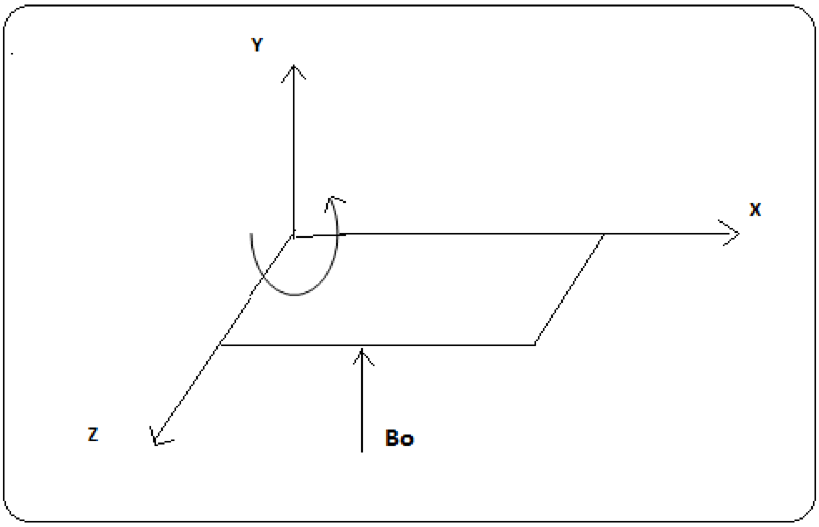

Fig.1 : Physical Configuration of the Problem

2. FORMULATION OF THE PROBLEM:

We consider the steady flow of an incompressible, viscous ,electrically conducting rotating fluid past a flat surface which is assuming from a horizontal slit on a vertical surface and is stretched with a velocity proportional to distance from a fixed origin O. We choose a stationary frame of reference O(x,y,z) such that x-axis is along the direction of motion of the stretching surface, y-axis is normal to this surface and z-axis is transverse to the xy-plane. A uniform magnetic field in the presence of fluid flow induces the current $(J_x, 0, J_z)$.

When the strength of the magnetic field is very large we include the Hall current so that the generalized Ohm's law (Cowling[12]) is modified to

$$\overline{J} + \omega_e \tau_e \overline{J} x \overline{H} = \sigma(\overline{E} + \mu_e \overline{q} x \overline{H}) \tag{1}$$

where $\overline{q}$ is the velocity vector. H is the magnetic field intensity vector. $\overline{E}$ is the electric field, $\overline{j}$ is the current density vector, ω_e is the cyclotron frequency, τ_e is the electron collision time,σ is the fluid conductivity and μ_e is the magnetic permeability. The effect of Hall current give rise to a force in the z-direction which in turn produces a cross flow velocity in this direction and thus the flow becomes three –dimensional. To simplify the analysis, we assume that the flow quantities do not vary along z-direction and this will be valid if the surface is of very width along the z-direction. Neglecting the electron pressure gradient, ion-slip and thermo-electric effects and assuming the electric field E=0, equation (1) reduces

$$j_x - m H_0 J_z = -\sigma\mu_e H_0 w \tag{2}$$

$$J_z + m H_0 J_x = \sigma\mu_e H_0 u \tag{3}$$

where m= $\omega_e \tau_e$ is the Hall parameter.

On solving equations (2)&(3) we obtain

$$j_x = -\frac{\sigma\mu_e^2 H_0^2}{1+m^2}(mu - w) \tag{4}$$

$$j_z = \frac{\sigma\mu_e^2 H_o^2}{1+m^2}(u + mw) \tag{5}$$

where u, w are the velocity components along x and z directions respectively,

The equation of Continuity is

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{6}$$

The Momentum equations are

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial z} - 2\,\Omega\, w = -\frac{\partial p}{\partial x} + \nu\frac{\partial^2 u}{\partial y^2} - \mu_e H_0 J_z - \rho\,\overline{g} \tag{7}$$

$$u\frac{\partial W}{\partial x} + v\frac{\partial W}{\partial y} + 2\Omega u = \nu\frac{\partial^2 W}{\partial y^2} + \mu_e H_0 J_x \tag{8}$$

The energy equation is

$$\rho C_p\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = k_f\frac{\partial^2 T}{\partial y^2} + q''' \tag{9}$$

The diffusion equation is

$$\left(u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y}\right) = D\frac{\partial^2 C}{\partial y^2} - k_0(C - C_\infty) \tag{10}$$

The equation of state is

$$\rho - \rho_0 = -\beta(T - T_\infty) - \beta^\bullet(C - C_\infty) \tag{11}$$

Substituting J_x and J_z from equations (4)&(5)in equations (7)&(8) we obtain

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - 2\Omega\, w = \nu\frac{\partial^2 u}{\partial y^2} - \frac{\sigma\mu_e H_0^2}{1+m^2}(u + mw) + -\left(\frac{\nu}{k}\right) u + \beta g(T - T_\infty) + \beta^\bullet g(C - C_\infty) \tag{12}$$

$$u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + 2\Omega u = \nu\frac{\partial^2 w}{\partial y^2}) + \frac{\sigma\mu_e^2 H_0^2}{1+m^2}(m_0 u - w) - \left(\frac{\nu}{k}\right) w \tag{13}$$

The coefficient q''' is the rate of internal heat generation (>0) or absorption(<0). The internal heat generation /absorption q''' is modeled as

$$q''' = \left(\frac{k u_s}{x\nu}\right)\left[A^*(T_w - T\infty)f'(\eta) + B^*(T - T\infty)\right] \tag{14}$$

Where A^* and B^* are coefficients of space dependent and temperature dependent internal heat generation or absorption respectively. It is noted that the case $A^*>0$ and $B^*>0$, corresponds to internal heat generation and that $A^*<0$ and $B^*<0$, the case corresponds to internal heat absorption case.

Using (14) equation (9) reduces to

$$\rho C_p\left(u\frac{\partial T}{\partial x}+w\frac{\partial T}{\partial z}\right)=k_f\frac{\partial^2 T}{\partial y^2}+\left[A^*\left(T_w-T_\infty\right)f'(\eta)+B^*\left(T-T_\infty\right)\right] \quad (15)$$

where T is the temperature and C is the concentration in the fluid. k_f is the thermal conductivity, Cp is the specific heat at constant pressure, β is the coefficient of thermal expansion, $\beta^\bullet$ is the volumetric expansion with concentration, Q_1^1 is the radiation absorption coefficient, q_r is the radiative heat flux, kc is the chemical reaction coefficient, D is the molecular viscosity, k is the porous permeability parameter.

The boundary conditions for this problem can be written as

$$u=bx, v=-v_w, w=0, T=T_w, C=C_w \qquad at\ \ y=0 \quad (16)$$

$$u=w=0, T=T_\infty, C=C_\infty \qquad as\ \ y\to\infty \quad (17)$$

Where b>0.The boundary conditions on the velocity in(17) are the no-slip conditions at the surface at y=0,while the boundary conditions on the velocity as $y\to\infty$ follow from the fact that there is no flow far away from the stretching surface. The temperature and species concentration are maintained at a prescribed constant values T_w and C_w at the sheet and are assumed to vanish far away from the sheet.

On introducing the similarity variables

$$\eta=\sqrt{\frac{b}{\nu}}y$$

$$u=bx\,f'(\eta)$$

$$v=-\sqrt{b\nu}\,f(\eta)$$

$$w=bx\,g(\eta)$$

$$\theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty}$$

$$\phi(\eta)=\frac{C-C_\infty}{C_w-C_\infty} \quad (19)$$

Equations (10), (12),(13) & (16) reduces to

$$f'''+f\,f''-f'^2+G(\theta+N\phi)-D^{-1}f'-\frac{M^2}{1+m^2}(f'+mg)-2Rg=0 \quad (20)$$

$$g''+fg'-(f'+\frac{M^2}{1+m^2})g-D^{-1}g++\frac{mM^2}{1+m^2}f'+2Rf'=0 \quad (21)$$

$$\theta''+P_1\,f\,\theta^1+P_1\left(A^*f'+B^*\theta\right)=0 \quad (22)$$

$$\phi''+Sc(\phi' f-\gamma\phi)=0 \quad (23)$$

It is pertinent to mention that $\gamma>0$ corresponds to a degenerating chemical reaction while $\gamma<0$ indicates a generation chemical reaction.

The boundary conditions (17)&(18) are now obtained from (19) as

$$f'(0)=1,\ \ f(0)=fw,\ \ \ \theta(0)=\phi(0)=0 \quad (24)$$

$$f'(\infty)=g(\infty)=\theta(\infty)=0 \quad (25)$$

Where $fw=\frac{v_w}{\sqrt{b\nu}}$ is the mass transfer coefficient such that fw>0 represents suction and fw<0 represents injection at the surface.

where

$$G=\frac{\beta g\left(T_w-T_\infty\right)}{b^2x} \qquad \text{(Grashof number)}$$

$$M^2=\frac{\sigma\mu_e^2H_0^2}{bx} \qquad \text{(Hartmann number)}$$

$$D^{-1}=\frac{L^2}{k} \qquad \text{(Inverse Darcy parameter)}$$

$N = \frac{\beta^*(C_w - C_\infty)}{\beta(T_w - T_\infty)}$ (Buoyancy ratio)

$Sc = \frac{\nu}{D}$ (Schmidt number)

$\gamma = \frac{k_0}{b}$ (Chemical reaction parameter)

$R = \frac{\Omega}{b}$ (Rotation parameter)

$\Pr = \frac{\mu C_p}{k_f}$ (Prandtl number)

$fw = \frac{v_w}{\sqrt{b\nu}}$ (Mass transfer coefficient)

For the computational purpose and without loss of generality ∞ has been fixed as 8.The whole domain is divided into 11 line elements of equal width, each element being three nodded.

3. FINITE ELEMENT ANALYSIS

The method basically involves the following steps:

(1) Division of the domain into elements, called the finite element mesh.
(2) Generation of the element equations using variational formulations.
(3) Assembly of element equations as in step 2.
(4) Imposition of boundary conditions to the equations obtained in step 3
(5) Solution of the assumed algebraic equations.

The assumed equations can be solved by any of the numerical technique viz. Gaussian elimination, LU Decomposition method etc.

VARIATIONAL FORMULATION : The variational form associated with the equations(17)-(20)over a typical two nodded line at element(η_e, η_{e+1}) is given by

$$\int_{\eta_e}^{\eta_{e+1}} w_1(f' - h)d\eta = 0 \quad (26)$$

$$\int_{\eta_e}^{\eta_{e+1}} w_{12}(h'' + fh' - h^2 + G(\theta + N\phi) - \frac{M^2}{1+m^2}(h + mg) - 2Rg)d\eta = 0 \quad (27)$$

$$\int_{\eta_e}^{\eta_{e+1}} w_3(g'' + fg' - (h + \frac{M^2}{1+m^2})g + \frac{mM^2}{1+m^2}h + 2Rf')d\eta = 0 \quad (28)$$

$$\int_{\eta_e}^{\eta_{e+1}} w_4(\theta'' + P_1 f\theta' + Q_1 N_2\phi + \alpha N_2 + P_1\left(A^* h + B^*\theta\right) + \frac{M^2 Ec}{1+m^2}\left(h^2 + g^2\right))d\eta = 0 \quad (29)$$

$$\int_{\eta_e}^{\eta_{e+1}} w_5(\phi'' + Sc(\phi' f - \gamma\phi))d\eta = 0 \quad (30)$$

Where w1, w2, w3, w4, w5 are arbitrary test functions and may be regarded as the variations in f, h, g, θ and ϕ respectively.

5. DISCUSSION OF THE NUMERICAL RESULTS

We analyse the combined influence of Hall currents, chemical reaction, thermal radiation and radiation absorption on convective heat and mass transfer flow of a viscous, electrically conducting rotating fluid past a stretching sheet. The non – linear coupled equations are solved by using a finite element technique with three modeling segments.

The variation of $f^1(\eta)$ with chemical reaction parameter γ shows that | $f^1(\eta)$| depreciates in both the degenerating and generating chemical reaction cases (fig 1). From fig.2 we find a depreciation in |$f^1(\eta)$|with increase in rotation parameter R. Figs.3&4 represent the effect of non-uniform internal heat source on $f^1(\eta)$.From the velocity profiles we find that the axial velocity enhances with increase in heat generation A1,B1>0 and reduces in the heat absorption A1,B1<0.

With respect to chemical reaction parameter γ, we notice that the transverse velocity depreciates both in the degenerating and generating chemical reaction cases (fig.5).From fig.6 we find that higher the coriolis force smaller the transverse velocity. From figs.7&8 we find that the transverse velocity enhances with increase in the heat generation $A_1,B_1>0$ and reduces with heat absorption $A_1,B_1<0$ in the flow region. It is found that |g| enhances with increase in R (fig10). The cross flow velocity enhances with increase in the heat generation $A_1,B_1>0$ and reduces with heat absorption $A_1,B_1<0$ in the boundary layer(figs.11&12).g(η) enhances in both the degenerating and generating chemical reaction cases(fig.9).

The actual temperature enhances with increase in the chemical reaction parameter | γ | in the boundary layer (fig.13).An increase in the rotation parameter R results in an enhancement in the actual temperature(fig.14). Figs.15,16 depict the effects of non-uniform heat generation $A_1,B_1>0$ or absorption $A_1,B_1<0$.It is observed an increase in the parameter on the temperature distribution shows a generation of energy in the thermal boundary layer by increasing the values of $A_1,B_1>0$(heat source) which causes the temperature of the fluid to increase which in turn results in further increase of the flow field due to the thermal buoyancy effects. This is the main reason behind the temperature profiles to increase ,whereas in the case of $A_1,B_1<0$(absorption) the boundary layer releases energy resulting in the temperature profiles to decrease with increase in the values of A_1,B_1 in the thermal boundary layer.

An increase in |γ| leads to a depreciation in the actual concentration (figs.17). Figs.19,20 depict the effect of non-uniform internal heat generation $A_1,B_1>0$ or absorption $A_1,B_1<0$ in the boundary layer of the concentration field. It is observed that the concentration profiles reduces by increasing the values of $A_1,B_1>0$(heat source) whereas reversed trend is seen in the concentration profiles by increasing the values of $A_1,B_1<0$(heat sink).An increase in R results in an enhancement in the concentration in the flow region(fig.18).

| τ_x | enhances with increase in the chemical reaction parameter γ and rotation parameter R. τ_x reduces with increase in $A_1,B_1>0$ and $A_1,B_1<0$. | τ_z | enhances with increase in R. With respect to γ we find that | τ_z | reduces in both the degenerating and generating chemical reaction cases. | τ_z | enhances with increase in A1,B1>0 and reduces with A1,B1<0.

Also |Nu| reduces in both the degenerating and generating chemical reaction cases. The rate of heat transfer at the wall reduces with increase in $A_1,B_1>0$ where reverse trend is noticed with increase in $A_1,B_1<0$.

Also it reduces with Prandtl number Pr or R. The variation of Sh with non-uniform heat source shows that the rate of mass transfer enhances with increase in $A_1,B_1>0$(heat source) and reduces with increase in $A_1,B_1<0$(heat absorption).

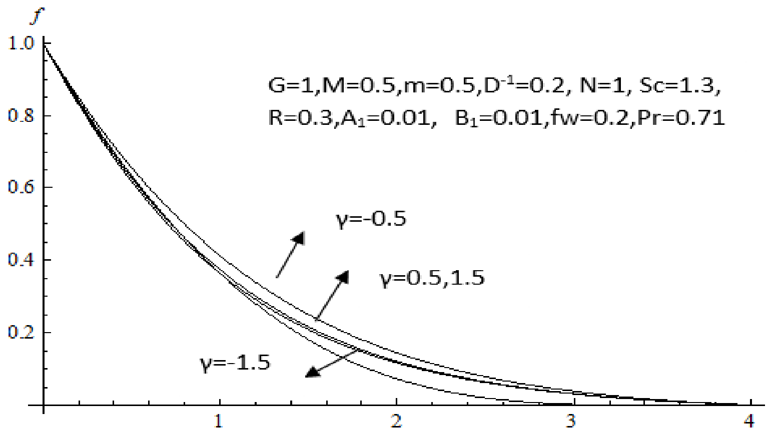

Fig .1 : Variation of f^1 with γ

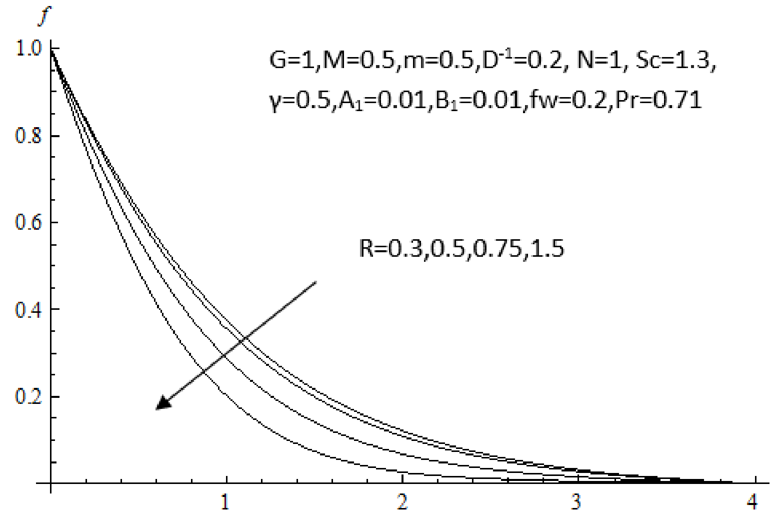

Fig .2 : Variation of f^1 with R

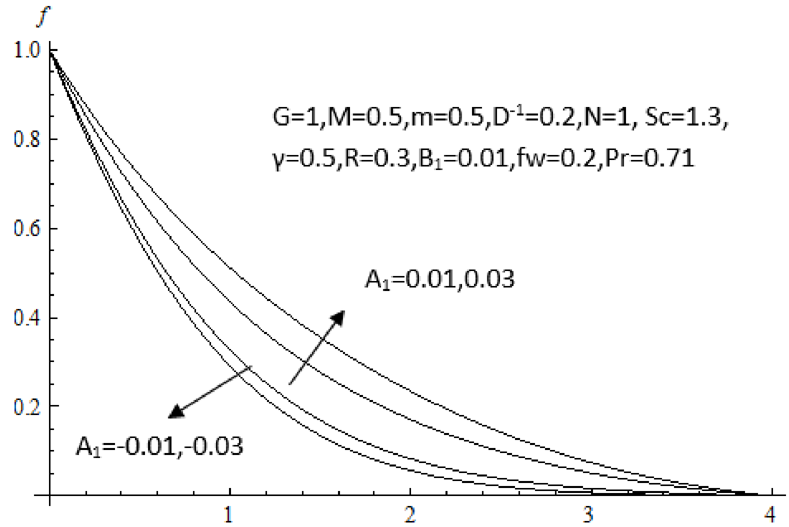

Fig .3 : Variation of f^1 with A1

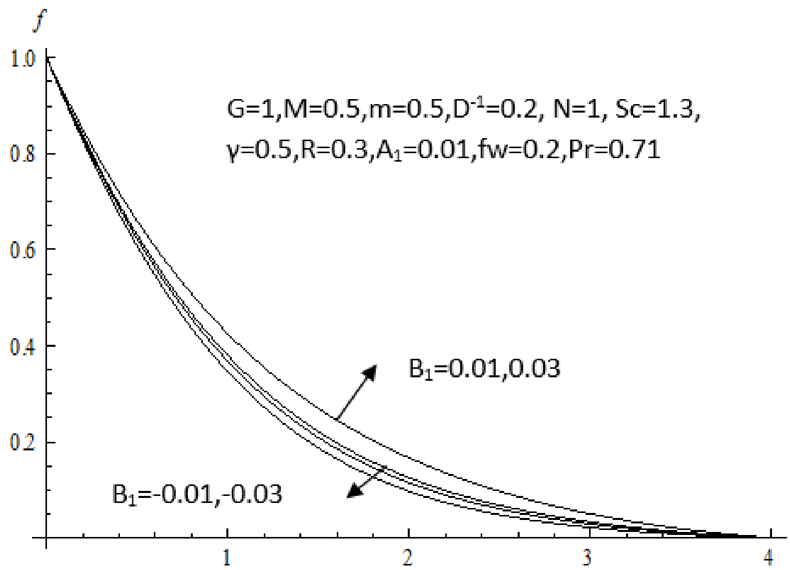

Fig .4 : Variation of f^1 with B1

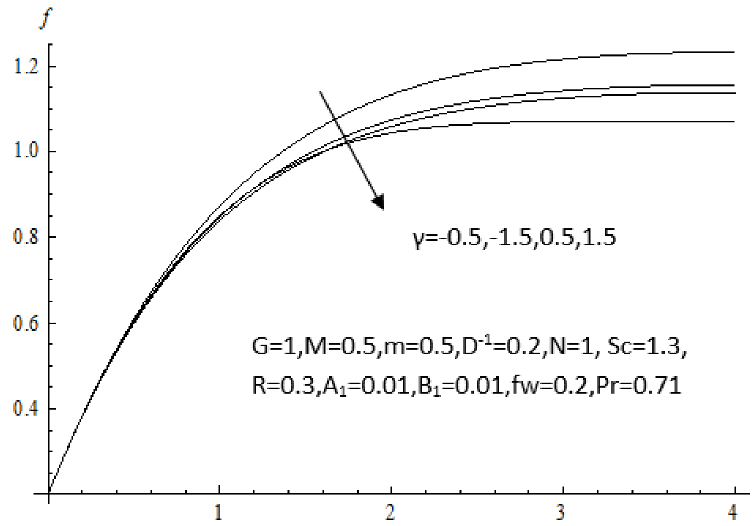

Fig .5 : Variation of f with γ

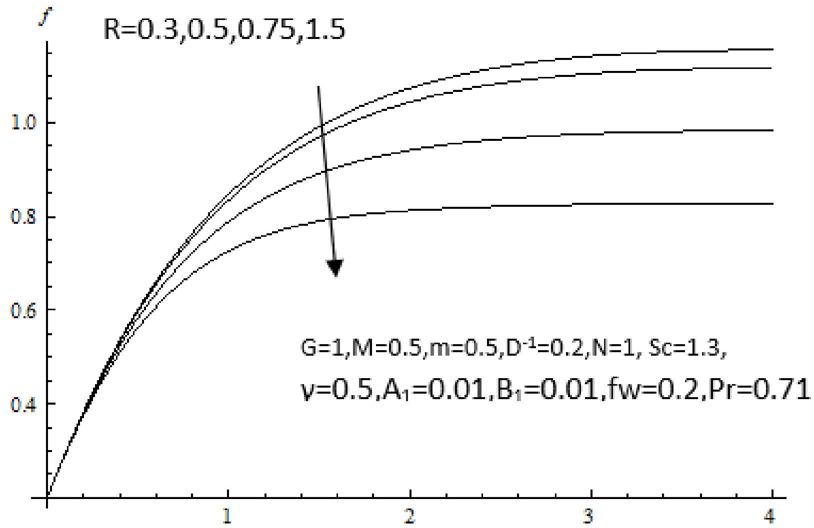

Fig .6 : Variation of f with R

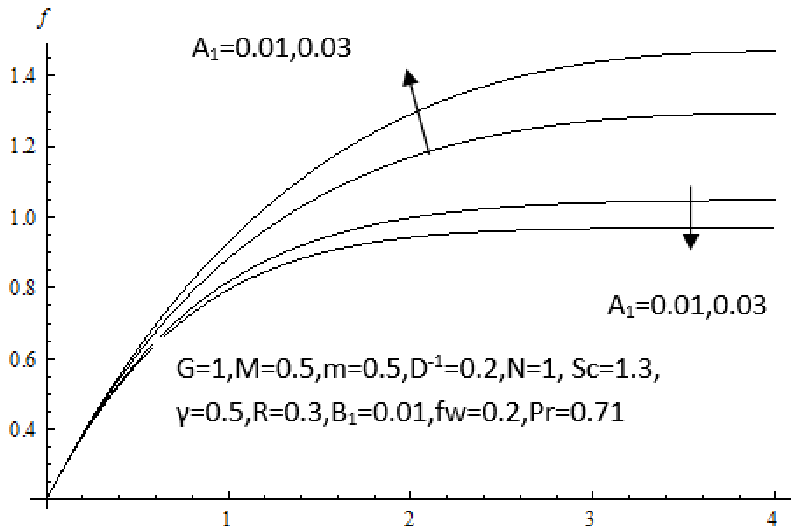

Fig .7 : Variation of f with A1

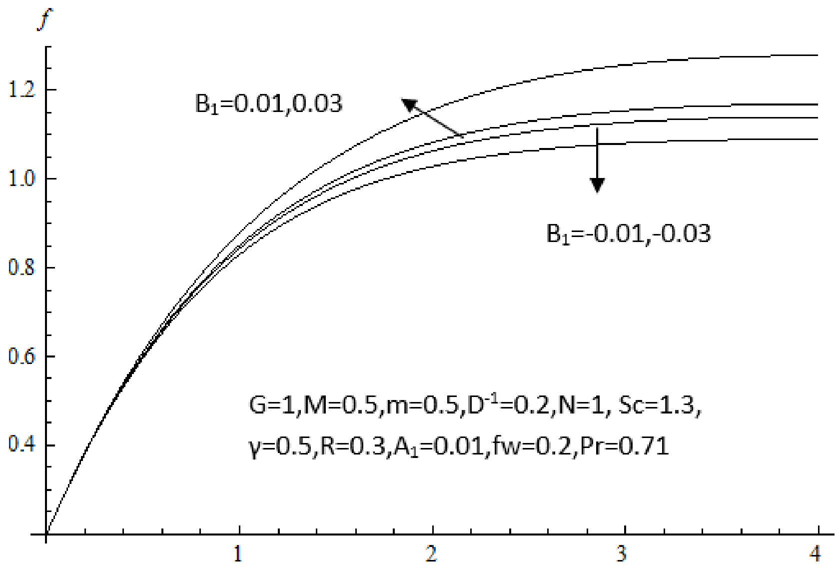

Fig .8 : Variation of f with B1

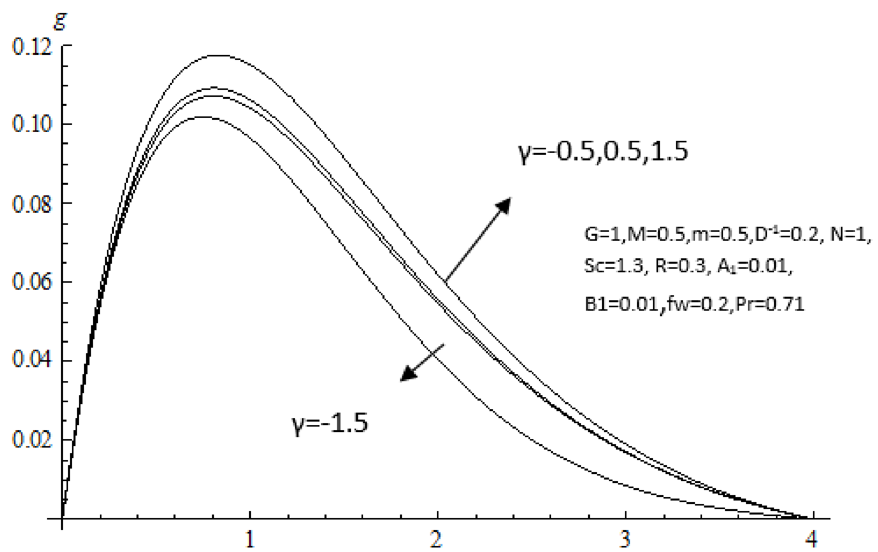

Fig .9 : Variation of g with γ

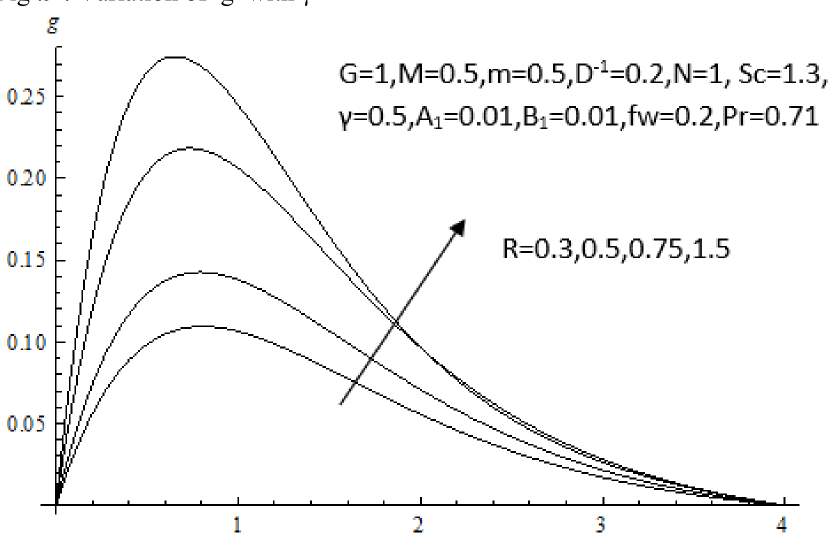

Fig .10 : Variation of g with R

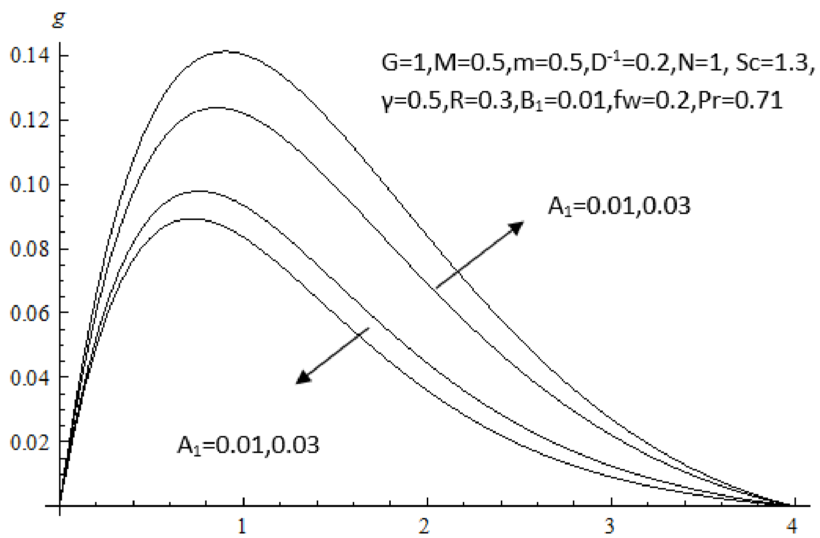

Fig .11 : Variation of g with A1

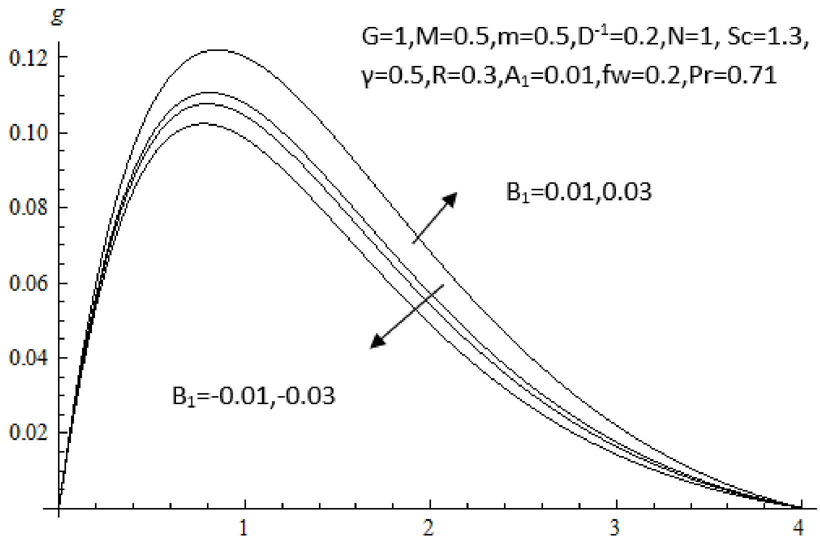

Fig .12 : Variation of g with B1

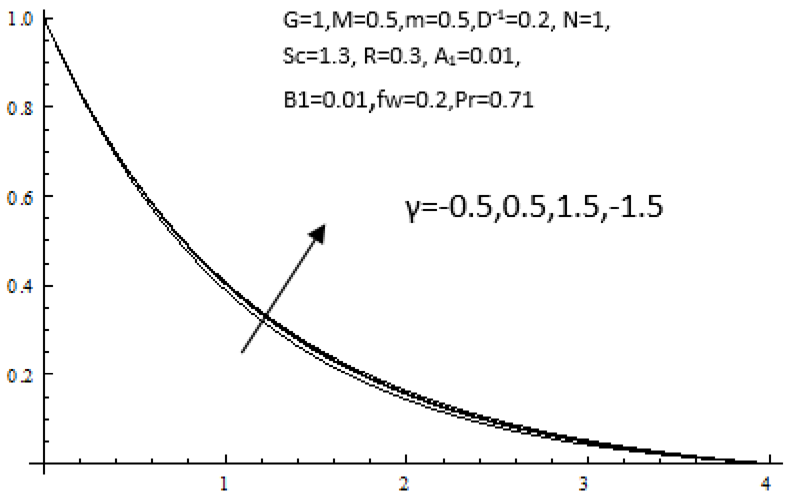

Fig .13 : Variation of θ with γ

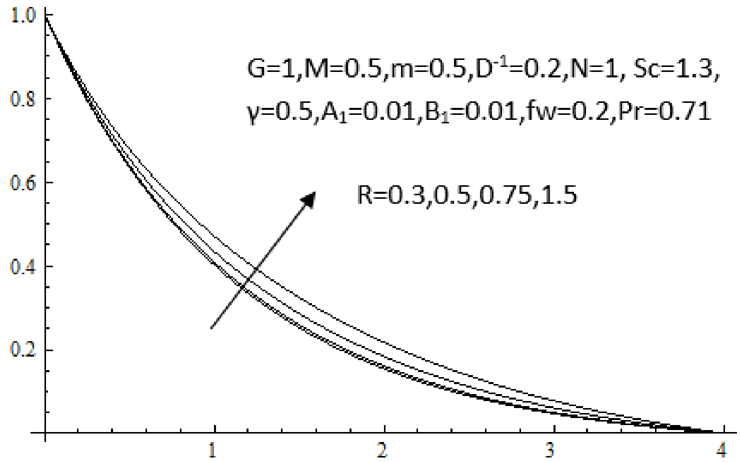

Fig .14 : Variation of θ with R

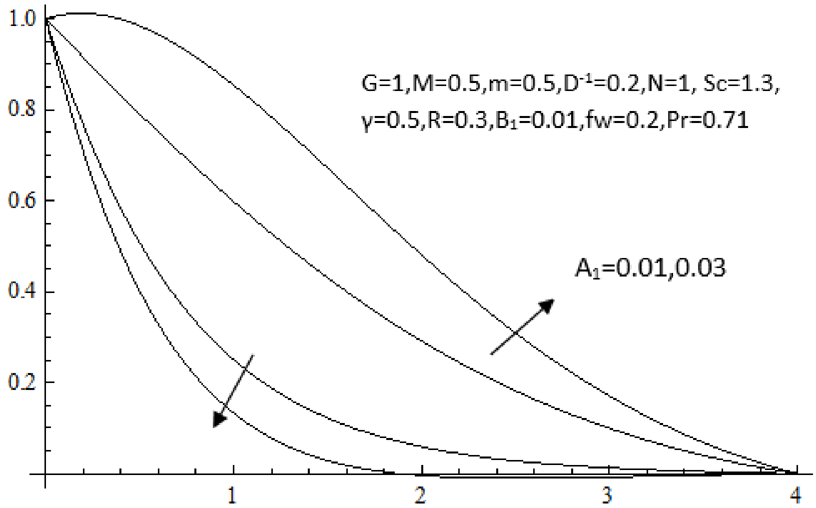

Fig .15 : Variation of θ with A1

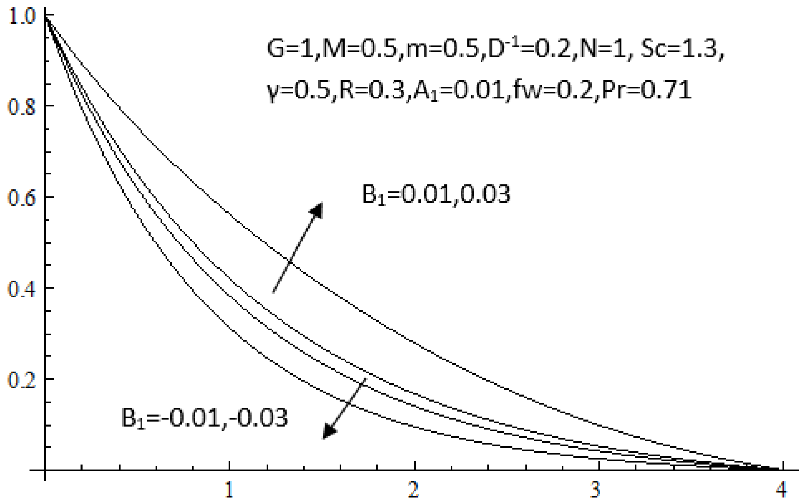

Fig .16 : Variation of θ with B1

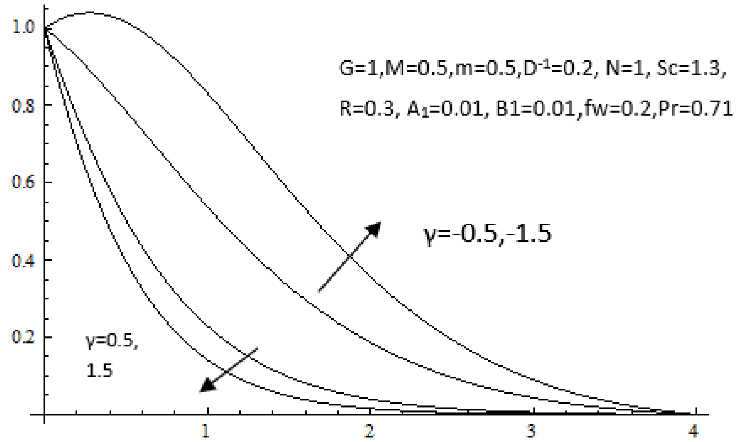

Fig .17 : Variation of ϕ with γ

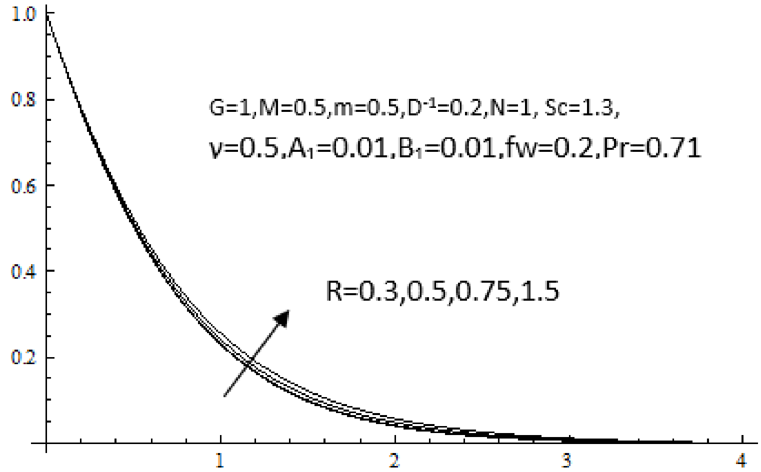

Fig .18: Variation of ϕ with R

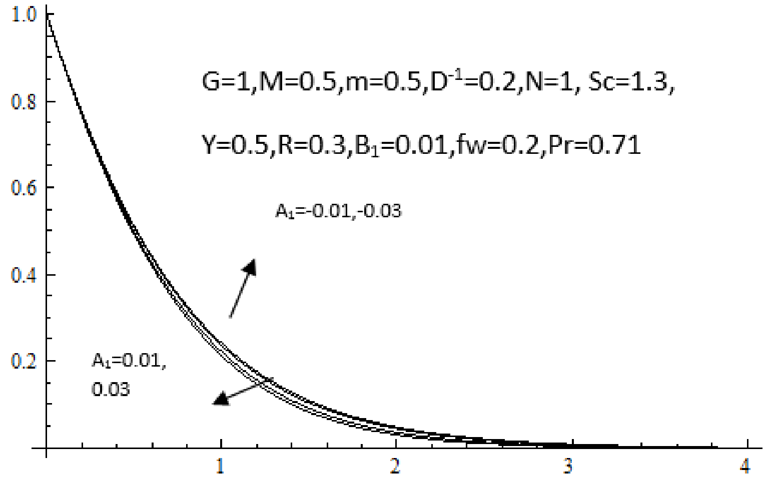

Fig .19 : Variation of ϕ with A1

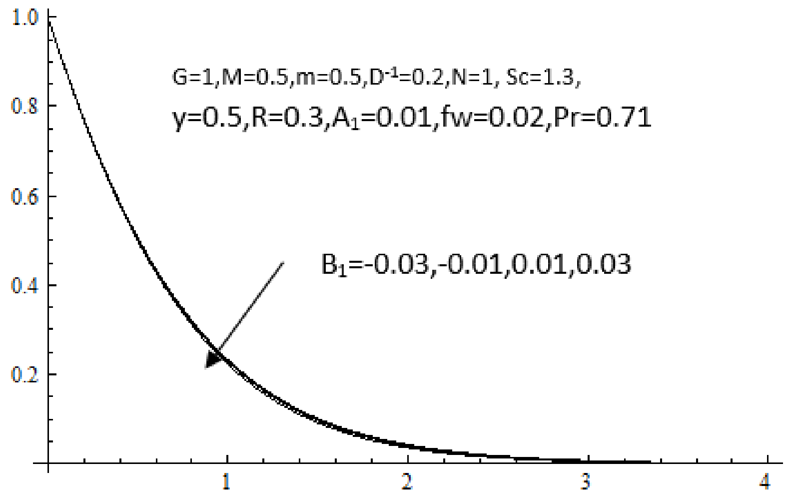

Fig .20 : Variation of ϕ with B1

Conclusions

1. An increase in chemical reaction parameter the axial velocity ($f^1(\eta)$) , the transverse velocity $f(\eta)$, $|\tau_z|$, |Nu| and depreciates in both the generating and degenerating chemical reaction case.
2. An increase in $|\gamma|$ leads to a depreciation in the actual concentration.
3. The actual temperature θ, $|\tau_x|$ |Sh| enhances both in degenerating and degenerating chemical reaction case.
4. An increase in the rotation parameter R, the axial velocity ($f^1(\eta)$), the transverse velocity $f(\eta)$, |Nu| and |Sh| depreciates.
5. An increase in the rotation parameter R, the actual temperature θ, concentration C, $|\tau_x|$ and |Sh| enhances in the flow regioin.
6. An increase in heat generation $A_1,B_1>0$, ($f^1(\eta)$), $f(\eta)$, actual temperature θ, $|\tau_z|$, Sh enhances where as ($f^1(\eta)$), $f(\eta)$ temperature θ, $|\tau_z|$ reduces with heat absorption $A_1,B_1<0$
7. The concentration C, τ_x , Nu reduces by increasing the values of $A_1,B_1>0$.

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